SHIP PRODUCTION COMMITTEE
FACILITIES AND ENVIRONMENTAL EFFECTS
SURFACE PREPARATION AND COATINGS
DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCE INNOVATION
MARINE INDUSTRY STANDARDS
WELDING
INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

September 1992
NSRP 0383

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

1992 Ship Production Symposium Proceedings

Paper No. 2B-1:
Computer-Integrated Manufacturing - A Perspective

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

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 1992**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **The National Shipbuilding Research Program, 1992 Ship Production Symposium Proceedings, Paper No. 2B-1: Computer-Integrated Manufacturing - A Perspective**	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 Tools Bldg 192, Room 128 9500 MacArthur Blvd, Bethesda, MD 20817-5000**	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**	

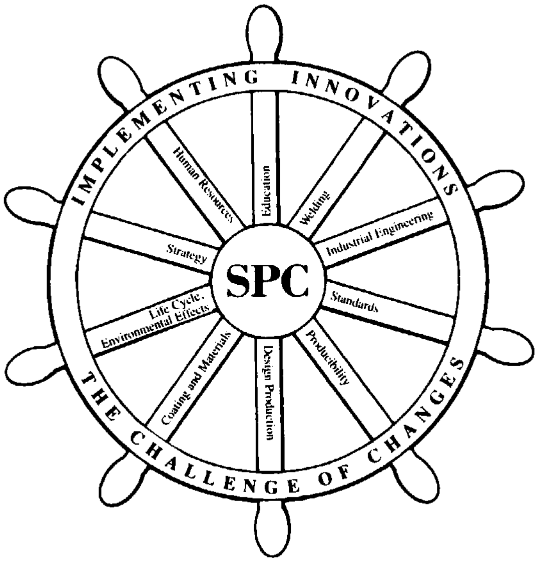
Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

DISCLAIMER

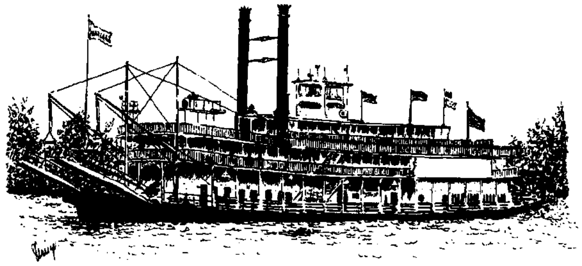
These reports were prepared as an account of government-sponsored work. Neither the United States, nor the United States Navy, nor any person acting on behalf of the United States Navy (A) makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness or usefulness of the information contained in this report/ manual, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or (B) assumes any liabilities with respect to the use of or for damages resulting from the use of any information, apparatus, method, or process disclosed in the report. As used in the above, “Persons acting on behalf of the United States Navy” includes any employee, contractor, or subcontractor to the contractor of the United States Navy to the extent that such employee, contractor, or subcontractor to the contractor prepares, handles, or distributes, or provides access to any information pursuant to his employment or contract or subcontract to the contractor with the United States Navy. ANY POSSIBLE IMPLIED WARRANTIES OF MERCHANTABILITY AND/OR FITNESS FOR PURPOSE ARE SPECIFICALLY DISCLAIMED.

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

1992 SHIP PRODUCTION SYMPOSIUM



SEPTEMBER 2 - 4, 1992
New Orleans Hyatt Regency
NEW ORLEANS, LOUISIANA



SPONSORED BY THE SHIP PRODUCTION COMMITTEE
AND HOSTED BY THE GULF SECTION OF
THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 PAVONIA AVENUE, JERSEY CITY, NJ 07306

Paper presented at the NSRP Production Symposium, New Orleans Hyatt Regency. New Orleans. Louisians, September 2-4, 1992

Computer Integrated Manufacturing: A Perspective

No. 2B-1

Robert Latorre, Member, University of New Orleans, and
Lawrence Zeidner, Visitor, Boston University

ABSTRACT

The introduction of computer integrated manufacturing in shin production will involve- more than linkage of separate automated ship production processes. It will create major changes from design through delivery. This paper presents the results from a three-part project: (1) a manufacturing literature survey of Computer Integrated Manufacturing (CIM) and supporting technologies, (2) a National Science Foundation (NSF)-sponsored Workshop on CIM in ship production, and (3) research and development recommendations to facilitate CIM in ship production.

ACRONYMS

AGG	Automatic Geometry Generators
AI	Artificial Intelligence
APG	Automatic Process Generators
CAD	Computer-Aided Drafting
CAM	Computer-Aided Manufacturing
CE	Concurrent Engineering
CERC	Concurrent Engineering Research Center
CIM	Computer-Integrated Manufacturing
DARPA	Defense Advanced Research Projects Agency
DFM	Design for Manufacturability
DFA	Design for Assembly
DOD	Department of Defense
EBD	Electric Boat Division
EDI	Electronic Data Interchange
FMS	Flexible Manufacturing Systems
GMT	General Motors Truck and Bus
GT	Group Technology
IBM	International Business Machine
IDA	Institute for Defense Analysis
IGES	International Graphics Exchange Standard
JIT	Just-in-Time
LOM	Laminated Object Manufacture
NC	Numerical Control
NSF	National Science Foundation
PDES	Product Definition Exchange Standard
SDTM	Seamless Design-to-Manufacture
SE	Simultaneous Engineering
WIP	Work in Process

INTRODUCTION

The use of computers in ship production has resulted in savings in costs and manhours in scheduling. material tracking and Computer-Aid& Drafting (CAD) drawings. The reduction in schedule and labor-is illustrated in Fig. 1 (1). Developments in manufacturing are now aimed at the integration of overall production from design to delivery through CIM (l-5).

CIM has grown from data exchange and the connection of individual automated activities (5) into an activity encompassing computers, software and production hardware. CIM introduction represents a substantial change in how ships and offshore structures will be designed and produced. Resolution of construction-activity problems, done today by the foreman and crew on site, will shift to being resolved during the initial planning phase of production. Full implementation of CIM in ship production involves more than purchasing and installing a system.

The authors have been involved in a three-part project of technology assessment of CIM for shipbuilding:

1) manufacturing literature survey of relevant publications on supporting technologies for ship production:
2) organization of NSF-sponsored workshop on CIM in ship

Naval Architecture and Marine Engin
911 Engineering Building
University of New Orleans
New Orleans, LA 70148
Tel (504) 286-7180
Fax (504) 286-7413

Department of Manufacturing Engin
Boston University
44 Cummington Street
Boston, MA 02215
Tel (617) 353-3291

NSRP Ship Production Symposium 9/92
New Orleans, LA

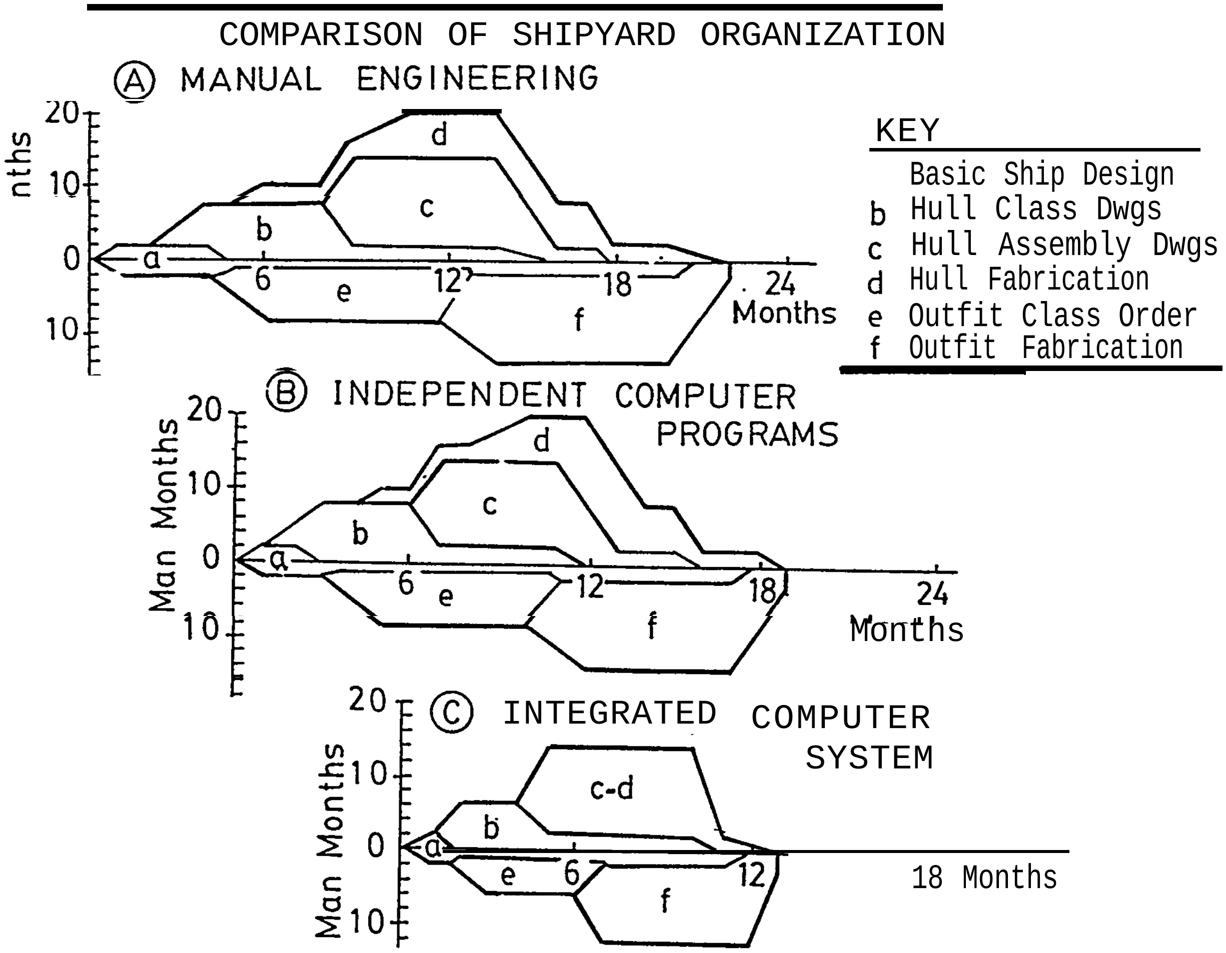


Figure 1. Example of Savings in Time and Manhours from adopting Integrated Computer System for Ship Production Engineering [1].

production (February 6-7, 1992 New Orleans, Louisiana); and

3) development of research and development recommendations to facilitate CIM introduction in ship production.

BACKGROUND PERSPECTIVE

CIM is analogous to shipboard automation which replaced the engine room telegraph with an electronic system. Stage I involved the component automation shown in Figure 2. Stage II involved connecting them and the development in stage III of an overall computerized engine room system. The engineer's activities expanded to maintaining the machinery and the monitoring system, and the rational scheduling of maintenance work. In an analogous manner, the shipyard staff will use the CIM computer system to do traditional shipbuilding and analyze their activities to improve productivity.

LITERATURE SURVEY OF CIM TECHNOLOGIES AND METHODS

Shipbuilding is unique among the industries adopting CIM. The shipbuilding industry differs from other manufacturing industries in its structure, methods, and functions. This characterization forms a basis for cost-benefit comparisons of before- and after-CIM use.

Eight existing or emerging CIM technologies have been identified in the literature search. Of the technologies relevant to CIM, these are the technologies that are also potentially relevant to shipbuilding. Most CIM systems do not employ all of these technologies, nor would they all be appropriate. These CIM technologies are:

Artificial Intelligence (AI)/knowledge-based systems,
Just-in-Time (JIT),
Vendor relationships/Electronic Data Interchange (EDI),
Concurrent Engineering (CE)

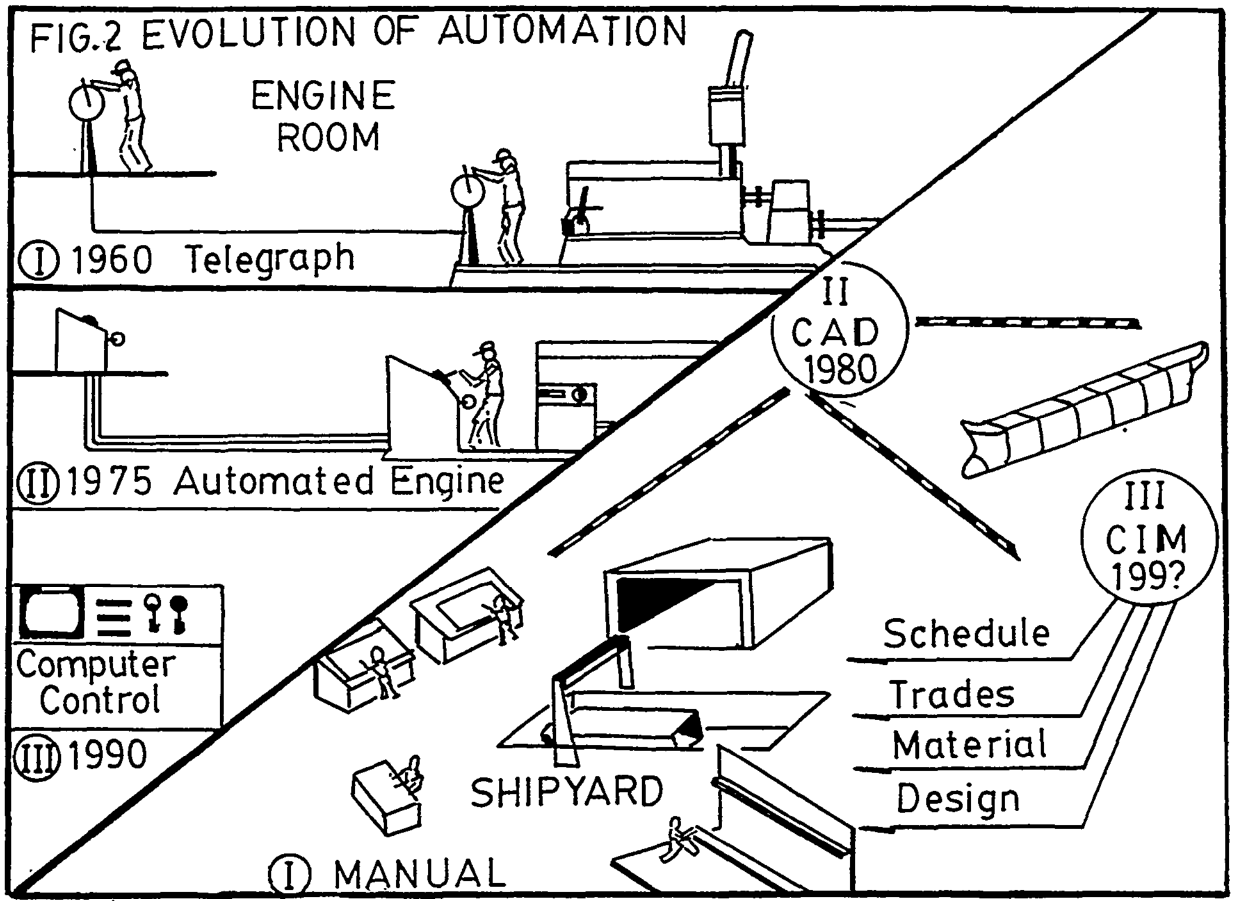


Figure 2. Development of Ship Engine Room Automation 1960-1975 and Today's Shipyard Automation.

- Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) systems,
- Rapid prototyping systems,
- Flexible Manufacturing Systems (FMS), and
- Virtual Reality.

The literature search involved over 110 articles and abstracts (87 articles, and 25 abstracts) from 36 journals and technical publications. It covers 21 industries, including shipbuilding/repair. Specific care was taken to isolate reports of technical accomplishments from the more numerous reports of anticipated benefits.

AI/Knowledge-Based Systems

AI has been developed to capture human expertise and create automated systems that appear to be (artificially) intelligent. AI distinguishes information (data) from knowledge (rules). Knowledge is viewed in AI as rules describing behavior of the data. The classical AI approach consists of a "knowledge engineer" interviewing experts, such as skilled shipfitters, to capture their expertise, and transforming this expertise into AI rules. Such a knowledge-based system (or "expert system") consists of rules, data, and "inference engine" software, shown in Fig. 3. AI systems have been successful in static diagnostic applications such as equipment fault diagnosis/repair (11) and medical diagnosis (12).

AI systems differ from sequential algorithmic systems. The rule order in AI systems is not critical. At the International Business Machine (IBM) Burlington semi-conductor plant, an AI system was developed to examine process rules used in plant operation, to identify sequential patterns of application. These patterns were subsequently captured in algorithmic software (13).

At General Dynamics Electric Boat Division (EBD) in Groton, Connecticut, attempts were made to develop a rule-based AI system to deal with "non conformance," involving lost, defective or damaged parts that did not conform to specifications. Although case by case rules were introduced, EBD found this rule-based AI approach to be too "brittle." Ultimately, a case-based reasoning system was developed. It inquires about the nonconformance details and matches them

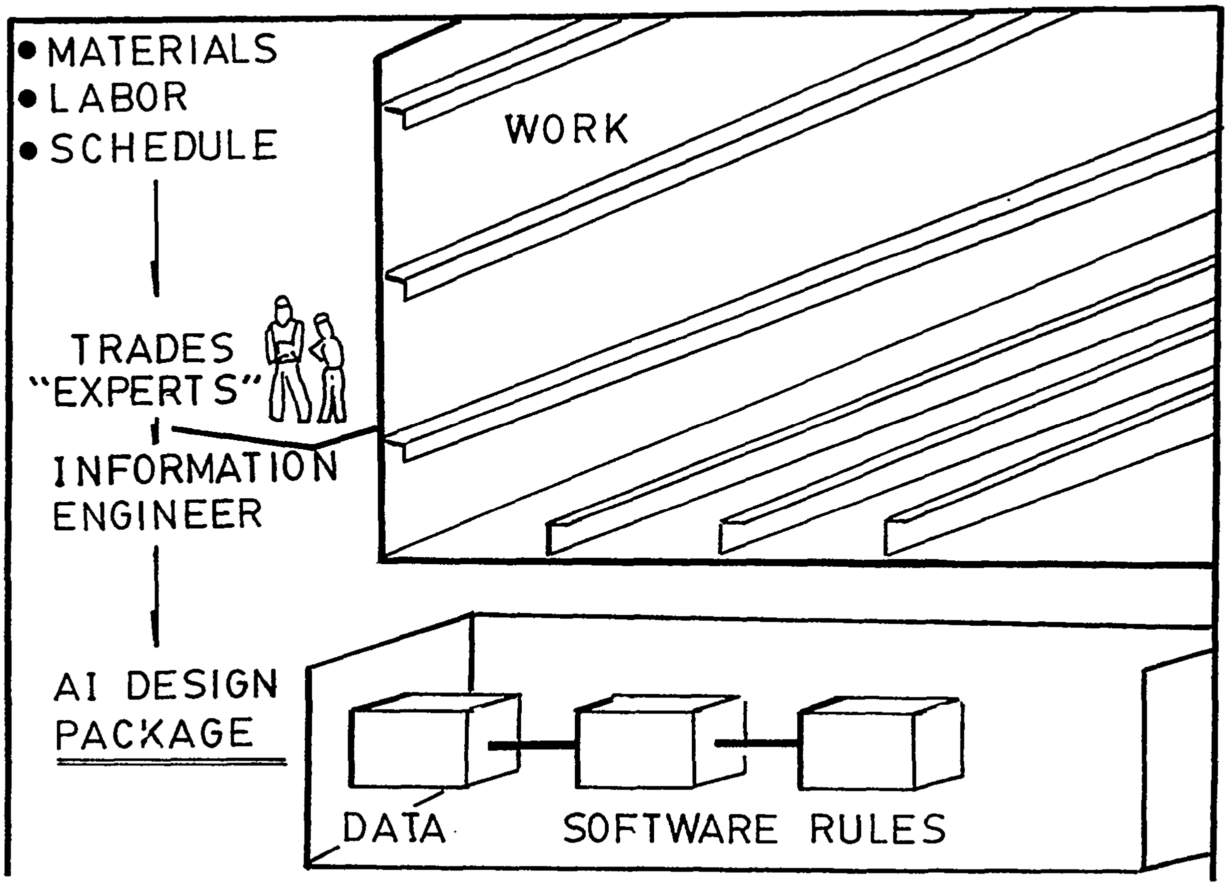


Figure 3. Illustration of AI-Knowledge Based Assembly **Work.**

with a database to find similar cases (14).

At Corning Asahi Video Products, in State College, Pennsylvania, the ICAD Lisp-based AI-CAD system was used to design and simulate molds for television-screen glass components. Glass video components must be free of defects. Corning achieves roughly 60% defect-free production. Although ICAD reduced mold-design time from ten weeks to one, the variety of product differentiation has offset this gain. While Corning's hopes to reach this 60% level after only 20 production hours, it still takes 2,000 hours (15-17).1

AI's use in manufacturing is often justified by the scarcity of young machinists and the need to capture an expert's expertise before retirement. Engineering experts are valuable due to their engineering ability, not for their ability to explain how they work. Experts are reluctant to participate in an exercise aimed at automating their job. Even if an AI system could capture their expertise, the AI system would lack their ability to continually develop new knowledge to respond to new materials, processes and computer techniques. An AI system is a static container for present knowledge. Current thinking is that an expert should be encouraged to train a "naturally intelligent" successor who will advance the state of the art by adding new rules.

The Edison Welding Institute in Columbus, Ohio, is developing AI systems for welding. One 'AI system, called Preheat, is designed to avoid hydrogen cracking of thick steel plates. AI systems for welding are under development at Carnegie Mellon University and the American Welding Institute (18).

Project-based management systems (PBMS) are an AI-based approach to the task of planning and labor-assignment phase of ship repair. The cost of ship repair is roughly 60% labor and 40% material. PBMS systems are therefore organized around the labor component, as compared with material requirements planning (MRP) systems. PBMS systems tie material to labor, and schedule material to be available, based upon lead times. PBMS systems include hierarchical indices which contain information in their nodes, and use expert relations to link these nodes. Ship-repair work assignment is expressed as the establishment of a relation between a trade (a node in the

FIG.4 PRODUCTION AND INVENTORY LEVEL

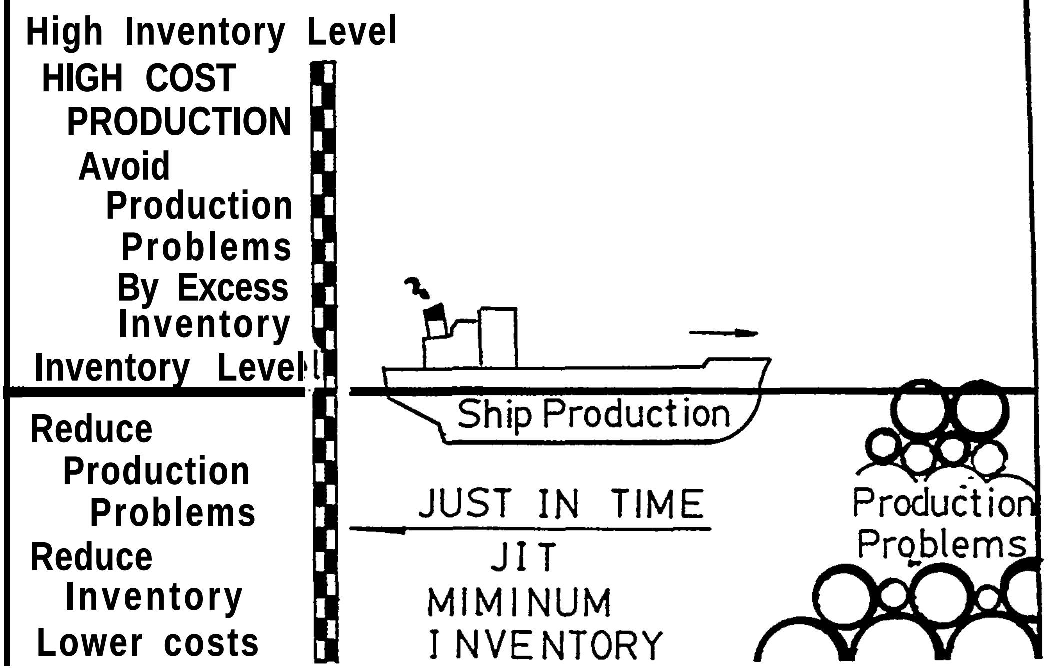


Figure 4. Illustration of How Excess Inventory Covers Ship Production Problems but also Results in High Production Costs.

personnel index) and a task (a node in the operation index) (20).

Just-In-Time (JIT)

JIT is a production philosophy that attempts to operate closer to deadlines, with less inventory, to reduce the cost of maintaining this form of production-delay insurance. The JIT philosophy is often expressed as in Fig. 4. Ship production is similar to navigating a ship in shallow water. Manufacturing problems are analogous to rocks, and inventory is analogous to the water that covers them. Two strategies exist: 1) add more water (inventory) to raise the ship above the rocks (problems), or 2) decrease the water (inventory) level to expose the rocks (problems) completely and ultimately remove them. Shipyards have, in the past, raised inventory levels to maintain production, hiding but not solving the delivery/manufacturing problems. JIT reduces inventory and its associated costs, thus exposing inherent delivery/manufacturing problems so they can be solved. "Just-in-case" inventory is eliminated, along with "expediters," since there is no excess inventory with which to expedite production. However, without the excess inventory, navigating around manufacturing problems, requires closer relationships with vendors (21).

A comprehensive JIT program at the Minneapolis Valve Plant of Dana Corp., has yielded a 32% increase in productivity. This represents a 92% reduction in through time, a 40% reduction in paperwork, a 50% reduction in inventory costs, and a reduction of customer lead time from six months to a week (22).

At Mack Truck in Winnsboro SC, the JIT system reduces errors and insures parts are presented to assemblers in the order they are needed for assembly. Vendors are given precise delivery lists. The suppliers then load delivery trucks in inverse order so the parts arrive in the required order for assembly (21).

Vendor Relationships/Electronic Data Interchange (EDI)

Japanese shipbuilders have benefited from maintaining long term relations with their suppliers. This has been recognized in the U. S. and adopted in a number of nonshipbuilding industries. Bose Corp. in Framingham, Massachussetts has limited its critical vendors to a full-time in-house representative who participates in design meetings by suggesting products that cut cost or better fit Bose's needs (24). In addition to material and component vendors this includes service vendors like trucking companies. The vendor benefits by "evergreen" contracts, that are not periodically rebid, as well as reduced costs and paperwork. Vendors manage an account, rather than reacting to it. Bose benefits by a smaller supplier Pool, better vendor service, and pricing flexibility since the vendor does not have to make large profits on each sale.

The Boeing Company conducts supplier "surveillance." It sends out representatives to monitor suppliers' capacity, production rates, and product work for other customers (25).

Longer contracts provide stability, reduced bidding costs, and reduced need for short-term economic gain. Some of Boeing's contracts reach 14 years into the future, assuming the vendor provides better product quality. In such long-term contracts the customer and vendor share some of the risk of expanded or specialized production, along with sharing associated benefits. McDonnell Douglas Corp. furnishes certain suppliers with business projections and strategies. It provides technical assistance as problems arise, rather than switching suppliers (25).

EDI is a CIM technology that helps industry maintain close relationships with their suppliers and customers. EDI is a combination of communication and computer hardware and software that replaces the normal flood of customer-vendor paperwork. As a significant step toward paperless JIT, EDI sends computerized "forms" containing price quotes, orders, delivery notices, invoices, bills, and account summaries. This is illustrated in Fig. 5.

In 1990, General Motors Truck and Bus (GMT) in Indianapolis was the first plant to order raw-materials by EDI. The plant, using 1,980 tonnes (2,200 tons)- of sheet metal to produce truck and bus panels, turns over its inventory 55 times per year. GMT transmits order schedules to steel vendors. The vendors reply with information describing the truck number, shipping company, departure and expected arrival time. This information is used throughout GMT, from the guard who directs the truck to the appropriate dock, to the schedule to unload the steel. GMT monitors vendor and carrier performance and traces job status in process. Outgoing shipments are also controlled by EDI. GMT communicates with CONRAIL, ordering rail cars configured to hold specific panel types. With EDI, fewer shipments are lost or misplaced, cutting the use of premium shipments by more than 50% (26).

Commercial EDI began with sets of corporations defining communication formats and has evolved into whole industries and EDI vendors adopting standard forms. The emphasis has always been on the data formats with the EDI investment in the complex software systems that send, receive, and Process the EDI data. These systems are constantly modified to handle new types of data formats. The EDI users are developing advanced software-development methods for designing, implementing, testing, and maintaining these distributed EDI software systems. "Server networks" are software systems distributed across computing networks which cooperate to solve engineering and computing problems (27). Their primary advantage is the ease with which they can be programmed and reconfigured graphically (28). Their applicability to EDI systems is in their flexibility to meet the needs of the EDI partners.

Concurrent Engineering (CE)

As international markets became competitive, several approaches were developed to improve product quality, accelerate the transition from concept to manufacture, and reduce manufacturing costs. Each approach encompasses product design, process design, product development, product quality, customer satisfaction, process improvement, employee empowerment, and vendor relationships (20). Many companies have attempted to implement these approaches, and have reported varying levels of success. The Department of Defense (DOD) received many success claims attributed to these improvement programs. It tasked the Institute for Defense Analysis (IDA) to examine the evidence to predict potential benefit. In 1988, this DOD-sponsored IDA study [29] of thirteen American companies explored the use of CE, and found that CE was characterized by changes in corporate culture and management combined with adoption of a few existing methods and technologies. CE was associated with improved design quality, reduced manufacturing cost, and faster product development.

A variety of names are used to describe this approach. The names include CE, simultaneous engineering (SE), design for manufacturability (DFW), and design for assembly (DFA). In these approaches process design begins when initial assembly design is complete (Fig. 6-B). In sequential engineering the assembly design is completed before process design begins (Fig. 6-A). Experienced part and process designers have long recognized the advantages of simultaneously doing the assembly and process designs. The entire design-to- manufacture cycle is shortened, and more design problems are found and corrected at initial design

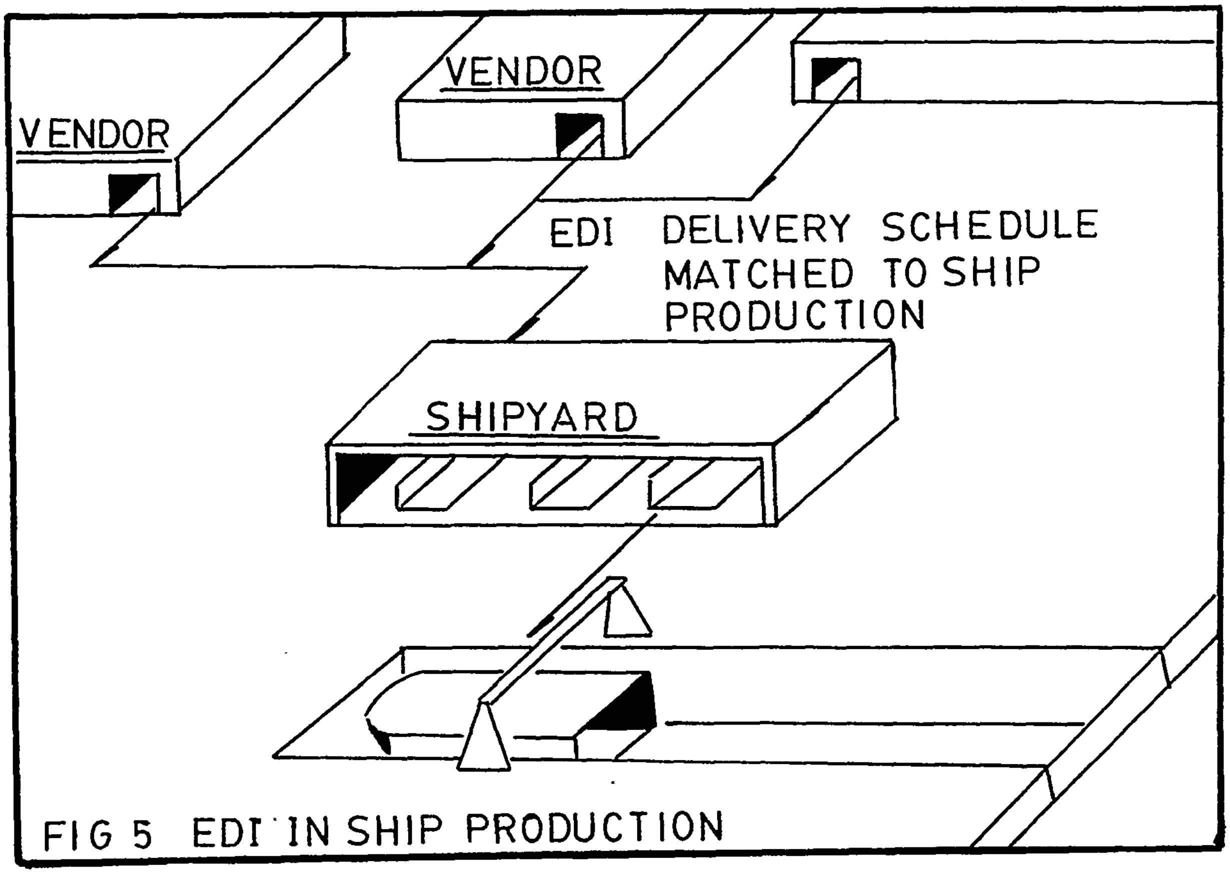


Figure 5. Illustration of EDI in snip Production.

stages, rather than later. This is illustrated in both Figs. 1 and 6, showing a 12-month reduction in engineering time. Difficulties with CE lie in performing downstream design work with incomplete upstream design decisions. This requires reorganizing the design process to identify downstream information dependencies and decoupling independent tasks.

In 1988 the Defense Advanced Research Projects Agency (DARPA) awarded funding of a 5-year $100M Concurrent Engineering Research Center (CERC) to the University of West Virginia at Morgantown. This effort includes a demonstration testbed consisting of different engineering workstations networked together to illustrate the implementation of a collocated CE virtual team. The software approach adopted was to employ (without modification) an existing set of CAD, CAE, and CAM software packages interconnected via a CE communication platform. Attempts were made to employ relevant data-exchange standards such as the International Graphics Exchange Standard (IGES) and the Product Definition Exchange Standard (PDES). Effort made to integrate incompatible systems is Often several times the cost of either original system (32).

At Ingersoll-Rand's Portable Compressor Division in Mocksville, North Carolina, DFM techniques were used. In two compressor assemblies, DFM reduced the number of parts by 64%, reduced the number of fasteners by 47%, and reduced assembly operations by 75%, which cut assembly time by 60% (30).

Major shipbuilding programs such as the DDG 51 class destroyer program (32) and the SEAWOLF submarine program (33) involved concurrent engineering efforts. They demonstrated applications of model-data communication and CAD/CAM solutions.

CAD/CAM Systems

CAD/CAM is not new to shipbuilding. A variety of CAD and CAD\CAM systems have been used (1,34-39). The level of technology and the level of integration varies from shipyard to shipyard.

To increase world market share, manufacturers are aware that "rapid responsiveness" to change is critical, and depends upon accelerating the concept-to-manufacture cycle. Conventional CAD/CAM is an obstacle to this acceleration. The characteristics that enabled CAD/CAM to replace drafting and manual part programming now limit its productivity. CAD\CAM systems require numerous interactive

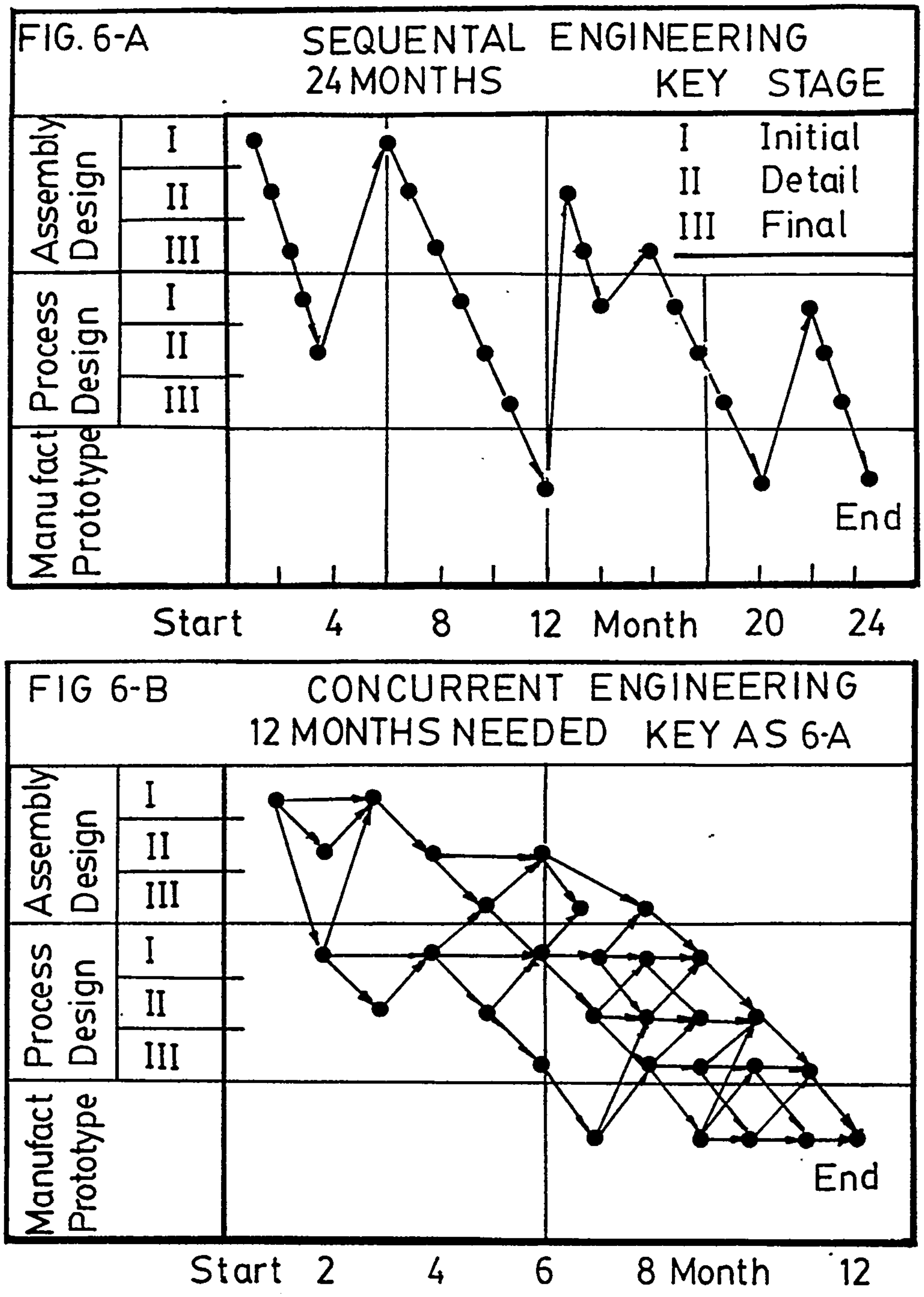


Figure 6. Comparison of Start-End Time for Sequential and Concurrent Engineering.

steps or "seams" which prevent rapid responsiveness. While CAD systems produce only a CAD drawing, the major interface or seam in CAD\CAM systems exists between CAD and CAM, which are employed sequentially. First an item is designed in CAD and then the manufacturing process is developed in CAM. In conventional CAD/CAM systems, assembly design changes require redoing the CAM work. This makes such systems inflexible to changes. Conventional CAD/CAM systems do not address conceptual assembly and process design. They assume that the engineer does the conceptual assembly and process design on paper.

Seamless- Design-to-Manufacture (SDTM) is a post-CAD/CAM technology that offers rapid responsiveness by eliminating many interactive seams and by automating others (40). Figure 7 compares STDM and traditional CAD/CAM systems. SDTM systems consist of an interactive conceptual assembly- and

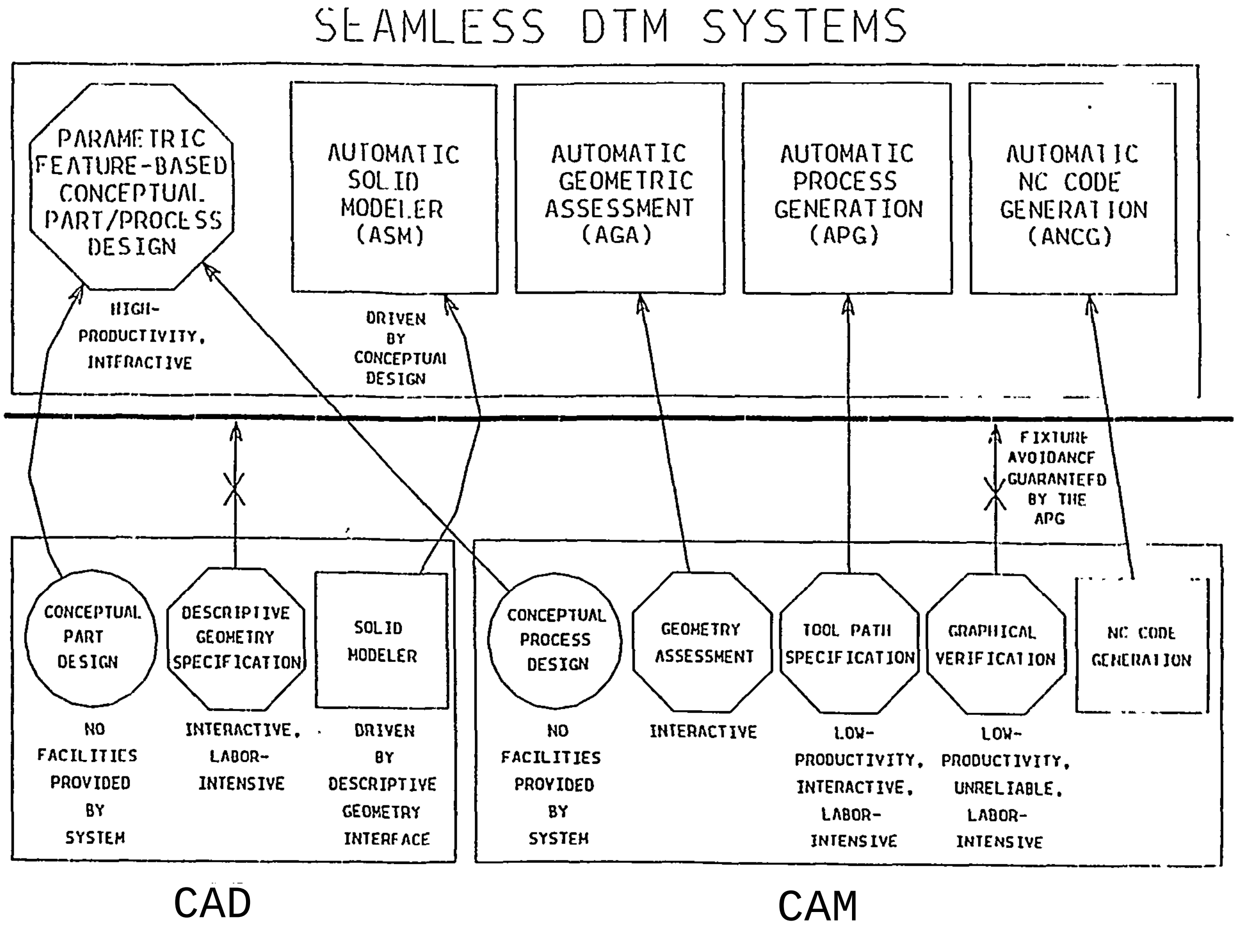


Figure 7. Illustration of Seamless DTM Systems.

process-design component, a set of Automatic Geometry Generators (AGG), and a set of Automatic Process Generators (APG) (41). The feature-based assembly- and process-design components are customized for a Group Technology (GT) family of similar assemblies. CAD/CAM's most serious flaw is overcome by SDTM's rapid responsiveness to product and process change. SDTM uses new or traditional manufacturing processes, and rapidly introduces engineering changes into production. An APG system generates process geometry and either numerical control (NC) code for manufacture, or production schedules, work assignments, production diagrams and material requirements for production, using the family of assemblies* shared process similarity. CAD/CAM is in a poor position to use reduced computer cost and higher speed to improve its responsiveness to change. SDTM is suited intensive and well- to benefit from distributed cooperative processing.

computer and communication hardware technology developments have continued to improve computer processor and communication speeds. However, software-development productivity has made comparatively little progress. Conventional CAD/CAM systems development has been slow and costly due to the traditional low-productivity methods employed. To distribute this development cost over the largest possible market, generic CAD/CAM systems are marketed to design a wide range of products. Unfortunately, they are not responsive to change. Due to new high-productivity software-development methods (28), customized SDTM systems have been created quickly, at relatively low cost. These high-productivity methods make it economical to customize SDTM systems for similar GT families of assemblies. SDTM systems utilize these similarities, elevating design interaction to a highly productive parametric feature-based conceptual level. Although some companies pursued proprietary efforts to customize their CAD/CAM systems in the 1980's, those efforts have been costly and have subsequently involved those companies in more-costly customized upgrades. By devoting their resources to CAD/CAM customization, these companies have missed opportunities to benefit from many advances in technology. High-productivity software-development methods used to build and customize SDTM systems avoid these costs and enable the introduction of new technology.

Unlike conventional CAD/CAM systems, SDTM Automatic Geometry Generators employs "geometric integrity" to generate solid models automatically from assembly-design parameters (42). With SDTM, unlike conventional CAD/CAM, feature-based geometric assembly design, parameterization, and automatic generation of a solid model exhibiting geometric integrity are feasible.

Each SDTM system is built around a flexible process plan that suits the entire GT family of assemblies. A robust APG system is built for this flexible process plan and verified. Thereafter, the parametric design of a new assembly, in the family, produces an assembly automatically. APG eliminates the need for extensive pre-production verification for each assembly, to debug process geometry and either NC code or production schedules and material/work assignments. SDTM also eliminates the need for NC verification software included in many CAD/CAM systems, or sold separately (43). Graphical verification of NC toolpaths is imprecise, time consuming, and extremely costly, often more costly than the machining operation itself.

Within the shipbuilding industry, the SDTM concept-to-production approach can be employed to introduce CIM into shipbuilding without the adoption of NC processes, as explained further, later in this paper.

An FMS is a manufacturing system specifically designed to produce different GT families of parts together, without sacrificing efficiency, as compared with individual factories for each part. Shipbuilding and repair yards also use the same facilities and workforce to produce and repair different types of ships simultaneously. In this sense, they are tackling-the same generic problem as FMS. Enabling technologies of FMS must be examined to determine their applicability to shipbuilding and repair.

Some critics judge existing FMS implementations to be inflexible. They cite early FMS implementations developed in the 1980's, which manufactured a basic design with minor modifications. They also note that during economic downturns the company's capital is tied up in FMS that make unwanted quantities of products (45). These criticisms are directed to the degree of flexibility of FMS, rather than the advantages of FMS over normal automation. In manufacturing, machining centers and turning centers are recommended as being more flexible than FMS that use customized work cells (46,47).

Caterpillar Inc., East Peoria, Illinois, used an FMS to cut lead time and in-process inventory in half, and triple productivity. Parts for elevated sprocket tractors, previously experiencing a throughput of three weeks, now take only a few hours. The part family consists of 41 steel parts fitting within a 150 cm (5 foot) cube. The FMS system includes CNC machining centers with automatic tool changers and automatic work changers, and an automated storage/retrieval system (44).

A major California-based air conditioning manufacturer replaced its five separate batch lines, each producing five component types, by a flexible new line that eliminates work in process (WIP) inventory. This line can produce all five Component types as individual units in any sequence. Now, no tooling changes are required, and only one sixth the workforce is required (21).

Rapid Prototyping Systems

In adopting CIM in shipbuilding, it will become necessary to speed up manual activities like model making. This requires adopting "rapid prototyping" technologies. Recently, several rapid prototyping technologies have emerged [48,49]. These technologies have demonstrated the ability to create geometric models that roughly match part designs. However, for many applications they are unable to generate prototypes that can withstand physical testing and realistic thermal environments. Stereolithographic plastic models are suitable for judging aesthetics and fit of many consumer products. But these plastic models are inappropriate for applications such as instrumented water-tunnel testing of metal marine propulsers, to judge their structural, acoustic, and hydrodynamic response, or for engineering applications that involve appreciable heat. In addition, rapid prototyping speed and accuracy varies greatly from one geometry to another. Other problems include differential shrinkage and polymer toxicity.

Stereolithography and solid imaging selectively cure a liquid photopolymer to build a solid object slice by slice. Selective laser sintering selectively fuses powder, to build prototypes slice by slice. Other processes, based on material deposition. include laminated object manufacture (LOM), ballistic particle manufacture, and fused deposition modeling. Stereolithography has led rapid prototyping, dominating sales.

While most of these processes are driven from standard CAD data, the slice geometries must be fully closed. Most conventional CAD systems do not preserve geometric integrity (42), so CAD rework to close the slices is required for each part.

SDTM provides rapid prototyping using conventional machining processes and the intended part materials (40). SDTM produces prototypes which are both geometrically correct and can be evaluated in realistic physical and thermal test environments. These prototypes are also acceptable final products.

Virtual Reality

Virtual reality is an emerging technology that enables an observer to experience an environment or a task by means of visual, auditory, and sensory simulation (50). The equipment includes a helmet that features graphical screens as goggles, stereo sound, and a pair of gloves equipped with position and orientation sensors. A person moving their hands and arms sees graphical depictions of their hands and arms moving in the goggle screens. By walking on a treadmill, the operator can tour workplace or a designed environment such as a ship. A pilot may see a virtual cockpit dashboard with gages and knobs. As he reaches out to touch them, he sees the image of his arms doing so, and experiences the effects. This is an effective way to prototype instrument panels. The computational requirements of presenting realistic images and computing intersection of virtual objects, and the physical effects of exerting forces on these objects are enormous. Advances in computer hardware technology will supply the computational power to provide better and more convincing realistic Visual and auditory images. Less progress has been made on general-purpose tactile sensory response equipment.

Quasi-realistic graphical output has already helped in many design areas. It is possible with commercial packages to visualize the simulated interior of a ship cabin. Designers can check ergonomic issues such as head clearance, or the clearance for a crew member carrying equipment. These systems differ from virtual reality systems in the nature of their input devices or interfaces, and by the use of workstation screens.

In ship production, a tradesman wearing virtual reality equipment could see an overlayed image of the correct placement of the next component to be attached superimposed over the existing assembly. Ship designers could digitally explore the final assembly interferences of large system subassemblies. Maintenance requirements and difficulties could be assessed quickly during the design stage of engines and other complex intertwined 3-D assemblies using virtual reality [50].

WORKSHOP ON APPLYING CIM TO SHIPBUILDING/SHIP REPAIR

An NSF-sponsored workshop was held at the University of New Orleans on February 6th and 7th. The objectives of this workshop were:

- to expose U.S. shipbuilders to developments in CIM,
- to develop a consensus of what bottlenecks stand in the way of realizing CIM, and
- to develop research themes which address the problems facing introduction of CIM in U.S. shipyards.

Representatives of academia, from Boston University, the Massachussetts Institute of Technology, and the University of New Orleans were in attendance. Shipyard representatives of Avondale Industries, Beth Ship, Ingalls Shipbuilding, and Swiftships participated.

Workshop Observations

Substantial implementation of CIM in shipyards will change the traditional boundaries between engineering, production, and scheduling. It will shift the sequence of these activities (Fig. 1). It will also alter the scope and conceptual level of shipyard job responsibilities, and work force job skills. This will impact supervisors, planners, designers and engineers (everyone other than the workers actually performing shipbuilding trades). Routine work will be automated, saving time for conceptual planning and comparative decision-making.

Ship production planning involves a hierarchy of planning levels and different levels of detail. The lowest level involves the foreman who examines the job, its location and its accessibility, and then accurately specifies the detailed sequence of tradesmen, equipment and the time

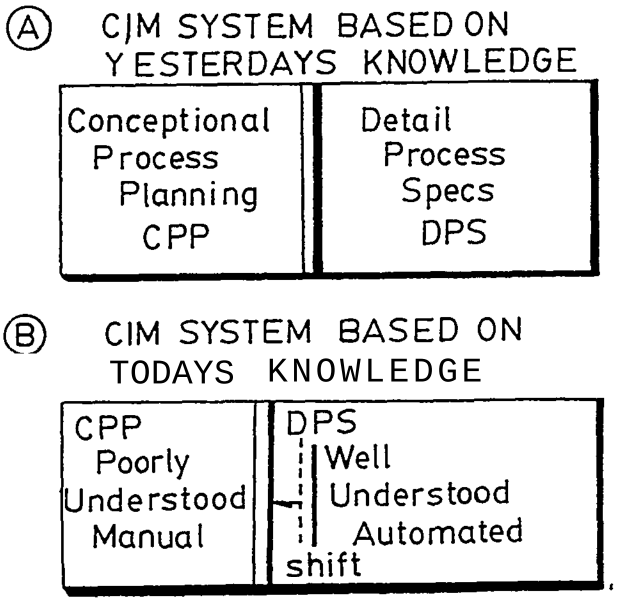


Figure 8. Illustration of DPS-CPP Shift

required for each outfitting process. Shipyard process planning Consists of two activities, conceptual process planning and detailed process specification as shown in Fig. 8. The detailed process specification is the well-understood portion of process planning. It has become routine, and can be automated. Conceptual process Planning is the portion that is not understood well enough to be automated. The division between these two levels shifts gradually, as the employees learn and their understanding increases and as the shipyard technology base grows (Fig. 8).

The detailed design, planning, scheduling, purchasing, and cost-estimation of ship production is too massive, tightly coupled, and dynamic to afford the luxury of performing detailed process specification manually or even as a computer assisted activity (51). Detailed process specification must first be automated into CIM systems so that shipyard personnel can progress to conceptual process planning. This will allow a better capability to compare design alternatives, evaluate design changes, and understand the impact of delivery and work delays. The CIM Workshop attendees agreed that a shipyard CIM system must be able to respond to engineering change. This involves using the existing process plan, performing the detailed process specification automatically, and producing a budget and production schedule that conforms to current lead times and manpower/equipment constraints. This allows different engineering changes to be compared to select the best. Today's manually detailed process specification will be automated to achieve SDTM in ship production.

It was noted that attemps to fully automate shipyard process planning may not yield a successful shipyard CIM system. Since many of these process planning skills are poorly understood, they are not easy to capture. Most generative process planning systems are still at the research level. The few commercially available systems have not found widespread acceptance in industry because they require manual coding of part features, and the development and maintenance of extensive databases and decision logic that is unique to each manufacturing firm (52).

Rather than automating all of process planning, the detailed shipyard process specification of well understood tasks, such as welding or outfitting, should be automated first. Then, the foremen can deal with the next-highest assemblies. In doing so they can identify any errors in the planning software and later, they can add additional tasks not previously automated. In this way, shipyard supervisory expertise is available to improve the CIM system continuously. Rather than displacing skilled shipyard foremen, their job is expanded and improved as a result of shipyard CIM.

This approach to CIM differs from the call to mechanize, automate and numerically control shipbuilding processes. Although automation has been demonstrated to be effective in the Japanese shipbuilding industry, it is linked to the Japanese shipbuilding industry's division into specialized shipyards, each building a certain type of ship. Japan enjoys sufficient volume to make mechanized assembly processes effective. Presently, American shipbuilding has too small an order book to reorganize itself in this fashion.

Rather than automating shipbuilding, the approach to realizing CIM seeks to automate the process specification. Tradesmen are needed to build ships: however, as knowledge of shipbuilding grows, more and more complex process-specification tasks will be automated, freeing those workers to consider more important productivity issues, rather than repeatedly "fighting the same fires" throughout their careers.

CONCLUSION: RESEARCH RECOMMENDATIONS

The workshop attendees strongly endorsed the concept University-based Center for Advanced Marine Technology similar to an NSF Center of Excellence. In this university-affiliated center, advanced technologies would be developed and made accessible for ship production. It would be associated with a university program in naval architecture and be close to the shipyards.

The workshop attendees also indicated that the role of the Center should be focused on research and development in areas critical to the maintenance of the U. S. shipbuilding base. They suggested that the Center should conduct research in four areas that would accelerate the adoption of U. S. ship production and repair. These four research areas are summarized below.

Development of Quantitative Index of CIM-Related Improvements in Ship production/Repair

The cost for a shipyard to adopt CIM must be balanced with the projected improvements. This raises several issues which must be addressed for the CIM system to be adopted. The scope of this research would include the areas listed below.

- Identification of areas which will see:
  - a. significant improvement,
  - b. moderate improvement, and
  - c. long-term improvement (initially small improvement).
- Development of an index to assess these gains. This index would include improvement in costs, schedule, and profitability in shipyard production.
- Application of this index to a cross-section of ships and offshore structures to identify where the highest gains will occur.

This research will also clarify the extent of benefits from incremental adoption of CIM, versus a complete switchover to CIM.

characterization of Shin Production Activity and Manpower Shift with CIM Adoption

The introduction of CIM into shipyards will have far-reaching implications on present and future shipyard staff. Implications which should be explored will include:

- their required skills,
- their training,
- how their expertise will be incorporated into CIM systems,
- how they will use and supervise these CIM systems,
- what new opportunities for career growth paths are presented by their use of these CIM systems, and ultimately
- who will seize the opportunity to advance and grow with the technology or be made obsolete by it.

In the long term, shipyard jobs (above the level of tradesmen actually performing shipbuilding processes) will be integrally tied to the use of CIM systems.

This shift in personnel requirements can only be accomplished in an evolutionary manner. Many obstacles, both technical and social, obstruct the transition from present shipyard structures to CIM based shipyard. Cooperation of process-planning experts is necessary, although unlikely unless shipyard management can take serious steps to prove that their goal for CIM automation is not to displace workers.

Development of Shipyard Production Testbed for CIM Development and Training

Emerging CIM technologies are rarely presented in the ontext of shipbuilding. Due to differences between shipbuilding and other manufacturing industries, some of these technologies are inappropriate for use in ship production, while others are quite effective. Because of the high cost of. implementing large corporate CIM efforts, the shipbuilding industry will either duplicate efforts in testing emerging CIM technologies or choose to ignore them. A computer-based ship production testbed can provide a prototyping environment to test emerging CIM technologies and demonstrate their relevance to ship production. Specific examples of individual shipyard production methods can be used to customize the application of these technologies to production activities at specific yards, helping member yards to gauge the detailed performance of the technologies on their own work, through their own evaluation criteria. Once technologies have been demonstrated using the testbed, better decisions can be made regarding their benefits, costs of scale-up, expected difficulties, and technology transfer into the shipyards

Characterization of the Costs and Scope of Engineering Changes Throughout the Production Cycle

To achieve low costs, quick delivery, and high quality, the costs and delays from engineering changes must be minimized. The CIM system provides a mechanism with which to make frequent changes easily, however, once production begins, these changes can have costs that are not readily discernible. These costs can involve not only material and services that have already been ordered, but by delaying other work, engineering changes can affect tasks along the critical path and cause delays which add significant costs. Other engineering changes actually reduce costs and positively impact the schedule.

It is imperative that the CIM system determine these cost increases/decreases and schedule improvements/delays so that decisions can be made by the production managers Other alternatives involve 1) strictly limiting all engineering changes, with no knowledge of their implications, or 2) freely permitting all engineering changes, blindly hoping that the implications will be positive or minimal. Neither of these two alternatives is acceptable. Instead, shipyard planners must have the information with which to gauge the impact of their proposed changes, so that alternative changes can be compared to build the best ship at the lowest cost in the shortest time.

ACKNOWLEDGMENTS

This work was supported by the Division of Design and Manufacturing Systems of the National Science Foundation, Grant No. DDM-9116723. The opinions are those of the authors and do not represent the views of the National Science Foundation. The authors are grateful to Mrs. Latapie for typing this manuscript.

REFERENCES

1. Wake, M., "CAD-CAM Goes from Strength to Strength," THE NAVAL ARCHITECT, April, 1991, p. E-185.
2. Minemura, T., Horiuchi, K., Amemiya, T., "Production Control System for CIM for Shipbuilding," Journal Naval Architects of Japan, Vol. 170, December, 1991, pp. 827-841.
3. Amemiya, T., "Process Planning System for CIM for Shipbuilding," Journal Naval Architects of Japan, vol. 170, December, 1991, pp. 843-856. (In Japanese).
4. Nogase, Y., "A Study on Consistency of Model Information for CIM in Shipbuilding," Journal Naval Architects of Japan, Vol. 170, December, 1991, pp. 857-866. (In Japanese).
5. Brodda, J., "Shipyard Modeling -- An Approach to a Comprehensive Understanding of Functions and Activities," Journal of Ship Production, SNAME, 7(2), pp. 79-93, May 1991.
6. Frenzel, L. E., Jr., Understanding Expert Systems, 1st ed., Howard W. Sams & co., Indianapolis, Ind., 1987.
7. Waterman, D. A., A Guide to Expert Systems, 1st ed., Addison-Wesley, Reading, MA 1986.
8. Hayes-Roth, F., Waterman, D. A., and Lenat, D. B., Building Expert Systems, Addison-Wesley, 1983.
9. Barr, A., and Feigenbaum, E., eds.. The Handbook of Artificial Intelligence, Heuristic Tech Press, Stanford, CA, 1982.
10. Nilsson, N., Principles of Artificial Intelligence, Springer Verlag, Berlin, 1982.
11. Andriole, S. J., and Hopple, G. ., eds., Defense Applications of Artificial Intelligence, D. c. Heath, 1987.
12. Buchanan, B. G. and Shortliffe, E. Rule-Based Expert Systems: The Mycin Experiment, Addison-Wesley, 1984.
13. Fordyce, K. and Sullivan, G., "Logistics Management System: Implementing the Technology of Logistics with Knowledge Based Expert Systems," Innovative Application of Artificial Intelligence, edited by H. Schorr and A. Rappaort, AAAI and MIT Press, 1989.
14. Radding, A., "AI in Action," Computer-world, July 29, 1991.
15. Teresko, J., "corning's Rebirth of the American Dream," Industry Week, pp. 44-47, January 7, 1991.
16. Koelsch, J. R., "1990 LEAD Award Report: CIM for Success," Manufacturing Engineering, SME, pp. 29-32, October 1990. 17. Welter, T. R., "Product Design: 10 Weeks' Design Collapses to One," Industry Week, pp. 58-59, July 16, 1990.

18. Miska, K. H., "The New Mavens of Manufacturing," Manufacturing Engineering, SME, PP. 36-39, October 1989.

19. Port, O., et. al., "Smart Factories: America's Turn?" Business Week, pp. 142-148, May 8, 1989.

20. Bensten, C. E., "Index-Based Management Information Systems: A Study in Structured Operations," Journal of Ship Production, SNAME, 7(3), pp. 170-175, August 1991.

21. Owen, J. V., "Rocks and Water: Making it JIT," Manufacturing Engineering, SME, pp. 68-72, September, 1990.

22. Rogers, H., "What Dana Learned from Japan," Industry Week, pp. 36-40, July 15, 1991.

23. Congdon, W. S., and Hitt, R. A., "How to Use JIT to Control Equipment Spare Parts," Automation, pp. 30-31, February 1991.

24. McClenahen, J. S., "So Long, Salespeople," Industry Week, pp. 48-51, February 18, 1991.

25. O'Lone, R. G., et. al., "Airframe Manufacturers, Suppliers Forge New Ties," Aviation Week & Space Technology, pp. 38-39, July 16, 1990.

26. "New Information Links in the Automated Factory," Material Handling Engineering, pp. 33-48, May 1990.

27. Zeidner, L., "Server Networks: A CIM Architecture Design Environment," Proceedings of CIM CON '90 International Conference on CIM Architecture, National Institute for Standards Technology (NIST), Gaithersburg, MD, pp. 95-113, May 1990.

28. Hazony, Y., and Zeidner, L., "Customized Systems for Engineering Applications," IBM Systems Journal, 31(1), 94-113, February 1992.

29. Winner, R. L., et. al., The Role of Concurrent Engineering in Weapons System Acquisition, IDA Report R-338, Institute for Defense Analyses, 1988.

30. Carlyle, R., "Martin Marietta Flies in Formation," Datamation, pp. 85-87, August 15, 1990.

31. Koelsch, J. R., "SE Team Cuts Assembly Operations," Manufacturing Engineering, SME, p. 45, November, 1990.

32. Schmidt, W. R., Vander Schaaf, J. R. and Shield, R. Y., III, "Modeling and Transfer of Product Model Digital Data for DDG 51 Class Destroyer Program," Journal of Ship Production, SNAME, 7(4), pp. 205-219, November, 1991.

33. Brucker, B. R., and Baseler, R. w "SEAWOLF Producibility II: Transition from Design to Production," Journal of Ship Production, SNAME, 7(4), pp. 258-266, November, 1991.

34. Gunville, J. M., "Shipbuilding Launches onto High Seas," Automation, pp. 48-52, October 1987.

35. Ichinose, Y., "Improving Shipyard Production with Standard Components and Modules," Paper No. 10, SNAME Spring Meeting/STAR Symposium, April 26-29, 1978.

36. Zhou, H., and Xue, Z., "Research and Development of CAD/CAM in the Chinese Shipbuilding Industry," Computers in Industry, 8, pp. 209-213, 1987.

37. Carr, B. A., Moulihan, I. M., and Polini, M. A., "CAD/CAM in Phased Maintenance," Journal of Ship Production, SNAME, 7(4), pp. 234-247, November, 1991.

38. West, H., and Gallo, M., "Design Through Manufacture: A Computer-Aided Design Advisor for the Manufacture of Submarine Hulls," Journal of Ship Production, 6(4), November 1990.

39. O'Hare, M. S., and Anderson, M. "An Integrated CAD/CAM Network for Work Packaging Development and Database Management," Journal of Ship Production, SNAME, 5(2), May 1989.

40. Zeidner, L., and Hazony, Y., "Seamless Design-to-Manufacture (SDTM)," Journal of Manufacturing Systems, American Society of Mechanical Engineers, accepted for publication (1992).

41. Zeidner, L., "Automatic Process Generation and the SURROUND Problem: Solution and Applications," Manufacturing Review, American Society of Mechanical Engineers, 4(1), PP. 53-60, 1991.

42. Hazony, Y., "Design for Manufacture: A Geometric Modeler for Geometric Integrity," Manufacturing Review, American Society of Mechanical Engineers, 4(1), pp. 33-43, 1991.

43. Krouse, J., et. al., "CAD/CAM Planning: Successfully Applying CAD/CAM," Industry Week, p. CC 56, July 2, 1990.

44. "Production Lines: Making Tracks to JIT," Manufacturing Engineering, SME, pp. 68-69, February, 1990.

45. Cook, B. M., "Automation's Role in World-Class Manufacturing," Industry Week, pp. 32-36, August 5, 1991.

46. Miska, K. H., "Driven Tools Turn on Turning Centers," Manufacturing Engineering, SME, pp. 63-66, May, 1990.

47. Noaker, P. M., "Turning it JIT," Manufacturing Engineering, SME, pp. 77-81, March, 1991.

48. Ashley, S., "Rapid Prototyping Systems," Mechanical Engineering," ASME, pp. 34-43, April 1991.

49. cook, B. M., "Rapid Prototyping: Designing a New Industrial Revolution," Industry Week, pp. 46-48, June 3, 1991.

50. Puttre, M., "CIME: Virtual Reality Comes into Focus," Mechanical Engineering, ASME, pp. 56-59, April, 1991.

51. Lamb, T., "Organization Theory in Shipbuilding: A Brief Overview," Marine Technology, Vol. 29, No. 2, pp. 71-83, 1992.

52. Bedworth, D. D., Henderson, M. R., Wolfe, P. M., COMPUTER INTEGRATED DESIGN AND MANUFACTURE, McGraw Hill, New York, 1991, pp. 233-242, 289-290.

Additional copies of this report can be obtained from the
National Shipbuilding Research and Documentation Center:

http://www.nsnet.com/docctr/

Documentation Center
The University of Michigan
Transportation Research Institute
Marine Systems Division
2901 Baxter Road
Ann Arbor, MI 48109-2150

Phone: 734-763-2465
Fax: 734-763-4862
E-mail: Doc.Center@umich.edu