SHIP PRODUCTION COMMITTEE
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WELDING
INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

November 1993
NSRP 0408

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

1993 Ship Production Symposium

Paper No. 11: Computer Aided Manufacturing in Small Shipyards: A U.S. and U.K. Comparative Study

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **NOV 1993**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **The National Shipbuilding Research Program, 1993 Ship Production Symposium Paper No. 11: Computer Aided Manufacturing in Small Shipyards: A U.S. and U.K. Comparative Study**	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) **Naval Surface Warfare Center CD Code 2230 - Design Integration Tower Bldg 192 Room 128 9500 MacArthur Blvd Bethesda, MD 20817-5700**	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
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**20**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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1993

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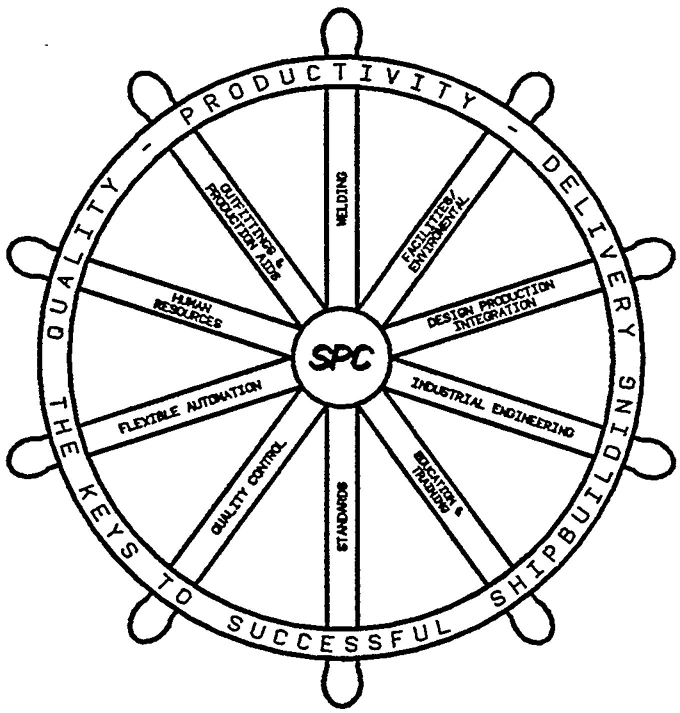

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Williamsburg Virginia, November 1-4, 1993

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1993 Ship Production Symposium
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Computer Aided Manufacturing in SmalI Shipyards: A U.S. and U.K Comparative Study

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ABSTRACT

Shipbuilders throughout the world are continuing to move toward Computer Integrated Manufacturing (CIM) Systems as a means of improving productivity, quality and competitiveness. The implementation of such systems provides unique challenges to all shipbuilders. One of the critical issues involves the choice of new versus existing computer systems (hardware and software) , the pace of change and the timing of implementation of new parts or totally new systems. These challenges and potential solutions are not only different for each shipyard, but are also significantly different for large and small shipyards.

Surveys of current uses and needs of small shipyards in the United States and the United Kingdom were conducted. These surveys were used to evaluate current systems and to make recommendations for potentially successful approaches to future implementation. The review focused on three major areas, including design (design, drafting, engineering, and lofting), production management (planning, estimating, material control, scheduling, purchasing, production/cost control, and quality control), and administration (payroll, time charging, and billing). Based on this review, recommendations concerning systems for implementation and a framework for integration is presented.

INTRODUCTION

In order to review the status of computer applications in small shipyards in the U.S. and the U.K., independent surveys of current uses and needs were conducted. The European Economic Community (EEC) definition for a small company is one with less than 500 employees. In this study, both for the U.S. and the U.K., the shipyards studied generally employ less than 200 people. The goal of the surveys was to identify common needs and solutions, so that recommendations as to future directions in computer applications can be made. A cross section of small shipyards in the two countries were surveyed, either by mail, telephone or in person. Although the survey instruments and technique varied between shipyards and countries, in general, the following areas of potential computer application were considered:

DESIGN

. design
. drafting
. engineering
. lofting

PRODUCTION MANAGEMENT

. planning support
. estimating
. material control
. scheduling
. purchasing
. production/cost control
. quality control

ADMINISTRATION

. payroll
. time charging
. billing

The results of these surveys were then used to develop recommendations.

SURVEY RESULTS

In depth surveys were conducted in 8 U.S. and 12 U.K. shipyards, including shipyards involved in either repair or new construction. Some did both but on separate sites. Due to this small sample size, the study sought levels of technology and trends which were representative of current practice in this segment of the industry. Thus no statistical analysis was conducted. Comparisons were also made to confidential surveys of Dutch, French and German yards carried out by several members of the U.K. team. These comparisons indicated that close similarities exist in those yards as well.

The results of the two surveys exhibited remarkable similarity between the two countries. [1,2] The primary differences noted were the specific software packages being employed, although there was significant overlap here as well.

In general, smaller shipyards have made only small capital investments in computer hardware and software. The primary investments are in computer aided design (CAD) systems and in simple software for word processing and accounting tasks. Nearly all hardware is stand alone PC'S. In most yards, little or no integration of computer generated information exists. A major cause of this situation is the relatively small number of trained computer users in the shipyards. In general, people are self–trained, and only employ computers to assist with their specific tasks. The major exception here is also in the area of CAD.

A large number of potential needs were identified. These include planning, estimating, production control and material control. These and other needs were mentioned in many individual surveys, but no consistent order or overwhelming priority was found.

Design

Most small shipyards involved in new construction have some design capability. This may be as little as a single person, but in all cases, it also includes CAD capability. Repair yards, on the other hand, had no in house CAD capability, and used external consultants when needed. The CAD systems are generally PC based. A wide variety of CAD software is employed, but if there is a "standard" , it is AutoCAD in the U.S., with SFOLDS, MAST and

AutoSHIP also common in the U.K. The majority of the use of CAD is for the generation of drawings, with first priority to the total vessel design, rather than separation by modules or problem areas. Information exchange with other departments and sub-contractors is normally by drawings. Despite CAD capability, most small shipyards do not develop a full set of detail design drawings, as is common in large shipyard practice. Instead, details are “left to the yard”, or not specified by design but established by and during production. Naturally, little consideration of design for production is given. What is considered are the major physical constraints of the ~yard, such as maximum lift capacity, rather than the development and refinement of a production strategy. Where employed, detail design drawings may be developed within the yard, either using CAD or manually, or by naval architectural sub–contractors.

Engineering computations are sometimes done using CAD related software at the shipyard design office. However, it is not uncommon for this work to be done manually or using software that is not directly integrated with the CAD software. Often, outside naval architectural consultants are employed to perform this work.

Lofting practice in small yards varies widely, both between the small yards and as compared to large yard practice. Direct development of Numerical Control (NC) data is uncommon. U.S. practice is moving quickly to the use of sub-contractors for the electronic development of NC data. U.K. practice does not yet seem to be following this pattern. The primary need is for good 3D hull definition, based on AutoCAD or other preliminary design software outputs. [3] There is also an apparent need for small yards to establish better internal control of the parts generation process. Thus, the use of sub-contractors may be reduced or some form of checking and tracking system will be needed. This can involve moving the sub-contractor to the shipyard for the NC data generation effort or moving a shipyard “lofter” to the sub–contractor. Additionally, the use of spreadsheets or other tracking tools may be required.

Production Management

Very little use (less than 10%) of production management software of any kind was found in the small shipyards in either the U.S. or U.K. Most systems are manual, with only informal inventory and production control systems found. There was no means of integrating any of these systems with each other or with design generated information. The most common computer application found here is some form of network scheduling software. Many such packages are available in both countries.

Another common feature of small yards in both countries is the lack of a repeatable product work breakdown structure (PWBS) or a build strategy. Instead, the small yards tend to use prior experience to plan construction. This results in most construction following traditional system by system approaches, with steel work fabrication and assembly nearly completed before any outfit work begins. Without a PWBS, build strategy and interim products are not defined. Thus application of CIM technology for work station loading and work organization cannot be carried out effectively. The primary exception to this is the somewhat common practice of completing small superstructure units independent of the hull, and landing those directly on board. This is usually confined to bridge/wheel house units, which do have significant outfitting work completed prior to landing on board.

Administration

Many of the small yards do employ computers for typical administrative functions. These include payroll and invoicing/billing. These systems are exclusively stand alone systems, with no interface with any other computer applications in the shipyard.

SURVEY CONCLUSIONS

Small shipyards have and continue to employ computers as an increasing part of their operations. The primary uses to date have been in support of basic administrative functions and in design. Although overall investment in computer hardware and software has generally been low, the benefits derived from these investments have fallen far short of the potential. There are a number of reasons for this shortfall in computer productivity:

- use of the systems for single purpose activities;
- lack of an overall computer application strategy, including a plan for integration of applications;
- lack of a manufacturing system capable of deriving maximum benefit from computer applications, i.e. lack of a product work breakdown structure;
- shortage of trained (computer literate) personnel; and
- lack of capital for investment in computer hardware and software.

Key productivity benefits from the application of computer hardware and software can be obtained by better utilization of existing systems. The ability to develop direct NC steel cutting and perhaps pipe piece manufacturing instructions is still generally not available to the small shipyards. The rapid development of PC based 3D modeling software, and it's continual decrease in cost, will likely produce solutions to this problem in the near future. The obvious gap in computer application between the administrative functions and the design functions (the production management functions), however, significantly limits the productivity potential of computer applications in small shipyards. Additionally, the need for integration of information among functions in the shipyard is critical. Thus, the goal for small shipyards is to find low cost solutions to the key questions of effectively employing computers. This includes (1) integration of computer supported functions, (2) performing some or all of the production management functions, and (3) incorporating a build strategy that relates the production management functions to marketing, preliminary design and estimating.

RECOMMENDED SMALL SHIPYARD COMPUTER STRATEGY

The availability of powerful CAD tools and the near term prospect of opportunities for direct NC control linked to these tools, makes this area a lower priority for small shipyard action in the near future. Naturally, these shipyards will need to evaluate the cost effectiveness of purchasing or expanding current systems to include these capabilities. The prospective market of the yard will dictate how effective CAD systems will be for these yards.

Since these decisions are somewhat more straight forward, the thrust of the recommendations will be toward the production management area, since this is the area that is currently addressed the least in most small shipyards. Effective computer (or manual) production management is dependent on two prerequisites:

- adoption of a product work breakdown structure, and
- system (data) integration.

Large vessel product work breakdown structures have been described in a number of sources. [4] Extension of this concept to small vessels has been considered, but still needs further definition. [5,6] The application of a PWBS is a prerequisite to successful computer application, because a PWBS employs the principles of group technology, which lead to repeatability. A key benefit of the use of computers is the reuse of data. A second key to effective computer utilization is the transfer of data used (or created) by one function to another function. This leads to the need for integration of computer data and company functions which employ the same data.

Spreadsheets

Spreadsheets are the computerized version of multiple column, multiple row financial accounting sheets. They are in common use and require little, if any training for users. They are very powerful software programs, however, and can be used to manage, update and transfer data, as well as providing simple arithmetic calculations. While they are not efficient for large data management tasks, their low cost and ease of operation make them an ideal choice for use by small shipyards. Many of the production management functions can be effectively performed using spreadsheets.

There are a number of very powerful spreadsheet programs that can be used on PC'S. Included among these are Lotus 123 and Excel, although there are many others available. Following are a series of examples of the potential uses of spreadsheets for production management functions.

Figure 1 presents a final ship account spreadsheet, summarizing the costs of tasks added and eliminated from a ship repair project. In a more complete spreadsheet application, this information would be derived directly from a data base.

Figure 2 illustrates how a spreadsheet can be used to compile estimated cost information for labor, materials, sub–contract and tariff items. Appropriate percentages and rates are applied to these figures and a final total calculated. This form could be completed with actual cost information to provide a figure for the overall cost of a contract.

Figures 3 through 6 show several sections of a more detailed spreadsheet for cost analysis. Labor cost data from time cards is collated in terms of job number and work center on a weekly basis. This information can then be arranged and displayed to provide a wide range of status reports and planning and analysis tools. In Figure 3, a summary of costs for interim products is given on a weekly basis. Figure 4 summarizes the cost to date of steel work jobs undertaken. Information comparing each job to the volume of work by interim product and for the whole ship is also provided. Similar summaries are provided for other interim products, such as superstructure, engine room outfit, etc. In Figure 5, the costs of steel work labor are shown in a matrix of job number and week ending dates. Similar data can be provided for other trades. Figure 6 provides a summary of costs incurred in each work center.

Spreadsheets can also be used for data that is not directly related to costs. For example, Figure 7 shows a sequence of hull blocks that form a ship, indicating the work content by work category (cutting, bending, sub-assembly, etc.) . This data can be rearranged to show weekly work content by work category (Figure 8), and the same spreadsheet program can be used to plot the total shipyard work load by week (Figure 9). Although this example is for a large ship, the approach could be easily modified to be used in a small shipyard. This information can be used to help plan and schedule work to develop a smoother work flow.

Integration

Developing an integrated computer system is somewhat more difficult. At least two models are possible. The first involves the use of a central data base management system. Here again, many simple, effective software packages are available, including dBase, DataEase, FoxBASE, Paradox, and RBase. Using any of these systems, data is collected in categories associated with interim products identified by the PWBS. Figure 10 shows this simple model. Data contained in the main classes includes: ship details, estimate details, specification details, personnel records, time card information, material requirements and costs, labor requirements, purchasing information, schedules, work status, and accounting information.

For smaller applications, one or a few people may be involved in the computer applications. In this case, a formal data base integration system may not be necessary. In fact, integration may be achieved indirectly by the computer user, who would manually update critical spreadsheet data as new information was generated. While not optimal, such a system would be inexpensive and provide a reasonable starting point.

CONCLUSIONS

Small shipyards face a difficult task in effectively employing computers. They generally face a shortage of capital for computer hardware and software investment, coupled with a shortage of trained and available personnel for performing computer work. In such a situation, inexpensive and off the shelf solutions are required. Spreadsheets and data base management systems offer these advantages. In order to effectively employ these programs, small shipyards must organize work to follow a product oriented work breakdown structure. Once such a system is in place, incrementally increasing use of computers will provide significant cost benefits.

Currently, small shipyards are not structured in a way to accept and utilize advanced software packages. They need to first move to a more structured shipbuilding system before attempting to employ and realize the benefits of CIM. Parts of a CIM system should be introduced incrementally, although a plan for the ultimate integration of these parts must be developed, updated and followed.

The real benefits of computer application are the supply of real time information to top management. This need was clearly understood by U.K. managers, particularly in repair yards, while their U.S. counterparts did not exhibit the same priority. Clear understanding of the benefits of computer application in small shipyards, including the need for integration was not evident. Such understanding, coupled with an investment in time and capital to plan and implement computer systems is required before significant advancement is likely.

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Contract Number: C111111			
Item No.	Description	Credit	Debit
	Original estimate	178000.00	
1	Cancel job number 530/31		150.00
2	Additional job number 450/12	275.00	
3	Additional job number 450/13	590.00	
4	Cancel job number 170/27		250.00
5	Cancel job number 126/32		850.00
6	Cancel job number 401/23		575.00
7	Additional job number 501/61	450.00	
8	Additional job number	950.00	
		180265.00	1825.00
	GRAND TOTAL	178440.00	

Figure 1: Ship account spreadsheet

Estimate Number:	**E1111**					
Specification	Description	Cost	Hours	Materials	Sub-Contractor's Cost	Total Cost
111/1	SERVICES					
c	Shore power (con/dis)	90				90
f	Cooling hose	80				80
	Water 16 days @ 30	480				480
i	Telephone (con/dis)	80				80
k	Sea trial		70		250	920
130/2	GENERAL SAFETY					
b	Fire hose	80				80
d	Halon gag				75	83
	Scaffold bridges		32			295
130/3	CLEANING					
	Accom Protection		40	450		864
					TOTAL	2770

Figure 2: Estimate compilation spreadsheet

Week Ending Date	Loft	Steel Cut	Weld	Pipe Bend	Engine Room Outfit	Superstructure	Labor	Week Total	Cumulative
11 Oct 91	264	0	0	0	0	0	0	264	264
18 Oct 91	256	0	0	0	0	0	0	256	520
25 Oct 91	305	0	0	0	0	0	0	305	825
01 Nov 91	609	304	0	0	0	0	0	913	1738
08 Nov 91	622	903	179	0	0	0	0	1704	3442
15 Nov 91	622	1777	483	0	0	0	0	2882	6324
22 Nov 91	658	2755	1430	574	0	0	772	6189	12513
29 Nov 91	698	3499	551	619	0	0	243	5609	18122
06 Dec 91	624	3656	2856	675	304	452	277	8843	26965
13 Dec 91	601	3557	4251	943	293	429	457	10532	37497
20 Dec 91	999	6119	6753	1476	1254	972	1207	18779	56276
27 Dec 91	0	0	0	0	0	0	0	0	56276
03 Jan 92	0	0	0	0	0	0	0	0	56276
10 Jan 92	625	3979	4186	929	304	1010	989	12022	68298
17 Jan 92	636	4000	4610	888	304	872	952	12260	80558
24 Jan 92	530	4001	4577	1044	304	850	971	12277	92835
31 Jan 92	320	2999	5041	1083	607	880	1243	12175	105010
07 Feb 92	322	3897	5144	1070	1245	511	1251	13440	118450
14 Feb 92	131	2265	5325	451	0	0	982	9155	127605
TOTAL	8821	43711	45385	9754	4614	5975	9344	128231	128231

Figure 3: Departmental labor cost summary

Job Code	Job Description	Cost to Date	% of Steel Work	% of Ship	Unit Cost	Measure Used	No. of Units
200	Hull unit prep. FRS 18.5-49.5	10213	7%	4%	165	tons	62
201	Focle unit prep. FRS 31-56.5	4023	3%	2%	297	tons	14
202	Hull unit fab. FRS 18.5-49.5	54667	38%	22%	882	tons	62
203	Hull construction to main deck	34142	24%	14%	255	tons	134
204	Superstructure construction	11531	8%	5%	684	tons	17
205	Outfit steel work/servicing etc.	4731	3%	2%	29	tons	165
206	Tank testing	2274	2%	1%	253	no. tanks	9
207	General work	3999	3%	2%	24	tons	165
208	Focle unit fab. FRS 31-56.5	4310	3%	2%	318	tons	14
209	Fabrication of fore end units	7623	5%	3%	406	tons	19
210	Bulwark fab. and construction	3817	3%	2%	947	tons	4
211	ER floors	0	0%	0%	0	tons	165
212	Holiday pay	3534	2%	1%	21	tons	165
	STEEL WORK CONTRACT TOTAL	144863	100%	59%	880	tons	165

Figure 4: Job cost summary report

Date	200	201	202	203	204	205	206	207	208	209	210	Week	Total
08 Nov 91	724.0	0.0	0.0	0.0	358.1	0.0	0.0	0.0	0.0	0.0	0.0	1082	1082
15 Nov 91	1115.2	0.0	840.7	0.0	303.6	0.0	0.0	0.0	0.0	0.0	0.0	2260	3342
22 Nov 91	2034.2	1543.4	0.0	0.0	607.2	0.0	0.0	0.0	0.0	0.0	0.0	4185	7527
29 Nov 91	1764.7	0.0	1734.6	0.0	303.6	0.0	0.0	0.0	0.0	0.0	0.0	3803	11330
06 Dec 91	1926.9	0.0	4281.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6209	17539
13 Dec 91	1292.3	0.0	5508.1	0.0	711.9	0.0	0.0	0.0	0.0	0.0	0.0	7512	25051
20 Dec 91	377.4	0.0	6840.4	942.8	804.4	0.0	0.0	0.0	0.0	0.0	0.0	12499	37550
10 Jan 92	612.1	0.0	4934.2	1717.5	303.6	0.0	0.0	0.0	0.0	0.0	445.0	8012	45562
17 Jan 92	0.0	712.5	5021.0	1148.8	488.0	0.0	0.0	0.0	607.2	0.0	445.0	8422	53984
24 Jan 92	0.0	712.5	3626.8	1666.6	1210.6	0.0	0.0	210.1	965.3	0.0	0.0	8392	62376
31 Jan 92	0.0	303.6	4037.6	1357.0	628.0	0.0	0.0	886.8	607.2	0.0	0.0	7820	70196
07 Feb 92	0.0	242.9	3841.0	3120.1	307.6	0.0	0.0	725.1	303.6	0.0	306.6	8847	79043
14 Feb 92	0.0	0.0	3930.4	2799.1	350.6	0.0	0.0	0.0	0.0	0.0	206.9	7287	86330
TOTAL	9846	3515	44597	12752	6377	0	0	1822	2483	0	1404	86330	86330

Figure 5: Steelwork job cost report (labor)

Date	Loft	Steel Cut and Weld	Pipe Bend	Engine Room Outfit	Superstructure Outfit	Labor	Week	Total
29 Sep 91	318.2	0.0	0.0	0.0	0.0	0.0	318	318
6 Oct 91	308.6	0.0	0.0	0.0	0.0	0.0	309	627
13 Oct 91	263.8	0.0	0.0	0.0	0.0	0.0	264	891
20 Oct 91	256.1	0.0	0.0	0.0	0.0	0.0	256	1147
27 Oct 91	305.3	0.0	0.0	0.0	0.0	0.0	305	1452
03 Nov 91	608.9	303.6	0.0	0.0	0.0	0.0	913	2365
10 Nov 91	622.0	1082.0	0.0	0.0	0.0	0.0	1704	4069
17 Nov 91	622.0	2259.6	0.0	0.0	0.0	0.0	2882	6950
24 Nov 91	658.2	4184.8	573.8	0.0	0.0	772.4	6189	13139
01 Dec 91	697.7	3802.9	866.0	0.0	0.0	242.8	5609	18749
08 Dec 91	623.7	6208.8	978.7	303.6	451.5	276.6	8843	27592
15 Dec 91	600.8	7512.3	1239.4	293.2	429.1	456.8	10532	38123
22 Dec 91	999.1	12498.6	1849.3	1253.8	972.1	1206.6	18779	56903
29 Dec 91	0.0	0.0	0.0	0.0	0.0	0.0	0	56903
05 Jan 92	0.0	0.0	0.0	0.0	0.0	0.0	0	56903
12 Jan 92	625.4	8012.4	1232.7	303.6	858.2	989.5	12022	68924
19 Jan 92	635.6	8422.5	1191.5	303.6	755.2	952.0	12260	81185
26 Jan 92	530.3	8391.8	1347.8	303.6	733.0	970.6	12277	93462
02 Feb 92	320.1	7820.2	1386.6	607.2	797.2	1243.5	12175	105636
09 Feb 92	321.8	8847.0	1374.0	1245.3	400.7	1251.0	13440	119076
16 Feb 92	130.6	7287.0	755.1	0.0	0.0	981.9	9155	128231
23 Feb 92	254.4	6414.8	1362.4	180.5	0.0	996.2	9208	137439
TOTAL	9702.8	93048.3	14157.3	4794.4	5396.9	10339.8	137439	162855

Figure 6: Activity cost summary

Sequence Number	Unit Number	Weight, Tons	Cutting Weeks	Cum Cutting Weeks	Bending Weeks	Cum Bending Weeks	Sub-Asbm Weeks	Sub-Asbm Weeks	Main Asmb Weeks	Main Asmb Weeks	Paint Weeks	Cum Paint Weeks	Erect Weeks	Cum Erect Weeks	Total Weeks
1	101	73.54	0.08	0.08	0.00	0.00	0.97	0.97	0.54	0.54	0.18	0.18	0.33	0.33	2.11
2	326	99.62	0.10	0.18	0.00	0.00	1.18	2.15	0.66	1.20	0.22	0.41	0.41	0.74	2.57
3	544	55.77	0.06	0.24	0.00	0.00	0.73	2.88	0.41	1.61	0.14	0.55	0.25	1.00	1.60
4	654	67.77	0.08	0.32	0.00	0.00	0.89	3.77	0.50	2.11	0.17	0.72	0.31	1.30	1.94
5	102	98.48	0.11	0.43	0.00	0.00	1.30	5.07	0.72	2.83	0.25	0.96	0.45	1.75	2.82
6	210	78.69	0.09	0.52	0.00	0.00	1.04	6.10	0.58	3.41	0.20	1.16	0.36	2.11	2.26
7	211	58.94	0.07	0.58	0.00	0.00	0.78	6.88	0.43	3.84	0.15	1.31	0.27	2.38	1.69
8	322	76.98	0.09	0.67	0.00	0.00	1.01	7.89	0.57	4.41	0.19	1.50	0.35	2.73	2.21
9	323	78.69	0.09	0.75	0.00	0.00	1.04	8.93	0.58	4.99	0.20	1.70	0.36	3.08	2.26
10	542	87.54	0.10	0.85	0.00	0.00	1.15	10.08	0.64	5.63	0.22	1.92	0.40	3.48	2.51
11	655	56.12	0.06	0.91	0.00	0.00	0.74	10.82	0.41	6.05	0.14	2.06	0.26	3.74	1.61
12	105	97.94	0.11	1.02	0.20	0.20	1.29	12.11	0.72	6.77	0.24	2.30	0.45	4.18	3.00
13	214	100.43	0.11	1.13	0.20	0.40	1.32	13.43	0.74	7.50	0.25	2.55	0.46	4.64	3.08
14	432	71.92	0.08	1.21	0.14	0.54	0.95	14.37	0.53	8.03	0.18	2.73	0.33	4.97	2.21
15	541	54.83	0.06	1.27	0.11	0.65	0.72	15.10	0.40	8.44	0.14	2.87	0.25	5.21	1.68
16	653	57.34	0.06	1.34	0.11	0.76	0.75	15.85	0.42	8.86	0.14	3.01	0.26	5.48	1.76
17	104	57.90	0.06	1.40	0.00	0.76	0.76	16.61	0.43	9.23	0.14	3.16	0.26	5.74	1.66
18	106	76.98	0.09	1.49	0.00	0.76	1.01	17.62	0.57	9.85	0.19	3.35	0.35	6.09	2.21
19	212	69.51	0.08	1.57	0.00	0.76	0.91	18.54	0.51	10.36	0.17	3.52	0.32	6.40	1.99
20	324	58.94	0.07	1.63	0.00	0.76	0.78	19.31	0.43	10.79	0.15	3.67	0.27	6.67	1.69
21	325	76.54	0.09	1.72	0.00	0.76	1.01	20.32	0.56	11.36	0.19	3.86	0.35	7.02	2.19
22	434	84.70	0.09	1.81	-0.00	0.76	1.11	21.44	0.62	11.98	0.21	4.07	0.39	7.41	2.43
23	436	68.55	0.08	1.89	0.00	0.76	0.90	22.34	0.50	12.48	0.17	4.24	0.31	7.72	1.97
24	652	92.90	0.10	1.99	0.00	0.76	1.22	23.56	0.68	13.17	0.23	4.48	0.42	8.14	2.66
25	103	102.98	0.11	2.10	0.00	0.76	1.36	24.92	0.76	13.92	0.26	4.73	0.47	8.61	2.95
26	213	103.43	0.11	2.22	0.00	0.76	1.36	26.28	0.76	14.68	0.26	4.99	0.47	9.08	2.97
27	216	97.94	0.11	2.33	0.00	0.76	1.29	27.57	0.72	15.40	0.24	5.24	0.45	9.52	2.81
28	431	49.52	0.06	2.38	0.00	0.76	0.65	28.22	0.36	15.77	0.12	5.36	0.23	9.75	1.42
29	433	92.90	0.10	2.49	0.00	0.76	1.22	29.44	0.68	16.45	0.23	5.59	0.42	10.17	2.66
30	435	59.83	0.07	2.55	0.00	0.76	0.79	30.23	0.44	16.89	0.15	5.74	0.27	10.44	1.72
31	546	69.75	0.08	2.63	0.00	0.76	0.92	31.14	0.51	17.40	0.17	5.92	0.32	10.76	2.00
32	547	65.97	0.07	2.70	0.00	0.76	0.87	32.01	0.49	17.89	0.16	6.08	0.30	11.06	1.89
33	651	84.01	0.09	2.80	0.00	0.76	1.11	33.12	0.62	18.51	0.21	6.29	0.38	11.44	2.41
34	215	57.90	0.06	2.86	0.12	0.88	0.76	33.88	0.43	18.93	0.14	6.44	0.26	11.70	1.78
35	321	123.87	0.14	3.00	0.00	0.88	1.63	35.51	0.91	19.84	0.31	6.75	0.56	12.27	3.55
36	327	56.87	0.06	3.06	0.00	0.88	0.75	36.26	0.42	20.26	0.14	6.89	0.26	12.53	1.63
37	543	88.92	0.10	3.16	0.00	0.88	1.17	37.43	0.65	20.92	0.22	7.11	0.40	12.93	2.55
38	545	60.73	0.07	3.23	0.00	0.88	0.80	38.23	0.45	21.36	0.15	7.26	0.28	13.21	1.74
39	656	91.05	0.10	3.33	0.18	1.06	1.20	39.42	0.67	22.03	0.23	7.49	0.41	13.62	2.79
		2996.29	3.33		1.06		39.42		22.03		7.49		13.62		26.96

Figure 7: Example spreadsheet for work content by block

Workarea	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Cutting		899.82	899.82	899.82	296.94									
Bending						299.63	299.63	299.63	299.63	299.63	299.63	299.63	299.63	299.63
Subasmbl		69.93	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01
Mainasmbl														
Painting														
Erection														
Total	0.00	969.75	975.83	975.83	372.95	375.64	375.64	375.64	375.64	375.64	375.64	375.64	375.64	375.64

Workarea	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25	Week 26	Week 27	Week 28	Week 29
Cutting																
Bending	299.63															
Subasmbl	76 01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01
Mainasmbl					116.97	136.01	136.01	136.01	136.01	136.01	136.01	136.01	136.01	136.01	136.01	136.01
Painting														214 02	214.02	214.02
Erection														178.19	219.99	219.99
Total	375.64	76.01	76.01	76.01	192.98	212.02	212.02	212.02	212.02	212.02	212.02	212.02	212.02	604 23	646.03	646.03

Workarea	Week 30	Week 31	Week 32	Week 33	Week 34	Week 35	Week 36	Week 37	Week 38	Week 39	Week 40	Week 41	
Cutting												0.00	2996.40
Bending												0.00	2996.29
Subasmbl	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	76.01	38.00	0.00	2996.29
Mainasmbl	136.01	136.01	136.01	136.01	136.01	136.01	136.01	136.01	136.01	136.01	23.12	0.00	2996.29
Painting	214.02	214.02	214.02	214.02	214.02	214.02	214.02	214.02	214.02	214.02	214.02	0.00	2996.29
Erection	219.99	219.99	219.99	219.99	219.99	219.99	219.99	219.99	219.99	219.99	178.19	0.00	2996.29
Total	646.03	646.03	646.03	646.03	646.03	646.03	646.03	646.03	646.03	646.03	453.34	0.00	

Figure 8: Example spreadsheet showing weekly workloads

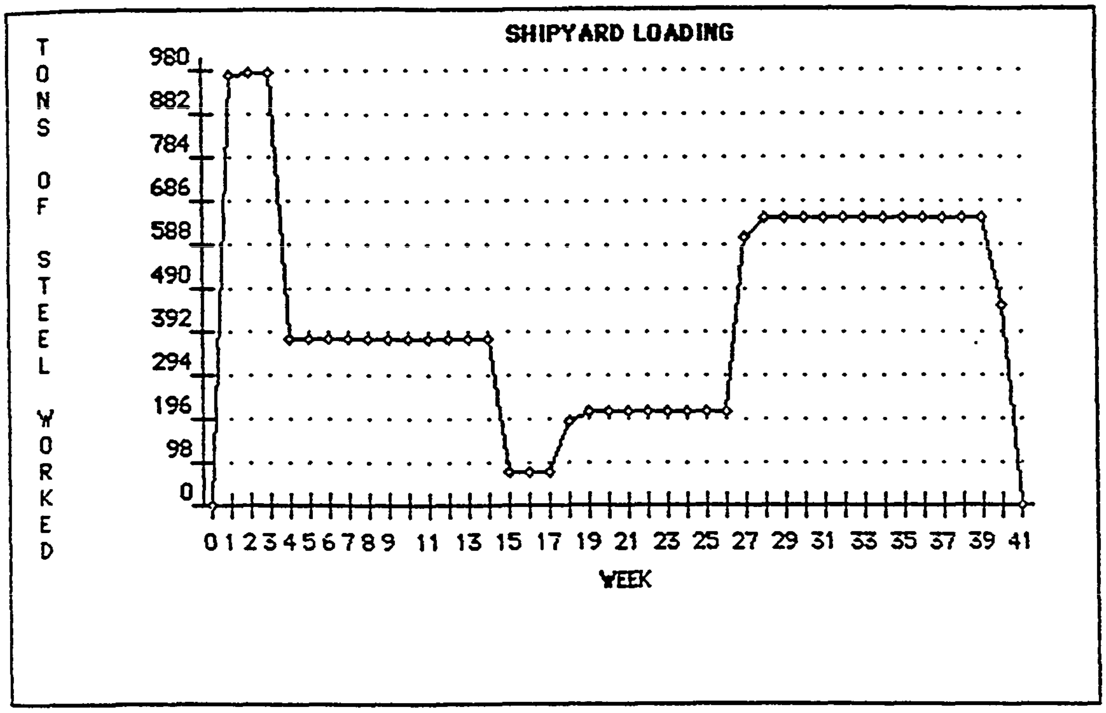

Figure 9: Shipyard Loading Histogram

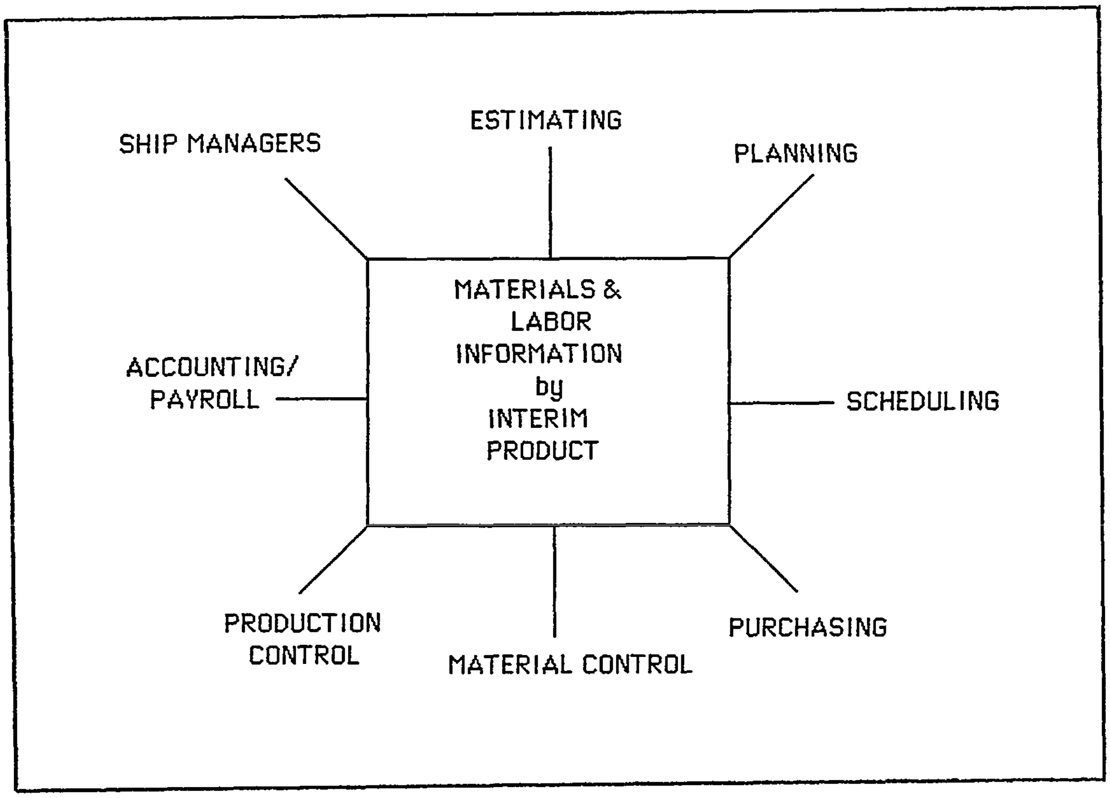

Figure 10: Integration Model Based on Interim Products

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