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DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCE INNOVATION
MARINE INDUSTRY STANDARDS
WELDING
INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Evaluation of Shipbuilding CAD/CAM/CIM Systems - Phase II (Requirements for Future Systems)

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

in cooperation with
Newport News Shipbuilding

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FINAL REPORT

NSRP 4-94-1

EVALUATION OF SHIPBUILDING CAD/CAM/CIM SYSTEMS PHASEII

(REQUIREMENTS FOR FUTURE SYSTEMS)

A PROJECT OF

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

FOR

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

SHIP PRODUCTION COMMITEE

SP-4 DESIGN\PRODUCTION ENGINEERING PANEL

by
NATIONAL STEEL AND SHIPBUILDING CO.
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FEBRUARY 1997

EXECUTIVE SUMMARY

The Phase II Report of NSRP project 4-94-1 documents an analysis of CAD/CAM/CIM in shipyards, ship-design software firms, and alIied industries in Europe, Japan and the U.S. The purpose of the analysis was two fold:

- To describe the requirements of a competitive, future-oriented computer-aided design/computer-aided manufacturing/computer-integrated management (CAD/CAMYCIM) system for shipbuilding
- To describe how shipyard business goals may be used as the basis for selecting requirements for a shipyard CAD/CAM/CIM system.

In carrying out the analysis, the project team concluded that increased utilization of CAD/CAM/CIM is necessary in order for U.S. shipyards to become competitive worldwide. The technology is already wide ranging in world-class shipyards, spanning design, manufacturing and management. However, there are opportunities for U.S. yards not only to catch up with but to leapfrog, the competition. Numerous areas exist for innovation particularly in areas of integration. Indeed, one U.S. company has successfully developed a *datacentric* approach that has dramatically strengthened its business position in the world market.

The team also concluded that European and Japanese shipyards have succeeded in part by recognizing that a shipyard's executive level management has a specific role to play in implementing CAD/CAM/CIM technology. The role requires becoming familiar with the capabilities of the technology, considering the technology when developing shipyard business strategies and working with technical management to translate business objectives into priorities for the selection and implementation of the most appropriate parts of the technology for each shipyard.

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Odense Steel Shipyard
SENER Ingenieria y Sistemas
Peter Marks and Kathleen Riles, Authors *of Aligning Technology*
Torben Andersen, Executive Vice President, Odense Steel Shipyard

CONTENTS

1.0 INTRODUCTION

1.1 Background

This report was prepared in conjunction with National Shipbuilding Research Program (NSRP) project 4-94-1 to evaluate world-class shipbuilders' CAD/CAM/CIM systems. Five U.S. shipyards (Avondale Industries, Bath Iron Works, McDermott Shipbuilding Newport News Shipbuilding and National Steel and Shipbuilding) participated in this study along with personnel from University of Michigan, Proteus Engineering, and Cybo Robots. Project participants had backgrounds in ship design, computer-aided design (CAD), manufacturing processes, computer-aided manufacturing (CAM), production planning, and computer-integrated manufacturing (CIM).

This report presents the results of Phase II of the NSRP CAD/CAM/CIM project. The project comprises three phases, as follows:

- Phase I-Evaluate Existing Systems - Visit world-class shipyards in Europe and Japan and learn about state of-the-art shipbuilding CAD/CAM/CIM approaches (documented in NSRP Report 0476).
- Phase II - Requirements - Build upon the knowledge gained in Phase I to develop a set of requirements for a competitive, future-oriented, shipbuilding-design-and-production CAD/CAM/CIM system.
- Phase III - Workshops - Prepare for and conduct executive-level workshops that show how CAD/CAM/CIM technology requirements relate to shipyards from a business perspective.

1.2 Organization of This Report

This report comprises the following sections:

1.0- Introduction provides background on the NSRP CAD/CAM/CIM project, describes the organization of this report, summarizes the evolution of CAD/CAM/CIM and lists CAD/CAM/CIM trends.
2.0- The Requirement Development Process describes how requirements fit within the software development process, how requirements are described and how they are tested.
3.0 CAD/CAM/CIM Requirements- presents the CAD/CAM/CIM requirements developed by the project team and shows how they may be grouped to be consistent with U.S. shipyard typical practices.
4.0- Requirement Selection Methodology presents a methodology, based on shipyard business considerations, for the selection of CAD/CAM/CIM requirements. Included are discussions of innovation customerization optimization and the theory of constraints.

5.0- Conclusions and Recommendations makes conclusions and recommendations, applicable to the competitiveness of U. S. shipyards in the international commercial market.

6.0- References lists the references cited in the text of the report.

Appendix A provides data sheets for each requirement, with a description summary of how near the requirement is to practical application what the requirement is designed to do, and how the requirement can help meet a shipyard's business goals.

Appendix B describes a recent Japanese CIM study from a high-level requirements perspective and compares the results to those of the NSRP study.

Appendix C presents citations of professional papers and reports that provide further insight into the CAD/CAM/CIM requirements. Included is a cross-reference matrix that matches citations to requirements.

1.3 Evolution of CAD/CAM/CIM Systems -An Overview

In order to provide a general context in which to view requirements for a CAD/CAM/CIM system, it is useful to review the evolution of CAD/CAM/ClM systems in the shipbuilding industry. Perhaps the most striking element in this evolution is that it has taken place in such a short time span relative to the present age of industrialized shipbuilding. Table 1-1 illustrates this point [2](Numbers in brackets indicate references listed in Section 6.0). While the birth of industrialized shipbuilding can be set in the middle of the last century, well over one hundred years ago, the birth of shipbuilding CAD/CAM/CIM can be dated from the early 1970s, less than a quarter of a century ago. Another point that this table makes is that CAD/CAM/CIM is increasingly becoming a capability not only of the big yards but of the medium and small yards as well. The table illustrates the trend from mainframe computers to local area networks, workstations and PC hardware, coupled with integrated software. Also, present-day systems may include a single integrated database, called a product model.

The table shows the evolution of shipbuilding CAD/CAM/CIM in general; not every shipyard evolves through each of the steps of the process. Also, a number of U.S. shipyards do not yet possess the computing capabilities of the "87-96" row of Table 1-1. For them obtaining a modem CAD/CAM/CIM capability can represent not just an evolutionary step but a quantum leap.

Table 1-1
Evolution of Shipbuilding CAD/CAM/CIM Systems
(adapted from [2])

YR	HARDWARE	SOFTWARE	END USERS/ COMPUTING POWER
1972 78	Big computing centers. Main frames. Punched cards and alphanumeric terminals.	Independent applications. Sequential files. Batch processes.	Big shipyards. High computing level.
79 86	Medium computing centers. Midi/Mini computers. Alphanumeric terminals and **graphic terminals.**	Integrated applications. Medium level independent databases. Interactive processes.	Big and medium shipyards. Medium computing level.
87 96	Local area networks. Workstations. X-Terminals Pcs.	Fully integrated applications. Single database. Interactive graphic processes. Open systems.	Big, medium and small shipyards. Low computing level.

Shipbuilding CAD/CAM/CIM software today may be characterized as follows:

- UNIX-based
- CAD-Oriented database
- Proprietary
- costly
- Workstation-based
- Non-Standard.

There are exceptions to the above characteristics. Some shipbuilding CAD/CAM/CIM software resides in several separate databases instead of single product model database. Some software runs in a PC environment and is much less expensive (and to dateless capable) than the UNIX-based workstation software. However, the leading systems generally have the above characteristics.

1.4 Summary of CAD/CAM/CIM Trends

The NSRP project team visited five CAD/CAM/CIM vendors to observe state-of-the-art systems. The vendors and their respective software products were as follows:

- HITACHI - HICADEC
- Kockums Computer Systems - TRIBON
- Sener Ingenieria y Sistemas - FORAN

- Intergraph-ISDP
- Black and Veatch - POWRTRAK.

The information gleaned from these visits was immense. Perhaps of most relevance to this report, which focuses *on CAD/CAM/CIM* requirements, are software development trends, or directions that appear to offer significant enhancements to today's state of the art. Nine trends were identified:

1. User Friendliness - The software is easy to learn and to use, with features such as carefully designed graphical user interfaces, seamless integration of program modules into a conceptual whole, and a "natural" program operation.
2. Open Architecture-The software may be readily and easily linked with other applications. A related trend is the capability to use several applications together to accomplish a ship design project. For example, a CAD program may be used in concert with a spreadsheet program, taking advantage of features such as linking and cut-and-paste.
3. Expansion of Program Scope - The software may be used beyond the narrow ship-design limits traditionally set, to areas such as production cost estimation and program management. This expansion is either through in-house software development and addition to the baseline program or by links to second party applications.
4. Assignment of Ownership -All data is assigned ownership to particular project persons. Advantages include a speed-up of the design and production process by the owners "freezing" portions of the design in a timely fashion as they complete them, and making that freeze status available to all project personnel so they may proceed with their portions with confidence (knowing there will be no subsequent changes to the basis of their own portions of the design). Also, ownership enables automatic assigning of design requirements across disciplines (e.g., a pump may be owned by one designer, but the program will tag another designer to provide piping pressure as it relates to the pump.).
5. Sophisticated Data Search Techniques - This capability makes it easy to locate and retrieve specific data (e.g., all pumps that will be delivered to the shipyard within the coming week) and is of great value to an ongoing project.
6. Document Management - The ship design is extended beyond the physical description of the ship to include documents and other associated data. This is a logical extension of the product model. This approach may include the ability to model ships outside of the graphics environment (e.g., by developing a relationship between an engine and its volume, weight and output power) and thus assist in reducing design time through enhancing concurrent engineering.
7. Intelligent Identifiers of Components - This identifier includes recognizable alphanumeric digits that identify key elements (e.g., "P" may mean pump), followed by an identifier of the specific component.
8. Remote Networking Capability - The 3D product model may be placed at each of several separate sites and viewed at each site. The multiple-site residence of the model minimizes data transmission among sites while allowing people at each site to view the

same model simultaneously. One site is the “driver,” and controls views, requests for attribute displays, and call-ups of other data files (e.g., technical manuals, raster image drawings and videos). The other sites are “passengers,” with view-only status. The driver function may be exchanged from site to site. Non-permanent “what-if" changes may be made to the model. Another aspect of remote networking may involve the Internet, to share data with other members of a design and production team. Extended even further, remote networking helps make possible the realization of concepts such as enterprise-wide integration and virtual shipyards.

9. PC-Based Hardware- This trend is actually a reflection of the increasing power of PCs, which may provide a more cost-effective platform than traditionally more powerful and expensive workstations. Indeed, PCs may prove to be the platform of choice for second and third tier shipyards and design firms.

2.0 THE REQUIREMENT DEVELOPMENT PROCESS

2.1 General

CAD/CAM/CIM requirements represent one stage in the software life cycle process. This process may be summarized by the following steps:

1. Determine user needs.
2. Develop software requirements.
3. Develop software specifications.
4. Conduct programming.
5. Test and debug.
6. Implement, train users.
7. Maintain.
8. Decommission.

The steps most relevant to this report are 1 and 2, which parallel the phases of the NSRP CAD/CAM/CIM project. step 1 has been completed as a part of Phase I of the project and step 2 is the subject of Phase II. Note that a requirement (step 2) describes "what" function must be performed by the system, a specification (step 3) describes "how" the system is to perform that function.

2.2 Where Requirements Fit Within the Software Development Process

As stated above, the development of requirements is one step in an overall software development process. In this creative process, requirement descriptions usually tend to be "generally poor," not because of any fault of the software designers or of the process, but rather because the requirements are not known until the software is developed and the users try it out [1]. Because the rest of the design process is based on the requirements, every effort should be made to make the requirement descriptions as complete, accurate, and precise as possible; this was the goal of the NSRP CAD/CAM/CIM project team.

Requirements have the following characteristics:

- derived based on an understanding of user needs
- written statements
- tell what the software must do
- tell how the software is structured

Requirements do *not* tell how the software is programmed.

There is a difference between the goals of the NSRP CAD/CAM/CIM project and a ship-production software-development project. The CAD/CAM/CIM project will not result in actual software. Ship-production needs have been identified and CAD/CAM/CIM requirements have been developed. However, the end product is not computer software. Reports and a description of requirements are the end products.

This should affect how the requirements are viewed. They should be viewed collectively as the needs of future-oriented, competitive, shipbuilding CAD/CAM/CIM software. The requirements are not to be thought of as comprising modules of such software, but rather as features that are to be found within the software. The requirements do not tell how to design the software, they simply state needs the software must fulfill. Thus, various solutions may exist each of which may meet the requirements, but in different ways. There is no single “right” solution.

2.3 How Requirements are Described

In this report, requirements are described on requirement sheets. One sheet is provided for each requirement, in the format shown in figure 2-1, and as described below:

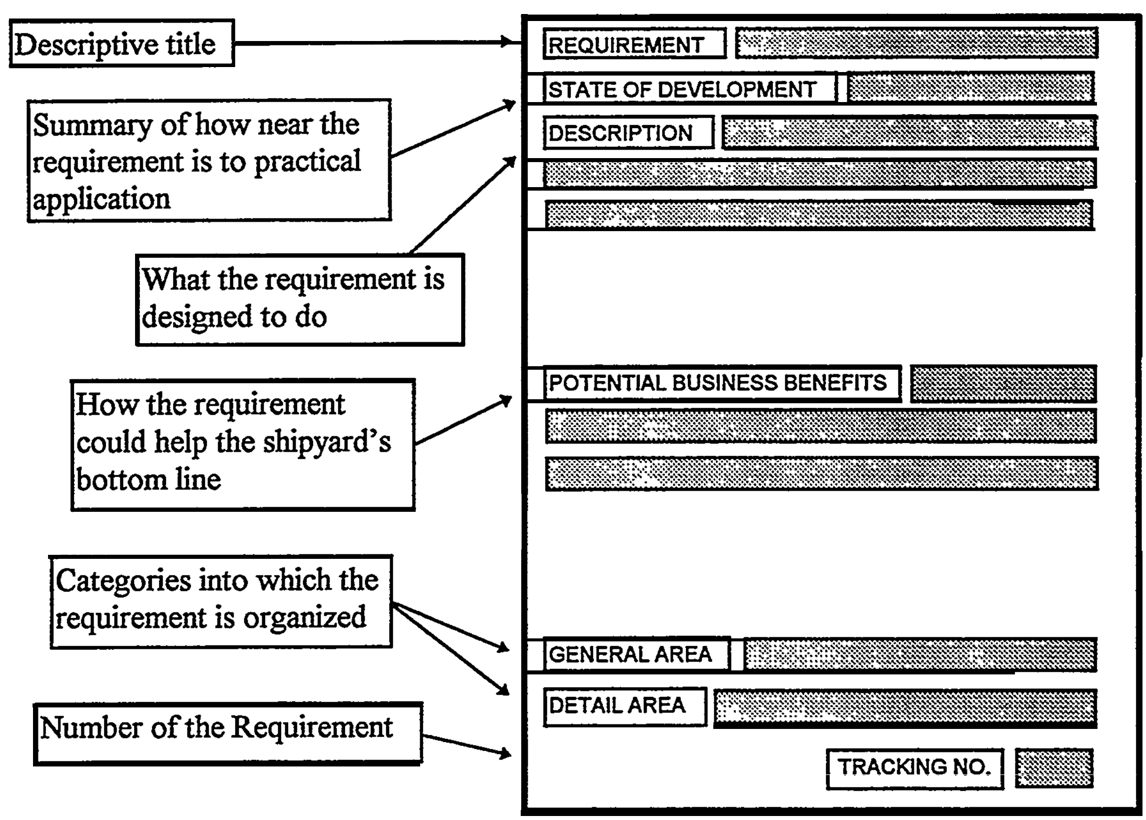

Figure 2-1

- Retirement - Descriptive title of the individual requirement
- State of development - Indication of how far the requirement has advanced toward actual practice conceptual stage, initial development, prototype testing proprietary versions and available on the market. A requirement may be at several stages of development. For example, a requirement may exist in software that is proprietary in one shipyard, yet also be available on the market in other software. The most' advanced of the choices is provided on the requirement sheet.
- Description - Definition of the requirement and explanation of its role in the context of a CAD/CAM/CIM system.
- Potential business benefits - Description of how the requirement can help a shipyard from the business perspective, for example, in the areas of innovation, addressing a customer's needs or through optimization.
- General area - Denotes which of four overall categories apply to a given requirement, as explained in section 3.
- Detail area - Denotes which of 13 particular categories apply to a given requirement as explained in section 3.

2.4 Testing

Testing is the approach that software developers use to detect and correct errors. It has been stated that "more than half the errors are usually introduced in the requirements phase" [4]. To prevent migration of errors onward to the specifications phase and beyond, testing should be carried out as part of the development of requirements. In fact, testing and error correction should be carried out at each phase of software development. For example, the following checklist, adapted from [4] and [6], may be used to test requirements:

1. Complete - All items needed to specify the solution to the problem have been included.
2. Correct - Each item is free from error.
3. Precise, unambiguous, and clear - Each item is exact and not vague; there is a single interpretation the meaning of each item is understood; the description is easy to read.
4. Consistent - No item conflicts with another item.
5. Relevant - Each item is pertinent to the problem and its solution.
6. Testable - During program development and acceptance testing it will be possible to determine whether the item has been satisfied.
7. Traceable - Each item can be traced to its origin in the problem environment.
8. Feasible - Each item can be implemented with the available techniques, tools, resources, and personnel, and within the specified cost and schedule constraints.
9. Free of unwarranted design detail - The requirements are statements of what must be satisfied by the problem solution, and they are not obscured by proposed solutions to the problem.
10. Manageable - The requirements are expressed in such a way that each item can be changed without excessive impact on other items.

3.0 CAD/CAM/CIM REQUIREMENTS

3.1 General

The CAD/CAM/CIM requirements are those elements that were identified by the project team as necessary for a competitive, future-oriented shipbuilding-design-and-production CAD/CAM/CIM system.

3.2 Requirements Listing

A requirements listing was developed by the project team and refined as the project progressed. This listing formed a basis for questions asked and information gathered during shipyard, vendor, arid allied industry visits by the team. The requirements were organized to be consistent with United States shipyard typical practices. AU requirements were first grouped into the general areas of design, production, operations management and umbrella (the umbrella area covered requirements generally common to one or more of the other areas). The requirements were further subdivided into detail areas as follows:

Design
- conceptual/preliminary design
- functional design
- detailed design

Production
- fabrication processes
- joining and assembly processes
- material control
- testing and inspection

Operations Management
- high-level resource planning and scheduling
- production engineering
- purchasing/procurement
- shop floor resource planning and scheduling

Umbrella
- umbrella.

Initially, a detail area entitled "Quality Control and Assurance, SQC" was included under Operations Management. The final version of the requirements deletes specific quality requirements, opting to make quality inherent in the overall System, much in the manner of European and Japanese shipyards.

The full list of requirements is presented in table 3-2, grouped in the two-tier manner presented above.

Table 3-2

Listing of Requirements Grouped into General and Detailed CAD/CAM/CIM Areas

GENERAL AREA	DETAIL AREA	NO.	REQUIREMENT NAME
DESIGN	Conceptual/Preliminary Design	1	Concept/Preliminary Design Engineering Analysis Tools
		2	Reusable Product Model
		3	Develop Initial Build Strategy, Cost and Schedule Estimates
		4	Classification/Regulatory Body and Owner Compliance Support
	Functional Design	5	Connectivity Among Objects
		6	Tools to Develop Standard Parts, Endcuts, Cutouts and Connections
	Detailed Design	7	Automated Documentation
		8	Detail Design Engineering Analysis Tools
		9	Design for Fabrication, Assembly and Erection
		10	Linkage to Fabrication Assembly and Erection
		11	Automatic Part Numbering
		12	Interference Checking
		13	Linkage to Bill of Material and Procurement
		14	Weld Design Capability
		15	Coating Specification Development
		16	Definition of Interim Products
		17	Consideration of Dimensional Tolerances
		18	Context-Sensitive Data Representations
PRODUCTION	Fabrication Processes	19	Processes to Cut/Form Structural Plates and Shapes
		20	Documentation of Production Processes
		21	Information Links to Production Work Centers
		22	Piece and Part Labeling
		23	Creation of Path or Process Programs for NC Machines and Robots
		24	Development of Interim Product Fabrication Instructions
		25	Simulation of Fabrication Sequences
	Joining and Assembly Processes	26	NC Programs for Joining and Assembly
		27	Automated Subassembly/Assembly Processes

Table 3-2 (Continued)
Listing of Requirements Grouped into General and Detailed CAD/CAM/CIM Areas

GENERAL AREA	DETAIL AREA	NO.	REQUIREMENT NAME
PRODUCTION	Joining and Assembly Processes	28	Programmable Welding Stations and Robotic Welding Machines
		29	Location Marking for Welded Attachments
		30	Definition of Fit-Up Tolerances
		31	Control of Welding to Minimize Shrinkage and Distortion
		32	Programming for Automated Processes
		33	Definition of Fit-Up Tolerances for Block Assembly Joints
	Material Control	34	Capabilities for Material Pick Lists, Marshalling, Kitting and Tracking
		35	Tracking of Piece/Parts Through Fabrication and Assembly
		36	Communication of Staging and Palletizing Requirements to Suppliers
		37	Documentation of Assembly and Subassembly Movement
		38	Handling and Staging of In-Process and Completed Parts
	Testing and Inspection	39	Testing and Inspection Guidelines
OPERATIONS MANAGEMENT	High-Level Resource Planning and Scheduling	40	High Level Development of Build Strategy
		41	Order Generation and Tracking
		42	Performance Measurement
		43	Production Status Tracking and Feedback
		44	Inventory Control
		45	High Level Planning and Scheduling
	Production Engineering	46	Development of Production Packages
		47	Development of Unit Handling Documentation
		48	Parts Nesting
		49	Development and Issue of Work Orders and Shop Information
	Purchasing/Procurement	50	Material Management
	Shop Floor Resource Planning and Scheduling	51	Provision of Planning and Scheduling Information to Shops
		52	Work Order/Work Station Tracking and Control
		53	Detailed Capacity Planning for Shops and Areas
		54	Collect and Calculate Costs for a Major Assembly

Table 3-2 (Continued)
Listing of Requirements Grouped into General and Detailed CAD/CAM/CIM Areas

GENERAL AREA	DETAIL AREA	NO.	REQUIREMENT NAME
UMBRELLA	Umbrella	55	Datacentric Architecture
		56	Computer-Automated as Well as Computer-Aided
		57	Interoperability of Software
		58	Open Software Architecture
		59	Accessible Database Architecture
		60	Remote Networking Capability
		61	Full Data Access (Read Only) to All Project Participants
		62	Assignment of Data Ownership
		63	User-Friendliness
		64	Enterprise Product Model
		65	Integration With Simulation
		66	Information Management
		67	Scalability
		68	Transportability
		69	Configuration Management
		70	Compliance With Data Exchange Standards

3.3 Requirement Sheets

As mentioned in section 2.3, each requirement is described on an individual requirement sheet. A complete set of requirement sheets is provided in appendix A. The requirement sheet for requirement 9 (Design for Fabrication, Assembly and Erection) is typical in its level of detail. The Description and Potential Business Benefits for this requirement are as follows:

- DESCRIPTION: Provide guidance for the processes of fabrication, assembly and erection, including the following:
  - definition of edge preparations
  - lifting arrangements
  - fixturing
  - weld shrinkage calculation
  - assembly Tolerances
  - marking
  - assembly tolerance stack-up (multi-stage/assembly issues)
  - clearance allowances
  - flexible documentation.

- POTENTIAL BUSINESS BENEFITS: Potential to improve the product by making the design more producible through more consistent and standard construction design by including manufacturing attributes in the product design process. The result will be reduced cycle time and cost.

3.4 Citations of Papers and Reports

For those with a need for a level of detail beyond that provided on the requirement sheets, a number of professional papers and reports have been linked to the requirements. For example, for requirement 9 (Design for Fabrication% Assembly and Erection), there are six citations. The six citations, and summaries of the contents of the respective sources, are provided below:

Citation 1. Garcia, Luis, Victor Fermandez and Jaime Torroja, 'The Role of CAD/CAE/CAM in Engineering for Production, " 8th International Conference on ComputerApplications in Shipbuilding Bremen, Germany, September 5-9, 1994.

> Computer-aided design, engineering, and manufacturing systems can help meet the requirements of engineering for production. A key tool is the computer-based product model approach in which a ship's hull form, hull structure and outfitting are contained in a single database. The product model contains all elements that comprise the ship design. These elements may be accessed and displayed to assist production. For example, 2D drawings and isometrics for structural blocks and interim products may be generated in a semiautomatic fashion. The product model approach considers various issues relevant to fabrication, assembly and erection, including interference checking, standards (shipyard, national and international), weights of interim products, nesting, fabrication jigs, and NC cutting commands.

Citation 2. Nomoto, Toshiharu and Kizzuhiro Aoyama, "An Implementation of a Product Definition System in Computer Integrated Design and Manufacturing, " 8th International_"onal Conference on Computer Applications in Shipbuilding, Bremen, Germany, September 5-9, 1994.

> The authors introduce a product model that comprises design and manufacturing information. The three functions of this product model are design, cutting, and assembling of structural plate. The authors' design system uses a "room" concept, in which a room is represented by an arbitrary polyhedron of walls covered with plate members. Geometry and connection information is thus available. From these basics, and the introduction of cutting and joining functions, a complex ship steel design, with related fabrication details, may be developed. Also, as a direct result, planning and management information may be generated.

*Citation 4. Bong Hyon-Soo, Seong-Hwan Han and In-Woo Hwang, "On the Development of Prohits: The Production-Oriented Hull Information Technology System for Ship Design and Production, " 8th International Conference on Computer Applications in Shipbuilding, Bremen, Germany, September*5-9,1994.

The authors discuss a three-element, multitechnique design approach which encompasses detail design, fabrication, and cutting. Their approach is to combine hull design software with production-oriented software. As a result, a single designer, using the combined software, may address detail design as well as fabrication and cutting. Included are capabilities in the areas of parts lists, weights, paint area, material control, and nesting. Along with combining the software, the sponsoring shipyard hull-design office changed from a functional organization (structure, assembly, and cutting) to a team organization (each of four teams addressing structure, assembly, and cutting). This new organization is believed to better suit the multitechnique design software capabilities, and is hoped to result in decreased design time and increased work shop productivity.

The authors also discuss a prototype expert system that a designer may use to automatically arrange the internal members (scantlings) in the hopper portion of a VLCC hull.

Citation 21. Ito, Keiji, "Product Model for Ship Structure form the Viewpoint of Structural Design," 8th International Conference on Computer Applications in Shipbuilding, Bremen, Germany, September 5-9, 1994.

The author describes a proposed computer model that addresses each of three stages of a ship's structural design: development of structural arrangements strength evaluation; and description of welded connections. The model addresses structure beginning at the piece and advancing through interim products to an entire ship. The model uses object-oriented techniques.

Citation 42. Nakayama, Hiroshi, "ExpertProcess Planning System of CIM for Shipbuilding, " 8th International Conference on Computer Applications in Shipbuilding, Bremen, Germany, September 5-9, 1994.

The author describes a proposed product model expert system that would assist in planning ship production. In this system, a product model would contain information defining the ship design shipyard production facilities and production rules. The expert system would carry out process planning definition of intermediate products, and election of processes applicable to fabricate the intermediate products.

Citation 49. Lee, Jae Kyu, KyoungJun Lee, June Seok Hong, Wooju Kim, Eun Young Kim, Soo Yeoul Choi, Ho Dong Kim, Ok Ryul Yang, HyungRim Choi, "Intelligent Scheduling Systemsfof Shipbuilding, " American Association for Artificial Intelligence, Winter 1995.

The authors describe the development of an expert system for shipyard production scheduling. Capabilities of the system include erection scheduling curved block assembly shop scheduling; labor hour estimator; and long-term production planner.

> *The* system has a hierarchical architecture, with part of the overall scheduling delegated to the lower-level schedulers, such as assembly plants. There is also a constraint-directed graph search capability, in which three classes of constraints are recognized: general technical constraints; constraints on partial sequence and constraints on precedence relationship.

As can be seen from this example, the cited reports provide a way to gain in-depth understanding of a requirement and, perhaps more important knowledge of the present state of the art and ongoing developmental efforts. Finally, the citations provide a basis for even further research into a requirement, and those companies and people carrying out its development.

A full listing of citations is provided in appendix C. For each citation listed, the applicable requirements are provided in parentheses. In addition, a matrix provides a cross-indexing between requirements and citations.

4.0 REQUIREMENT SELECTION METHODOLOGY

4.1 General

Not all shipyards will want, need, or be able to afford all of the requirements listed in the previous section. Thus, a selection methodology is needed to choose those requirements that will best serve the needs of each particular shipyard. As a first step in this methodology, shipyard top management should define their strategic plan, considering elements such as the following:

Ž market leadership goals
Ž strategic direction of the shipyard
Ž planned response to market needs
• costs of implementing CAD/CAM/CIM
• design and production processes within the shipyard
• relationships with suppliers and vendors
Ž relationships with customers

Whatever the detail of the strategic plan, of paramount importance is the involvement and buy-in of top management with regard to CAD/CAM/CIM selection and implementation. Involvement commonly includes educating top management in the general capabilities of CAD/CAM/CIM. Without the involvement of top management, there may be no connection between the CAD/CAM/CIM system that is selected and the business results envisioned in the shipyard's strategic plan [5].

Because the CAD/CAM/CIM selection process is business driven, participation of top management as well as middle management and technical personnel is essential. In a larger sense, the selection methodology may be viewed as a way to align technology with business results.

The idea of aligning CAD/CAM/CIM technology with desired business results is a major theme of this report. Two key steps for achieving this alignment are

1. Plan for innovation customization, and optimization
2. Use the theory of constraints to identify priorities [5].

The sections below describe these two steps, show how they are used as part of a selection methodology, and provide examples from industry that illustrate the methodology.

4.2 Innovation, Customerization and Optimization

CAD/CAM/CIM technology requirements may be aligned to business objectives by using the following equation:

$$(MS)^3 = \text{Profit}$$

Where,

MS_1 = Market Size,
MS_2 = Market Share, and
MS_3 = Margin on Sales [5].

For example, if a shipyard has a 10% share (MS_2 = 10%) in a $100 million market ($MS_1$ = $100 million), and its margin on sales are 20% (MS_3 = 20%), then,

$100 million x 0.10 x 0.20=$2 million Profit.

The thinking in this approach is that everything a company does should improve one of these three areas. Thus, these areas can be used to track trends and evaluate alternative business actions. Looking at each area in detail provides further insight as to their use

1. Market Size (MS_1) - Create or participate in attractive markets through new product innovation. Innovation drives market size.
2. Market Share (MS_2) - Win market share against competitors by providing products and services customers prefer. Customerization drives market share.
3. Margin on Sales (MS_3 - Earn healthy margins by some combination of earning a premium price and/or being the lower-cost provider. Optimization drives margin on sales.

Figure 4-1 expands upon these areas. Note that the three areas are not mutually exclusive a shipyard may simultaneously participate in two or even all three, especially if the yard is working several projects, some at the conceptual and marketing stage, others at more advanced stages of production. For example, one may think of innovation, customerization, and optimization in terms of product and process life cycle, as shown in figure 4-2.

Each of the three areas calls for different types of CAD/CAM/CIM software and hardware. For example, a yard with business goals in the area of innovation would want software and hardware that is easy to use, in order to generate imaginative, realistic-looking designs in a short amount of time. For customerization, the software and hardware must be more powerful, capable of technically correct parametric variations on a baseline design. Optimization calls for even more powerful systems, capable of determining the best configurations within set limits, such as the lightest-weight structure for a given set of loads. These and associated points are illustrated in table 4-1.

BUSINESS AND MARKET GOALS

MARKET SIZE	MARKET SHARE	MARGIN ON SALES
- today? - trend for future?	- today? - trend for future?	- today? - trend for future?

CUSTOMER INTEREST	CUSTOMER CHOICE	CUSTOMER LOYALTY
drives market size	drives market share	and internal costs drive margin on sale

PROCESS PERSPECTIVE

INNOVATION	CUSTOMERIZATION	**OPTIMIZATION**
creates customer interest and increases the market for new products. The goal is to be not just first, but right to market. For new features, aim to delight customers.	satisfies customer needs and maintains or grows market share. The process goes beyond concurrent engineering to sharing knowledge between all functions, customers, and suppliers.	increases perceived value and lowers cats, leaving higher margins for the company. Creating and maintaining customer loyalty decreases the cost of sales and increases profits. Lower costs, with no loss of perceived value, contribute **directly** to the bottom line.

TECHNOLOGY ALIGNMENT

CAD/CAM/CIM TO SUPPORT INNOVATION	**CAD/CAM/CIM** TO SUPPORT CUSTOMERIZATION	CAD/CAM/CIM TO SUPPORT OPTIMIZATION
Could include 2D and 3D brainstorming, what-if analysis, visualization, simulation getting physical fast, rapid tooling. The tool must be easy for innovators, who will not be full-time users.	should link diverse and broadly dispersed knowledge workers. In addition to a wide variety of applications, networking, data sharing and support are important issues.	will often include compute intensive applications. May be able to justify "best in breed" solutions that integrate with the primary tools for design review. (Without some level of integration, optimization in on area may adversely affect another.)

Figure 4-1
Framework for Aligning Business, Process and Technology
(Based on Figure III-7 of [5])

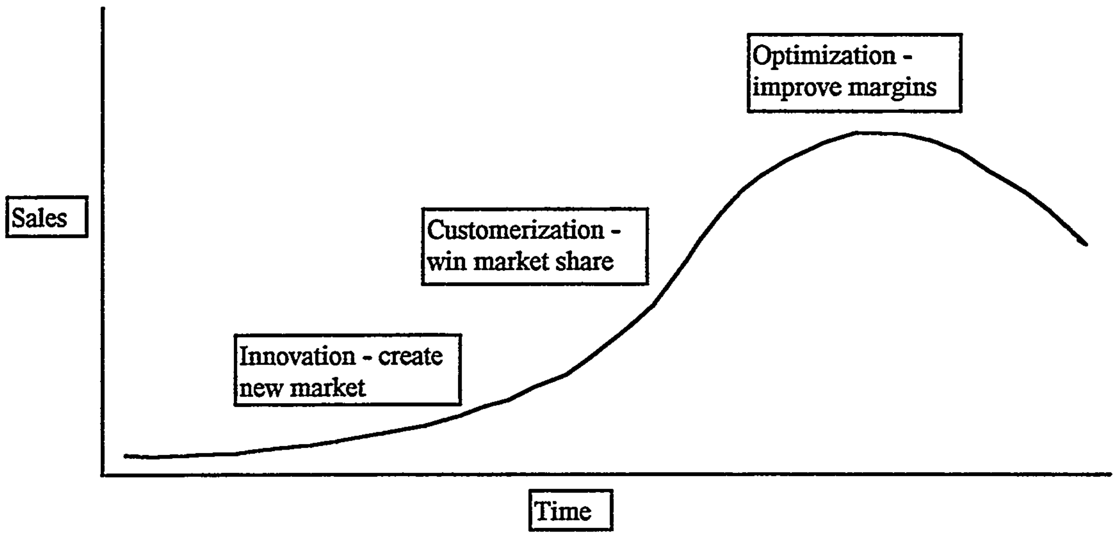

Figure 4-2
Product and Process Life Cycle
(Based on Figure III-7 of [5])

Table 4-1
Differences in Software and Hardware for the Three Business Areas
(Based on Figure III-9 of [5])

	INNOVATION	CUSTOMERIZATION	OPTIMIZATION
SOFTWARE	Ease of use Realism for presentations to customers Quick integrated analysis Rapid designing Explicit geometry	Full set of applications High integration of applications Product model database Concurrent data sharing Parametric design capability	Specialized analysis DFM and DFA capabilities* Emphasis on data input/output to specialized applica-tions
HARDWARE	Ease of use Excellent visualization	Full range of systems Network support Servers	High-end machines

Note: DFM is Design for Manufacture; DFA is Design for Assembly

4.3 **Use of the Theory of Constraints to Identify Priorities**

The Theory of Constraints is a way to focus on where to improve a process. For example, a shipyard may want to improve throughput in a plate nesting and cutting operation. At first, the best approach may seem to be to replace an existing manual cutting operation with robotics. Closer study may show that robotic cutting would reduce the number of personnel in the operation, but not increase throughput, because of downtime while waiting to receive cutting data Robots or people could work only a fraction of the time, and must wait the rest. Thus, throughput would remain as before. In this case, the constraint is the lofting operation, which is slowing down the overall throughput. If the lofting time is decreased (for instance, through CAD/CAM automation), then the constraint is removed.

Knowing the constraints in the shipbuilding process will help a shipyard focus on how CAD/CAM/CIM technology can improve that process. The principles of the Theory of Constraints may be summarized as follows:

- The throughput of an entire system is held back by constraints. Constraints may be both physical (e.g., limited throughput of computer systems) and nonphysical (e.g., bureaucratic procedures or competition between departments); thus a thorough knowledge of the process being evaluated is mandatory.
- Most systems have relatively few real constraints. Improvements at just these constraints will dramatically improve throughput. However, "gains" in areas where there are no constraints have zero value.
- Traditional measures of productivity fail to recognize the importance of constraints. For example, a 10% productivity improvement on a $10/hour clerical job might really be worth $1000/hour to the company, while a 30% improvement on a higher profile $100/hour job may prove worthless.
- Constraints provide a focal point for managing the entire system.
- Constrained processes should run as close to 100% efficiency as possible. Never starve them for necessary inputs. Keep nonproductive times (e.g., set-ups) to *a minimum.*
- *In* manufacturing operations, inventories usually pile up in front of bottleneck

Questions that define whether something really is a constraint:

Ž Back-up -Is this operation aback-up for work?
Ž Impact on product delivery- If this process is backed up for a day, is delivery delayed for a day?
Ž Impact on(MS)[3]- If this operation were performed better, would that improvement be reflected in improved market size, market share, or margins?

4.4 Selection Methodology

The selection methodology is the way a shipyard chooses its CAD/CAM/CIM system. As mentioned above, this process must involve top management and must be based on achieving business results. The steps of the selection methodology areas follows and as presented in figure 4-3:

1. Conduct business assessment - The real objective is "business results," so begin by defining your shipyard's goals in the areas of market size, market share, and margins. This is commonly a task of top management and may take several days of meetings to carry out. The goals are stated in a shipyard's business strategy.
2. Define new processes - New processes (which may be variations of existing processes) will be necessary as a result of the new direction defined in step 1. Old processes, even with new tools, will yield old results. The processes may run in parallel, and will comprise one or more of *innovation,, customerization, and optimization.* It is important to define the process before choosing requirements or technologies.
3. Identify priorities - Use the Theory of Constraints to identify problem areas in processes. This is a critical link *between productivity improvements* and *business benefits.*
4. *Select* requirements - Select appropriate requirements that will address the priorities of step 3. Many of the requirements of this report should apply to United States shipyards' priorities (modifications or additions will be appropriate in certain cases). While all the requirements may look attractive, care should be taken to select only those applicable to the identified priorities.
5. Select technologies - Technologies (e.g., anew CAD system) should be selected to meet the requirements of step 4.

This selection methodology is business driven and not technology driven. Shipyards may be tempted to purchase new technologies (such as a product model CAD/CAM system) without thinking through the implications at the business level. Will the new CAD/CAM system reduce or remove a constraint in the shipyard? Sometimes that question is assumed to be yes but not actually investigated.

1. Conduct Business Assessment

⇓

2. Define New Processes

⇓

3. Identify Priorities

⇓

4. Select Requirements

⇓

5. Select Technologies

Figure 4-3
Selection Methodology

In conjunction with this selection methodology, shipyards should ensure that the expectations of affected people are set. Changes in processes mean changes in behavior and organization are often necessary. For example, CAD/CAM/CIM tools may eliminate the need for a lofting department. Loftsmen may find themselves part of a design team or they may be shifted to production. In either new role, the experience gained in the lofting department would be applied to a part of a new process. The loftsmen would be expected to learn and contribute to the new process and understand that it is different from the process they had participated in prior to the adaptation of CAD/CAM/CIM. Generally, everyone involved in CAD/CAM/CIM changes must be aware of the expectations placed upon them, from top management to shop personnel.

As can be seen from the preceding sections, there is a great deal of information available as a result of the CAD/CAM/CIM project. Much of the information is purposely structured to assist shipyards in the practical aspects of selecting a shipyard CAD/CAM/CIM system. This selection-related information is summarized in table 4-2. The table lists information by topic, describes the information, and provides the location of the information in the Phase I and Phase II CAD/CAM/CIM project Reports.

Table 4-2
Sources of Selection-Related CAD/CAM/CIM Information

TOPIC	DESCRIPTION	LOCATION
Significant CAD/CAM/CIM Findings	Findings of the project team are presented in areas that include shipbuilding business objectives; technology alignment; implementation strategies; capabilities and operations; application commonalities; and unique implementations.	Phase I Report, Chapter 3
World-Class Shipyard Use of CAD/CAM/CIM Technology	Information gleaned by visiting six shipyards is presented in topics that include business strategy, competitive strategies, degree of automation, description of major CAD/CAM systems, planning and control, CAD/CAM/CIM integration, research and development programs, and purchasing and vendor relationships.	Phase I Report, Chapter 4-9
CAD/CAM/CIM Software	Information gathered from four software vendors is presented, with topics that include system overview, implementation approaches, product modeling technology, integration, and future projections.	Phase I Report, Chapters 10-13
Non-Shipyard Use of CAD/CAM/CIM	The approach is presented of Black & Veatch, major energy company which designs and constructs non-nuclear power plants world wide.	Phase I Report, Chapters 14, 15
Technique for Selecting Among a Group of Candidates	The Quality Function Deployment methodology is described as a methodology for helping to select the choices best suited for a desired result.	Phase I Report, Appendix A
Shipyard Planning	An example is provided of a 3-level planning approach for Odense Steel Shipyard	Phase I Report, Appendix B
Robotics and Automated Welding	The Hitachi Zosen approach to robotics and welding is presented.	Phase I Report, Appendix D
Production System Applications	The Hitachi Zosen approach to computer-aided production is presented.	Phase I Report, Appendix E
Shipyard Levels of CAD/CAM/CIM Implementation	Responses to detailed questionnaires are presented, showing world-class shipyards' levels of automation in 13 categories of design, production and operations management.	Phase I Report, Appendix G
CAD/CAM/CIM System Requirements	A description of the requirements of a competitive, future-oriented shipbuilding CAD/CAM/CIM system is presented.	Phase II Report, Appendix A
Japanese CIM Study	A CIM study carried out by a group of Japanese shipyards is summarized, and its requirement areas are compared to those of the NSRP study.	Phase II Report, Appendix B
Citations for Further Detail on Requirements	Sources (papers and reports) are cited and cross-referenced to the requirements developed by the project team as a way to assist in gathering additional information on specific requirements.	Phase II Report, Appendix C

4.5 **Example Using Selection Methodology**

The following paragraphs present a hypothetical example of how to use the four-step selection methodology presented in the previous section.

1. Conduct business assessment - In this example, the shipyard is in the market of designing and constructing high-speed aluminum ferries to transport passengers and vehicles between ports over potentially rough waters, such as those of the North Sea. The shipyard is well established in the high-speed ferry market and has earned a good reputation for its willingness to customerize ferries for the needs of each owner. The shipyard's top management has dicussed how to improve business results. Discussion has revealed that the competition, which in the pas .only offered stock designs, is now successfully customerizing its ferries. Thus, a previous market advantage, willingness to customerize, has been compromised. Top management decides on a strategy of optimization to regain their overall business advantage. They understand that high-speed ferries are weight critical, and decide to optimize ferry structural weight in their ferry designs. In this case, "optimize" means minimize structural weight, while maintaining strength to safely meet design loading."

2. Define new process - Investigation shows that significant weight savings cannot be achieved as part of the production process. Production simply cuts the parts as defined by the design, and there is no opportunity for decreasing weight at this stage. Thus, the focus turns to design. The shipyard's present design approach uses classification society rules to generate structural designs. Engineering and design management point out that this rules-based approach provides little opportunity for future weight savings, and they set about finding anew process that will enable the shipyard to optimize the structural weight. The new process is defined as *computational engineering methodology.*

3. Identify priorities - Using the Theory of Constraints, engineering and design management note that manual optimization processes are too time consuming to be practical. Manual optimization would hold up the design process as a whole. Thus, the shipyard identifies the need for a computer-aided approach as its priority.

4. Select requirements - Two requirements address the priority of optimizing structural weight when switching from a rules-based process to a computational engineering process. The two requirements are:
   Requirement 1- Concept/Preliminary Design Engineering Analysis Tools - This requirement addresses engineering tools to assist in structural analysis (including optimization), such as hull girder analysis, finite element analysis, and weights and centers calculations.
   Requirement 8- Detail Design Engineering Analysis Tools - This requirement addresses the subject of dynamic hull loading and fatigue analysis. Fatigue analysis is an attractive feature to the shipyard, because its ferries are constructed of aluminum, which is subject to fatigue, especially in rough waters.

The shipyard further investigates these requirements by reviewing the citations listed in appendix C. The following citations apply to Requirement 1: 7, 8, 15, 17,20,33,35-38,44,54,56,60,64,66-72, 74, and 77-82. Of these, the yard finds that the following address structure and may be relevant to structural optimization 7,8,33, 35,54,60,64,66,69,72, 74,81 and 82. For example, the citation 7 report includes the following information pertinent to structural optimization "...Once the model is assembled and design loads defined, the program can be used to engineer and optimize the structure with multiple, user-managed objectives to minimize weight, cost and/or vertical center of gravity. Structural optimization can be used as a rapid design refinement tool, which iterates and reengineers the structural design, enabling the structural engineer to rapidly evaluate a number of design alternatives. The optimization process uses safety factors controlled by the structural engineer to revise the scantlings of the structure. The changes ensure that all structural limits (stresses and failures) are satisfied, including safety margins, while reducing and redistributing scantlings where excess margins exist. Physical constraints are included in the process to provide proper structural proportions, and in the last optimization cycle the scantlings are rounded to match a standard library of plate thicknesses and structural shapes specified by the engineer. The net result is a structure which has material distributed to ensure all safety margins are satisfied, while optimizing the weight, cost and/or vertical center of gravity of the structure... ."

The shipyard makes a similar search for citations relevant to requirement 8. Through study of the citations and discussion with selected authors, the shipyard becomes familiar with the present state of the art and the structural optimization software and hardware available on the market.

5. Select technologies - The shipyard contacts the vendors identified in the citations and follow-on search of step 4, and selects the software and hardware most suited for its own weight optimization process for its aluminum ferries. As part of this process, the shipyard opens a dialogue with the classification societies and ensures that the proposed software is acceptable to the classification society. Typical considerations relevant to the selection process include determining the following
   - What specific features are necessary or desired for the selected software
   - What hardware and software configurations are suitable for integration with the shipyard's existing system
   - What start-up timeframe factors are drivers (e.g., training).

4.6 Examples from Industry

To further illustrate the selection methodology as it may be applied in the real world, several examples have been chosen from industry. These examples were observed by members of the project team. The requirements were chosen from the list in table 3-2 One example illustrates each of the three business areas:

1. Market Size (MS_1) - Innovation: Odense Steel Shipyard
2. Market Share (MS_2) - Customerization: Japanese CIM Project
3. Margin on Sales (MS_3) - Optimization: Black and Veatch

Each is summarized in Table 4-3 and discussed in the following paragraphs.

Table 4-3
Industry Examples of Use of Selection Methodology

SELECTION METHODOLOGY	ODENSE STEEL SHIPYARD	JAPANESE CIM PROJECT	BLACK AND VEATCH
1. Conduct Business Assessment	Need for a new product in the containership field	Need to increase market share, especially with regard to Korea	Need to increase margin in the power plant industry
⇓	⇓	⇓	⇓
2. Define New Processes	Process to produce accurate container guides	Process to efficiently carry out ship design and production planning	Process to reduce the costs associated with risk
⇓	⇓	⇓	⇓
3. Identify Priorities	Constraint: vendor-produced structural shapes decreased yard's capability for accuracy or speed of production of guides	Constraint: lack of integrated design/production capability	Constraint: insufficient availability of design and production information to all project participants
⇓	⇓	⇓	⇓
4. Select Requirements	19. "Processes to Cut/Form Structural Plates and Shapes"	64. "Enterprise Product Model"	61. "Full Data Access (Read Only) to All Project Participants"
⇓	⇓	⇓	⇓
5. Select Technologies	Automated line to cut and fabricate container guide shapes	Conceptual version of integrated design and production product model CAD/CAM/CIM system	Integrated design and production CAD/CAM/CIM system with remote access capability

Innovation: Odense Steel Shipyard

Odense Steel Shipyard is located in Odense, Denmark. The shipyard makes use of a number of CAD/CAM/CIM systems, integrated to work together, including HICADEC, NAPA, PROMOS, NISA and DPS. The yard carries out the design as well as the production of large, ocean-going ships, typically VLCCs and containerships.

Odense has developed a balance between manual and automated systems in areas such as material handling, marking, cutting, positioning and welding. A key goal of the yard is controlling the shipbuilding process. Toward this end, there is a high degree of automation in design and planning including production simulation, all readily addressed by today's CAD/CAM/CIM state of the art. On the other hand, there is manual intervention in much of material handling, marking, and welding. Automation is evident in repetitive process, such as fabricating built-up profiles and (using robots) certain well-defined welding tasks. A trend at the yard is to increase the proportion of automation and further refine the CAD/CAM/CIM system, both as means to help increase production efficiency, as measured by minimized build time. Through its present strategy, efficiency is increased both directly (e.g., by decreased welding times through robotic welding) and indirectly (e.g., by driving increased accuracy and quality to meet robotic welding tolerance requirements).

As shown in table 4-1, Odense's business assessment targeted the marketing segments of double hull VLCCs and large containerships. A recent Odense initiative was aimed at innovation (increasing market size through innovation- MS_1). The idea was to construct containerships of 6000+ TEUs, larger than any previous size, thus permitting owners to reduce the number of ships in their fleets as well as to realize other business-related advantages.

As part of the successful design, Odense maximized the number of containers through anew type of container guide. The new guide increased the number of containers that the ship could carry, but introduced a production constraint: Vendors do not produce structural shapes of sufficient accuracy. The yard decided to cut and form the container guide shapes in house, within the context of requirement 19, "Processes to Cut/Form Structural Plates and Shapes." In order to address the technical requirement created by the new business objective, the yard had to review their existing capabilities for generating NC data to loft, nest, bevel, cut and schedule work into their production area.

In the resulting process, the yard began with steel plate, carefully specified to be within acceptable thickness tolerances. The plate was cut, edge treated and fabricated into container guides. The operation, from generating NC data to fabrication, has proved successful. The first ship of this type, REGINA MAERSK, was delivered in January 1996.

Customerization: Japanese CIM Project

The Japanese CIM Project was conducted in the late 1980s and early 1990s [3]. The project was a cooperative effort among Japanese shipyards and was aimed at strengthening the management structure in the participating yards through emerging computer-based technology. The effort was aimed at countering the shipbuilding competition from Korea and maintaining Japan's share of the market.

The project comprised several initiatives, including development of a conceptual version of a frame model. The frame model is a shipbuilding industry computer integrated manufacturing (SICIM) methodology. It encompasses design and production and was designed to be flexible enough to be expanded in scope. The methodology was aimed at changing the ship design and production planning process (further discussion of the effort is provided in appendix B, below).

The constraint addressed by the Japanese CIM Project was a lack of integrated design-and-production capability. If this constraint could be reduced, the Japanese projected that their competitive position with the Koreans would improve to such an extent that the Japanese market share would benefit. The effort was carried out by teams headed by seven Japanese shipyards: Mitsui Zosen, Sumitoma Heavy Machine Industry, Nihon Kokan, Kawasaki Heavy Industry, Ishikawajima Takuma Heavy Industry, Hitachi Shipbuilding and Mitsubishi Heavy Industry. Each team addressed a separate task. For example, the Mitsubishi Heavy Industry team's goal was two-fold:

1. Confirm whether it is possible to enter design information about curved parts in an expanded product model.
2. Find out whether simulation-based design facilitates generation of a preliminary body of design information and whether it is useful for scheduling.

As the above description of scope makes evident, the Japanese CIM Project encompassed an *enterpriseproduci model, as* defined in Requirement 64 *(a* central database that encompasses not only the technical aspects of design, but planning and scheduling aspects as well). The Japanese were well equipped to take on such a task given their history of successful CAD/CAM programs, such as HICADEC, used at Hitachi Shipbuilding in Japan and Odense in Denmark. The project results comprise conceptual developments and pilot studies in selected areas. The efforts of the teams were reported individually, thus becoming a source of data for each yard to continue further development on its own.

Optimization: Black and Veatch

Black and Veatch is an engineering and construction firm specializing in the fields of energy, environment, process, and buildings. Headquartered in Kansas City, Missouri, where it was founded in 1915, the firm provides comprehensive planning, engineering design, and construction services to utilities, commerce, industry, and government agencies [7]. Since the late 1970s, the company's president and management have backed the expenditure of more that $50 million on CAD/CAM/CIM technology development.

The result of the effort was the development of Powrtrak, a proprietary software program used to design power plants for electric utilities. Among other features, Powrtrak allows changes made by any user to be stored systemwide [8]. This is a "datacentric" concept, and prevents duplication of data by allowing it to be entered only one time in a power plant product model. An allied feature of the system is that any operator may view (but not necessarily change) any data in the product model.

Powrtrak overcame various constraints found in traditional design approaches. For example, in traditional approaches, elements (e.g., a pump) may be represented numerous times in various parts of the design (e.g, system diagrams, composite drawings, weight estimate and bill of materials). For the traditional approach, a change of one representation will not automatically generate changes in the others, resulting in potential configuration management errors. Powrtrak ensures errors of that type are not made. Also, as mentioned above, a designer of one System, with a question about another system, may access the other system's data. This is a version of requirement 61, "Full data access (read only) to all project participants." An example of the effect of Powrtrak, is that a 400-megawatt fossil-fuel and pulverized-cord power plant that would have taken 60 months to design and build before Powrtrak can now be finished in 29 months [8].

Powrtrak and other software innovations at Black and Veatch are credited with boosting the company's revenue from $277.7 million in 1988 (when Powrtrak was implemented) to $693.4 million in 1993. The software helped the company submit lower bids (increasing margin in its industry), snare new business, and boost market share [8].

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In the course of carrying out the Phase II effort, and building on the knowledge gained during the conduct of the Phase I effort [9], the CAD/CAM/CIM team concluded that:

1. *CAD/CAM/CIM* is necessary for United States shipyards to become competitive with overseas yards.
2. Involvement of top management is key to ensuring that CAD/CAM/CIM is implemented in a way that will best meet a shipyard's business goals.
3. A business strategy is necessary in order to provide a framework within which to select the requirements of a CAD/CAM/CIM system that is best suited for a given shipyard.
4. A set of requirements can describe the elements necessary for a competitive, future-oriented shipbuilding design-and-production CAD/CAM/CIM system.
5. Participation in multi-organizational projects, such as NSRP projects, MARITECH projects, NEUTRABAS ESPRIT 2010, Japanese CIM Project and STEP can help shipyards enhance their competitive position.

5.2 Recommendations

The team recommends that United States shipyards:

1. Use the methodology presented in this report for selecting the most appropriate CAD/CAM/CIM for each shipyard. Especially for smaller yards, obtaining the technology in steps rather than in one leap should be considered. For example, begin with design, perhaps in the area of structure, and then expand into production and outfitting areas, then into planning and process simulation.
2. Implement CAD/CAM/ClM and involve top) management in the implementation process. While technical expertise resides in the middle management, line management, professionals and production personnel, the drive, guidance and support must originate at the top.
3. Ensure that their Top management become familiar with relevant CAD/CAM/CIM issues at the executive level, learning how CAD/CAM/CIM can help meet a shipyard's business objectives, developing their shipyards' business strategy, and supporting the efforts of other shipyard management and technical personnel in selecting and implementing CAD/CAM/CIM in their yards.
4. Become involved in multi-organizational projects with organizations in the United States and overseas and actively support research in areas such as better communication (data transfer) among CAD/CAM/CIM programs; involvement of customers, vendors and regulatory organizations in the ship design, procurement and

construction process; improvement of early design and costing programs to support proposals; and development of standards (in areas such as data exchange, welding procedures, material management, coatings, robotic control, and definition of fit-up tolerances).

5. Balance development within and outside the organization. For example, most shipyards will decide not to develop their own CAD/CAM/CIM systems, but they may decide to assist in the development of program software that helps tailor a vendor's system to their particular yard.

6.0 REFERENCES

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APPENDIX **A**

APPENDIX A - REQUIREMENT SHEETS

This appendix comprises the requirement sheets for all of the requirements developed by the project team. The requirement sheets are in numerical order (the tracking number is located at the lower right corner of each sheet).

REQUIREMENT NAME	NO.
Concept/Preliminary Design Engineering Analysis Tools	1
Reusable Product Model	2
Develop Initial Build Strategy, Cost and Schedule Estimates	3
Classification/Regulatory Body and Owner Compliance Support	4
Connectivity Among Objects	5
Tools to Develop Standard Parts, Endcuts, Cutouts and Connections	6
Automated Documentation	7
Detail Design Engineering Analysis Tools	8
Design for Fabrication, Assembly and Erection	9
Linkage to Fabrication Assembly and Erection	10
Automatic Part Numbering	11
Interference Checking	12
Linkage to Bill of Material and Procurement	13
Weld Design Capability	14
Coating Specification Development	15
Definition of Interim Products	16
Consideration of Dimensional Tolerances	17
Context-Sensitive Data Representations	18
Processes to Cut/Form Structural Plates and Shapes	19
Documentation of Production Processes	20
Information Links to Production Work Centers	21
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REQUIREMENT **Concept/Preliminary Design Engineering Analysis Tools**
STATE OF DEVELOPMENT **Available on the market and proprietary versions**
DESCRIPTION: **Provide engineering tools to assist in the conduct of the concept and preliminary design, including capabilities such as structural analysis, (hull girder analysis and finite element analysis), stability analysis (intact and damage stability, and loading conditions), distributed system design (automated path generation, and load analysis), resistance and powering analysis (for hull and propeller), hull form definition (based on offsets, hull coefficients or by parametric variation), weights and centers definition (for structure, outfit and interim products), and tank capacity determination.**

POTENTIAL BUSINESS BENEFITS: **Enable development of design at early stage for marketing, trade-off analysis and ordering long lead-time items, thus improving competitive position, customerizing the design or optimizing the design. Enable more accurate information at an earlier stage in the concept/preliminary design process, which in turn reduces time to execute the follow-on stages (contract design). Enable yards to quickly react to customer requests, including ability to supped better cost estimates and thus improve yard's marketing ability. Can improve market share and margin on sales.**

GENERAL AREA **Design**
DETAIL AREA **Conceptual/Preliminary Design**

TRACKING NO:

REQUIREMENT **Reusable Product Model**

STATE OF DEVELOPMENT Available on the market

DESCRIPTION: **Provide for conceptual and preliminary design engineering product models to be reusable for follow-on projects, including features such as**

- **Parametric hull form**
- **Arrangements**
- **System diagrams and schematics**
- **Design standards (e.g., parts, connections, details, foundations)**
- **Structure**
- **Major equipment and outfit**
- **3-D product modeling**
- **Interference checking**

POTENTIAL BUSINESS BENEFITS: **Enables faster response time to develop new designs, resulting in monetary savings and in more customer satisfaction. Provides benefits in the areas of market size and market share.**

GENERAL AREA: **Design**

DETAIL AREA: **Conceptual/Preliminary Design**

TRACKING NO: **2**

REQUIREMENT **Develop Initial Build Strategy, Cost and Schedule Estimates**

STATE OF DEVELOPMENT Available on the market

DESCRIPTION: Develop conceptual and preliminary design build strategy, cost and schedule estimates, to include:

- Cost and schedule estimation for tendering, taking into account models of product, facility and processes
- Compartmentation (space definition)
- Hull form divided into major blocks
- Work breakdown structure
- Optimization of hull structural design to facilities and processes
- System definition
- Major equipment selection
- Design standards (e.g., standard parts, features, connections, details and foundations)

POTENTIAL BUSINESS BENEFITS: This will enable yards to develop more accurate contract bids, which will improve their ability to win contracts (market share). The labor hours required would also be greatly reduced when compared to manual techniques. Also, enables all parties within the yard yard (and vendors as appropriate) to contribute to the building project and have a written agreement on the methods and processes to be employed in building the project. This results in each department in the yard (and individual vendors) understanding what the task is, how to accomplish the task, when to complete the task and the budget to complete the task. Finally, this capability reduces confusion, saving time and money, increasing margin on sales.

GENERAL AREA Design

DETAIL AREA Conceptual/Preliminary Design

TRACKING NO: 3

REQUIREMENT Classification/Regulatory **Body** and **Owner Compliance Support**

STATE OF DEVELOPMENT **Prototype testing**

DESCRIPTION: **Provide contract level documentation to show compliance with classification societies, regulatory agencies and owner requirements, including:**

- **Pre-approved analysis tools**
- **Minimization of time for compliance**
- **Automation of production of documentation (e.g., equipment arrangement, system schematics, general arrangement, midship section, major equipment suppliers)**
- **Remote access by classification/regulatory bodies and owners**

POTENTIAL BUSINESS BENEFITS: **Enables yard to reduce the time to get design approved, thus reducing the time to market by several months and improving margin on sales.**

GENERAL **AREA** **Design**

DETAIL AREA **Conceptual/Preliminary Design**

TRACKING NO:

REQUIREMENT Connectivity Among Objects

STATE OF DEVELOPMENT Initial development

DESCRIPTION: Provide logical, physical and process connectivity among objects. New software architectures will allow objects created in different software packages to be used by another piece of software without translation. This capability exists today for 3D graphical objects but is under development for attribute or database data. The capability would allow inheritance of attributes of various levels in a product structure. Objects can be shared between analysis, concept, fuction and detailed design, as compared to the practice of using different objects for each design phase.

POTENTIAL BUSINESS BENEFITS: Much higher reuse of data would allow data to be entered one time and then shared among applications. Benefits include

- Vendors or suppliers of services would be able to use the applications of choice rather than the CAD system chosen by the client shipyard. This would make it easier for shipyards and vendors to work together to reduce communication and specification and design costs and time, thus helping increase margin on sales
- Shipyard costs would be reduced by actually incorporating vendor work into the ship product model without rework, again, increasing margin on sales.

GENERAL AREA: Design

DETAIL AREA: Functional Design

TRACKING NO: 5

REQUIREMENT: Tools to Develop Standard Parts, Endcuts, Cutouts and Connections
STATE OF DEVELOPMENT Available on the market
DESCRIPTION: Capability to define standard parts and features, including the following:

- Parametric parts
- Catalog of standard parts
- Endcuts
- Cutouts
- Connections

POTENTIAL BUSINESS BENEFITS: Save design time and reduce design cost by not having to create new parts, thus increasing margin on sales.

GENERAL AREA: Design
DETAIL AREA: Functional Design

TRACKING NO:

REQUIREMENT: Automated Documentation
STATE OF DEVELOPMENT: Proprietary versions and available on the market
DESCRIPTION: Automatically produce standard documentation with the ability for the shipyard to change document format. Included is production documentation.

POTENTIAL BUSINESS BENEFITS: Reduced design labor hours associated with drafting of product documentation and reduction of human errors. This capability will produce a better quality design, which will reduce cost and schedule and increase margin on sales.

GENERAL AREA: Design
DETAIL AREA: Detailed Design

TRACKING NO:

REQUIREMENT **Detail Design Engineering Analysis Tools**

STATE OF DEVELOPMENT **Proprietary versions and available on the market**

DESCRIPTION: **Provide engineering tools to assist in the conduct of the concept and preliminary design, including the follow-rig:**

- **Resistance and powering including computational fluid dynamics**
- **Dynamic hull loading and fatigue analysis**
- **Hull vibration**
- **Distributed system design optimization**
- **Resistance and powering, including computational fluid dynamics**
- **Hull fairing**
- **Weights and centers**

POTENTIAL BUSINESS BENEFITS: **Potential to improve ship performance via simulation; potential to reduce time to market, potential to expand market via ability to process more ship designs in a shorter time span, and reduce design costs by production of detail information earlier in the design process. This results in a more optimal design and thus a better chance of winning contracts and reducing construction costs, thus increasing margin on sales.**

GENERAL AREA: **Design**

DETAIL AREA: **Detailed Design**

TRACKING NO:

REQUIREMENT: **Design for Fabrication, Assembly and Erection**

STATE OF DEVELOPMENT **Proprietary, versions and available on the market**

DESCRIPTION: **Provide guidance for the processes of fabrication, assembly and erection, including the following:**

- **Definition of edge preparations**
- **Lifting arrangements**
- **Fixturing to assist in assembly**
- **Distortion control (includes capabilities in the areas of temporary restraining structures and weld shrinkage compensation)**
- **Assembly tolerance determination (e.g., through standards or determined individually during detailed design)**
- **Marking**
- **Assembly tolerance stack-up (multi-stage/assembly issues)**
- **Clearance allowances**
- **Flexible documentation**
- **ability to develop, use and enforce product and process standards**

POTENTIAL BUSINESS BENEFITS: **Potential to improve the product by making the design more producible through more consistent and standard construction design via including manufacturing attributes in the product design process. The result will be reduced cycle time and cost, increasing margin on sales.**

GENERAL AREA: **Design**

DETAIL AREA: **Detailed Design**

TRACKING NO:

REQUIREMENT Linkage to Fabrication Assembly and Erection
STATE OF DEVELOPMENT Available on the market
DESCRIPTION: Provide a linkage (method of transferring) of the product information to assembly and erection. This linkage is automatic and takes into account the assembly and erection process definitions, factory automation, build strategy, work center characteristics, schedule and build strategy.

Included may be a design management capability to track the design development process and schedule, ensuring that designs are produced in a timely manner in order to support production (this is especially critical in shipyards where production begins before the design process has been completed).

POTENTIAL BUSINESS BENEFITS: Potential to improve the product and reduce construction costs by including manufacturing attributes in the product design process. This can reduce labor hours that would otherwise have been spent communicating between design and production functions in the shipyard and this capability can reduce human error. This requirement helps increase margin on sales.

GENERAL AREA: Design
DETAIL AREA: Detailed Design

TRACKING NO: 10

REQUIREMENT Automatic Part Numbering
STATE OF DEVELOPMENT Available on the market and proprietary versions
DESCRIPTION: Capability to automatically number all parts of the product. The numbering system is definable by the user.

POTENTIAL BUSINESS BENEFITS: Reduces design labor hours associated with creating and managing part numbers. Promotes standards definition to facilitate automatic documentation by providing a consistent numbering scheme. Decreases cost, increasing margin on sales.

GENERAL AREA: Design
DETAIL AREA: Detailed Design

TRACKING NO: 11

REQUIREMENT Interference Checking

STATE OF DEVELOPMENT Proprietary versions and available on the market

DESCRIPTION: Provide the capability to automatically check, display and document interferences of distributed systems and structure. Included are capabilities to:

- Check as-designed
- Real time
- Batch
- Factory automation issues
- Life cycle and operating issues (e.g., equipment removal and installation paths)

POTENTIAL BUSINESS BENEFITS: Reduced total labor hour and schedule impact, resulting from disruption to work process caused by discovering fouls during construction. Potential to reduce costs of mock-ups built to verify the design. This capability is most beneficial for single ship contracts. Thus, this capability results in a better quality design, which will reduce cycle time and cost and increase margin on sales.

GENERAL AREA: Design

DETAIL AREA: Detailed Design

TRACKING NO: 12

REQUIREMENT Linkage to Bill of Material and Procurement

STATE OF DEVELOPMENT Available on the market and proprietary versions

DESCRIPTION: Provide a linkage (method of transferring) of the product information to bill of material and procurement. This linkage is automatic and takes into account tree structure.

POTENTIAL BUSINESS BENEFITS: Potential to improve the product and reduce construction costs by including manufacturing attributes in the product design process. Increases margin on sales.

GENERAL AREA: Design

DETAIL AREA: Detailed Design

TRACKING NO: 13

REQUIREMENT **Weld Design Capability**

STATE OF DEVELOPMENT **Initial development for total capabilities listed in description**

DESCRIPTION: **Capability to develop weld design, including the following:**

- **Consideration of build strategy**
- **Consideration of facility**
- **Weld design standards**
- **Weld processes and procedures**
- **Geometry considerations**
- **Product model and connection information**
- **Weld design procedures**
- **Weld facility capabilities**
- **Weld distortion**
- **Weld sequence**

POTENTIAL BUSINESS BENEFITS: **This is a key area where construction and manufacturing rests as well as vessel safety are involved. There is a potential for improved products and reduced costs of fabrication on edge preparations and welds. Can increase market share and margin on sales.**

GENERAL AREA: **Design**

DETAIL AREA: **Detailed Design**

TRACKING NO: **14**

REQUIREMENT Coating Specification Development

STATE OF DEVELOPMENT: Proprietary versions

DESCRIPTION: Has the following capabilities

- Calculates paint areas on blocks by coating specification. Designer creates paint code specifications for paint shop and writes data to production planning for block components
- Selectable paint code application on interim products
- Selectable by art number or by zone (specifies cutting planes)
- Provides outputs that include the following:
  - Paint areas calculations
  - Paint quantities
  - Paint codes for part numbers
- Specifies paint by stage of construction

POTENTIAL BUSINESS BENEFITS: Helps determine paint order (paint codes and quantities) and decreases production risk, thus increasing margin on sales.

GENERAL AREA: Design

DETAIL AREA: Detailed Design

TRACKING NO: 15

REQUIREMENT Definition of Interim Products
STATE OF DEVELOPMENT Available on the market and proprietary versions
DESCRIPTION: Capability to define interim products, including:
- Integration with product model
- Tree visualization and editing option
- Automatic rule-driven approach option

POTENTIAL BUSINESS BENEFITS: Potential to reduce time to market, allow concurrent planning and model definition with feedback to improve producibility of the design, thus improving margin on sales.

GENERAL AREA: Design
DETAIL AREA: Detailed Design

TRACKING NO: 16

REQUIREMENT Consideration of Dimensional Tolerances
STATE OF DEVELOPMENT: Available on the market and proprietary designs
DESCRIPTION: Consideration of dimensional tolerances, including:

- Adjustments of part dimensions made in design based on as-built subassembly dimensional measurements
- Automatic where practical
- interface and analysis of advanced measuring collection data, with comparison of that data to the product model dimensions (example of measuring collection data is photogrametry)
- Availability of as-built dimensions maintained during life of ship

POTENTIAL BUSINESS BENEFITS: Potential to improve the product and reduce construction rests by including manufacturing attributes in the product design process and increase margin on sales.

GENERAL AREA: Design
DETAIL AREA: Detailed Design

TRACKING NO: 17

REQUIREMENT: Context-Sensitive Data Representations

STATE OF DEVELOPMENT Available on the market

DESCRIPTION: Data representations are context-sensitive for process and visualization. This includes geometry and attributes and is typically found in product model software. Context-sensitive may be characterized as follow

- The presentation differs with the purpose (e.g., symbols on process diagrams instead of solids model for visualization).
- Multi-level of details

POTENTIAL BUSINESS BENEFITS: Improve versatility of product model, thus decreasing cycle time and costs, and increasing margin on sales.

GENERAL AREA: Umbrella

DETAIL AREA:

TRACKING NO: 18

REQUIREMENT Processes to Cut Structural Plates and Shapes
STATE OF DEVELOPMENT Available on the market and proprietary versions
DESCRIPTION: Processes available to cut structural plates and shapes, including capabilities to:

- Automatically generate cutting information
- Develop scheduling and sequencing for cutting

POTENTIAL BUSINESS BENEFITS: Reduce post-design costs for development of NC data. Control of cutting data content by application of automation. Helps reduce cycle time by reducing touch labor through rules programming and standardization. Helps reduce errors in production, which reduces cost and increases margin on sales.

GENERAL AREA: Production
DETAIL AREA: Fabrication Processes

TRACKING NO: 19

REQUIREMENT: Documentation of Production Processes

STATE OF DEVELOPMENT Available on the market

DESCRIPTION: Document production processes with capabilities such as:

- Procedures manuals
- Process flow diagrams
- Imbedded applications
- Global tools to deal with various process definition and documentation activities
- Consistency throughout the processes of design, production and operations management
- Standards for intra-company documentation (e.g., IDEF)

Such processes form a foundation for operating a least-cost process.

POTENTIAL BUSINESS BENEFITS Documentation of production processes result in: increases to margin on sales by:

- Improved training and worker process knowledge
- Higher quality and reduced rework
- Improved accountability, resulting in higher productivity
- Ability to achieve and maintain control of processes, facilitating process improvement.

GENERAL AREA: Production

DETAIL AREA: Fabrication Processes

#REF!

TRACKING NO: 20

REQUIREMENT: Information Links to Production Work Centers

STATE OF DEVELOPMENT: Available on the market

- DESCRIPTION: Capability to have information links between the design and management areas of a shipyard and the production work centers that perform cutting, forming, casting and fabrication. These information links can decrease response time to production problems. Also, the links can provide access to the 3D product model pictorial information to enable a better understanding and planning by production personnel.

POTENTIAL BUSINESS BENEFITS: Increase productivity and decrease costs, thus increasing margin on sales.

GENERAL AREA: Production

DETAIL AREA: Fabrication Processes

TRACKING NO: 21

REQUIREMENT Piece and Part Labeling

STATE OF DEVELOPMENT Prototype testing

DESCRIPTION: Information links from the product model to the work centers for piece and part labeling, including the following capabilities:

- WL, BTK, FRAME reference marking for ship locations
- Edge beveling marking
- Piece ID
- Material ID
- Reference lines for welded structure (e.g., stiffeners and brackets)

POTENTIAL BUSINESS BENEFITS: Can reduce labor rests associated with manual marking of required information, correction of mismarking, and location of mismarked parts, thus increasing margin on sales.

GENERAL AREA: Production

DETAIL AREA: Fabrication Processes

TRACKING NO: 22

REQUIREMENT: Creation of Path or Process Programs for NC Machines and Robots
STATE OF DEVELOPMENT Available on the market
DESCRIPTION: Capability to create (manually and automatically) path or process programs for use by NC machines or robotic work cells. Thus, manufacturing attributes are included in the product design process.

POTENTIAL BUSINESS BENEFITS: The following benefits can be achieved, resulting in increased margin on sales:

- Reduced pre-production costs
- Increased productivity through increased part dimensioning, weld parameter control and decreased distortion, thus reducing fit up time, welding time and welding material
- Reduction in part generation and welding labor, through automation (including robotics)

GENERAL AREA: Production
DETAIL AREA: Fabrication Processes

TRACKING NO: 23

REQUIREMENT: Development of Interim Product Fabrication Instructions
STATE OF DEVELOPMENT Available on the market
DESCRIPTION: Development of production instructions used in the fabrication of interim products, including nesting.

POTENTIAL BUSINESS BENEFITS: Instructions and diagrams will reduce drawing interpretation by production personnel and result in reduced errors and better part or assembly dimensional quality. This reduces assembly labor hours and cycle time and reduces downstream fit up and weld time at installation. Increases margin on sales.

GENERAL AREA: Production
DETAIL AREA: Fabrication Processes

TRACKING NO: 24

REQUIREMENT: Simulation of Fabrication Sequences
STATE OF DEVELOPMENT: Available on the market
DESCRIPTION: Capability to simulate fabrication sequences by means of modeling. Included is simulation of interim product production processes.

POTENTIAL BUSINESS BENEFITS: Enables more precise shop planning and execution for increased floor productivity and capacity, thus increasing throughput/reducing costs. Increases margin on sales.

GENERAL AREA: Production
DETAIL AREA: Fabrication Processes

TRACKING NO: 25

REQUIREMENT: NC Programs for Joining and Assembly

STATE OF DEVELOPMENT Available on the market

DESCRIPTION: Capability of NC programs to support structural joining and assembly processes for structure and outfit, for example:

- Generation of NC programs for welding, cutting and coating by automated, off-line systems that use output files from product model
- Text-based neutral files created as interfaces between product model database and NC postprocessor
- Executable programs associate process parameters with path planning and sequencing by roles-based logic algorithms
- Capabilities of NC programs to support structural, cutting, joining and assembly processes include:
  - Structure: cutting and beleling of plate; cutting and beveling of structural shapes joining of plate
  - Outfit: cutting and beveling of pipe; joining of pipe for outfitting

POTENTIAL BUSINESS BENEFITS: Improved optimization of production through:

- Coordinated, rule-based path programming and sequencing
- Automated inputs to build strategy activities
- Automated outputs from build strategy activities
- Improved configuration management on NC files
- Labor reduction in lofting and production engineering activities
- Manufacture of designed components for structure and outfit from commodity materials with machinery directly from designs that have been electronically created and stored
- Reduces potential for error
- Reduces manual labor
- Improves the accuracy and quality of the cutting and joining operations

Increases margin on sales.

GENERAL AREA: Production

DETAIL AREA: Joining and Assembly Processes

TRACKING NO: 26

REQUIREMENT: Automated Subassembly/Assembly Processes
STATE OF DEVELOPMENT: Available on the market and proprietary versions
DESCRIPTION: Automated joining and assembly processes for subassemblies and assemblies, including:

- Reprogrammable robots that can perform cutting, joining, surface preparation and surface treatment operations with a wide range of process controls, programmable functions, sensing abilities, and adaptive control capabilities
- Dedicated NC robots and machines with limited range of process controls, programming functions, sensing abilities, and adaptive control capabilities
- PLC-controlled processes on automated or manual positioners limited process, programming, sensing and adaptive control capabilities
- Cleaning and surface preparation
- Surface treatment (e.g., painting)
- Programmable robot movers and manipulators to position and orient robots in work areas. Often a gantry, track, or manipulator that can move a robot(s) in 1, 2 or 3 axes

The product model would be data driven and associativity would be present between the product geometry data and process rules.

POTENTIAL BUSINESS BENEFITS: Improved optimization of production operations through:

- Integration of product database and production process database
- Reduction of process variability and improvement of production predictability
- Transference of critical labor skills to technological capabilities
- Reduction of span times
- Automatic assembly and processing of designed components for structure and outfit from commodity materials with machinery directly from designs
  that have been electronically created and stored
- Reduces potential for error
- Reduces manual labor
- Improves the accuracy and quality of the cutting, joining, cleaning and surface preparation and treatment processes

Increases margin on sales.

GENERAL AREA: Production
DETAIL AREA: Joining and Assembly Processes

REQUIREMENT: Programmable Welding Stations and Robotic Welding Machines

STATE OF DEVELOPMENT Available on the market

DESCRIPTION: Programmable welding stations and robotic welding machines for joining and assembly processes, including the following capabilities

- Intelligent, sensor-based robotic systems capable of welding a variety of assembly types without manual intervention
- Systems integrated with automated off-line programming systems capable of using product model data, directly from the database, for creation of welding programs
- Automated associativity of welding schedules (parameters) with assembly structure and weld segment paths

Programmable welding stations often resemble a machine tool with a range of motion and process controls to perform a series of tasks in a programmed sequence. These often require mechanical setup and adjustment prior to operation on a specific task.

Robotic welding stations often consist of a programmable robot, process equipment, a work piece holding means (tooling or fixturing), and often a work piece transfer mechanism, and an operator safety system integrated into a workcell environment.

POTENTIAL BUSINESS BENEFITS: Benefits include:

- Reduction of span times
- Transference of critical labor skills to technological capabilities
- Production predictability and reduction of process variability
- Enforcement of discipline and accuracy control on non-automated operations
- Automatic joining of components for structure and outfit from commodity materials with machinery from programs that have been taught by skilled workers.
- Reduces potential for error
- Reduces potential for error
- Reduces manual labor
- Improves the accuracy and quality of the joining process

These benefits will increase optimization of production operations and will increase margin on sales.

GENERAL AREA: Production

DETAIL AREA: Joining and Assembly Processes

TRACKING NO: 28

REQUIREMENT: Location Marking for Welded Attachments
STATE OF DEVELOPMENT: Available on the market
DESCRIPTION: Capability for marking locations for welded attachments for joining and assembly processes. Marks are commonly made by indelible inks, ink jet spray devices and zinc oxide powder applied with an oxy-fuel or plasma process. Marking is frequently applied with the same programmable NC or robot equipment used for cutting. The marking process is often integrated with the cutting process to minimize handling and application time.

Included are the following capabilities

- Automatic insertion of MRLs, stiffener and bracket locations into the NC files created for plate and panel cutting
- Automatic control of file configuration management
- Text-type neutral files creation from product model to NC path plan files

POTENTIAL BUSINESS BENEFITS: Improved optimization of production processes will be achieved through:

- Reduction of span times from design to fabrication
- Reduction of errors in configuration management (especially for multiple ship contracts conducted in parallel)
- Enables transfer of design information directly to the materials being joined and assembled, thus reducing potential for errors, accelerating the assembly processes and improving the accuracy of the location process.
- When automated, enables direct transfer of information from designs that have been electronically generated and stored, further reducing the potential for error, reducing manual labor and improving the accuracy and quality of the location process.

increases margin on sales.

GENERAL AREA: Production
DETAIL AREA: Joining and Assembly Processes

TRACKING NO: 29

REQUIREMENT: Definition of Fit-Up Tolerances
STATE OF DEVELOPMENT: Proprietary versions
DESCRIPTION: Capability to define fit-up tolerances for joining and assembly, with capabilities such as the follow-rig:

- Automated specification of tolerance allowables on all manufacturing output files
- Maintenance of specified tolerances in a database
- Availability of data for process sensing and inspection operations

This capability is required in order to employ most automation processes for joining and assembly, particularly for NC machine, NC robot and programmable robot applied processes. Fit-up tolerances are often specified by the equipment manufacturer, but may be dependent upon the process employed.

POTENTIAL BUSINESS BENEFITS: Improved optimization of production processes through:

- Multi-level communication of tolerance allowables
- Enabling automated sensing and collection of tolerance actuals
- Enabling process capability analysis (SPC)
- Reduction of labor
- Reduction of material processing
- Reduction of material handling
- Reduction of rework
- Reduction of potential error
- Improved accuracy and quality
- Enabling the automatic cutting, joining, surface preparation and treatment of components, structure and outfit from commodity materials with machinery directly from designs that have been electronically generated and stored.

Increases margin on sales.

GENERAL AREA: Production
DETAIL AREA: Joining and Assembly Processes

TRACKING NO: 30

REQUIREMENT: Control of Welding to Minimize Shrinkage and Distortion

STATE OF DEVELOPMENT Initial development

DESCRIPTION: Control of welding process parameters, method of application, and sequence of application to minimize weld shrinkage and distortions. This is usually performed at the cell level and not at a system level, and is dependent upon the specific design of the assembly and the process application method that is used. Component position measurement and other sensors are employed. There may be:

- Predictive association (rules) between weld size, parameters, process and shrinkage and distortion values
- Automated algorithm that calculates shrinkage values for weld segment programs
- Automated loading of welding schedules into NC path programs for automated and robotic cells

POTENTIAL BUSINESS BENEFITS: Improved optimization of production process through:

- Reduced process variations and improved predictability
- Improved product quality
- Shortened block assembly span times
- Enabling the manufacture of designed components for structure and outfit from commodity materials to a tolerance that eliminates secondary cutting operations or rework.
- Reduction of potential error
- Improved accuracy and quality

Increases margin on sales.

GENERAL AREA: Production

DETAIL AREA: Joining and Assembly Processes

TRACKING NO: 31

REQUIREMENT: Programming for Automated Processes
STATE OF DEVELOPMENT: Available on the market, proprietary versions
DESCRIPTION: This requirement comprises computer generated programming for robotic cutting, joining, surface preparation and surface treatment processes. Computer generated robot programming is necessary in order to use robots in low volume tasks where the cost of manual programming exceeds the labor savings of the robot process. Robot simulation computer programs are used in some instances, but may be limited because of labor intensive programming efforts required.
Capabilities inherent in this requirement may include the following:
- Automated, off-line programming
- Direct link to, and feedback from, product model database
- Rules-based sequence planning
- Automated, rules-based associativity of process parameters with path plan
- Automated cycle time analysis and collision detection
- Translatable to open architecture machine control systems

POTENTIAL BUSINESS BENEFITS: Improved optimization of production processes through the following:
- Reduction of production planning span time
- Reduction of process variability
- Increased application of standard production processes
- Enabling the timely and cost effective automatic robotic manufacture of low volume and one-of-a-kind designed components for structure and outfit from commodity materials with machinery directly from designs that have been electronically created and stored.
- Reduction of potential error
- Improved accuracy and quality of cutting and joining operations

Increases margin on sales.

GENERAL AREA: Production
DETAIL AREA: Joining and Assembly Processes

TRACKING NO: 32

REQUIREMENT: Definition of Fit-Up Tolerances for Block Assembly Joints
STATE OF DEVELOPMENT Proprietary versions
DESCRIPTION: Definition of fit-up tolerances for block assembly joints for joining.

POTENTIAL BUSINESS BENEFITS: Enables the manufacture of block assemblies that can be joined without cutting or rework. Reduces potential for error, decreases manual labor and improves the accuracy and quality of the cutting and joining operations. Decreases cost and increases margin on sales.

GENERAL AREA: Production
DETAIL AREA: Joining and Assembly Processes

TRACKING NO: 33

REQUIREMENT: Capabilities for Material Pick Lists, Marshaling, Kitting and Tracking

STATE OF DEVELOPMENT: Proprietary versions available on the market

DESCRIPTION: Generation of pick lists, material marshaling and kitting and material tracking for both structural and outfitting parts. To include object-based tools for documentation of processes (e.g., manuals and embedded software).

POTENTIAL BUSINESS BENEFITS Enable effective management of production processes in order to be a low cost provider and increase margin on sales.

GENERAL AREA: Production

DETAIL AREA: Material Control

TRACKING NO: 34

REQUIREMENT: Tracking of Piece/Parts Through Fabrication and Assembly
STATE OF DEVELOPMENT: Available on the market and proprietary versions
DESCRIPTION: Capability to track piece/parts through fabrication and assembly for both structural and outfitting parts.

POTENTIAL BUSINESS BENEFITS: Enable effective management of production processes in order to be a low cost provider and increase margin on sales.

GENERAL AREA: Production
DETAIL AREA: Material Control

TRACKING NO: 35

REQUIREMENT: Communication of Staging and Palletizing Requirements to Suppliers
STATE OF DEVELOPMENT Initial development
DESCRIPTION: Provide capabilities to communicate staging and palletizing requirements to suppliers for both structural and outfitting material so that the supplier can deliver material directly to the work site.

POTENTIAL BUSINESS BENEFITS: Enable effective management of production processes in order to be a low cost provider. Enable reduction of non-value added activities by having suppliers stage and palletize material as required by production. Decreases cost and increases margin on sales.

GENERAL AREA: Production
DETAIL AREA: Material Control

TRACKING NO: 36

REQUIREMENT: Documentation of Assembly and Subassembly Movement

STATE OF DEVELOPMENT: Proprietary versions

DESCRIPTION: Provide a scheduling system for assembly and major subassemblies that performs the following functions:

- Graphical display of ground assembly areas
- Edits to enforce facility constraints
- Yard-w-de access to on-line schedules
- Real time visual display of labor hour requirements by area and trade as block laydowns are manipulated to perform labor hour level loading
- Facilitate capacity planning for new contracts
- Track historical durations by block types to facilitate analysis in implementing learning curves on follow-on or similar ships
- Supports day-today maintenance of schedules
- Automatically interfaces with applicable material management systems

POTENTIAL BUSINESS BENEFITS: Increase knowledge and predictability of production processes, thus improving ability to predict cycle times and reduce risks of schedule overruns. This is achieved by documenting and tracking movements of interim products, enabling the shipyard to manage material from the raw state until erection on the ship. Increases margin on sales.

GENERAL AREA: Production

DETAIL AREA: Material Control

TRACKING NO: 37

REQUIREMENT: Handling and Staging of In-Process and Completed Parts
STATE OF DEVELOPMENT: Available on the market and proprietary versions
DESCRIPTION: Provide capabilities for tracking in-process and completed parts. Also provide direction for the material handling and staging.

POTENTIAL BUSINESS BENEFITS: Enable effective management of production processes in order to be a low cost provider and increase margin on sales.

GENERAL AREA: Production
DETAIL AREA: Material Control

TRACKING NO: 38

REQUIREMENT: Testing and Inspection Guidelines

STATE OF DEVELOPMENT: Proprietary versions and available on the market

DESCRIPTION: Testing and inspection guidelines

- Documented testing and inspection are recorded in specification at system level
- Non-documented testing and inspection are considered as normal workmanship standards (peer-based, agent-level quality assurance instead of quality control)
- Includes welding inspection, compartment tightness and strength tests, compartment completeness inspections, machinery inspections and tests, machinery inspections and tests, pipe hydro tests, electrical tests, HVAC pressure drop tests and final in-shop testing and inspection of interim products.

POTENTIAL BUSINESS BENEFITS: Decreases risk and rework, increasing margin on sales.

GENERAL AREA: Production

DETAIL AREA: Testing and Inspection

TRACKING NO: 39

REQUIREMENT: High Level Development of Build Strategy
STATE OF DEVELOPMENT: Proprietary versions
DESCRIPTION: High level resource planning and scheduling of build strategy, Including consideration of:

At highest planning level
- Interim product definition
- Tree structure and tasking sequence definition

At intermediate planning level
- Procurement plan and schedule
- Design schedule
- Integration and test plan schedule
- Assembly loading leveling of scheduling, including use of graphics with constraint rules and with labor additive/ "get chart"
- Erection schedule
- Integration and test plan schedule
- Future planning based on current status
- Supports facility, i.e., multi-product/contract
- Must be automatic and accurate (including automatic conflict resolution)

POTENTIAL BUSINESS BENEFITS: Assist in gaining market share by effective planning for facility utilization and ensuring delivery on commitments to customers by:
- Improved decision making through availability of dependable, up-to-date information, thus reducing risk
- Improved operational efficiency
- Reduced manual labor

GENERAL AREA: Operations Management
DETAIL AREA: High-Level Resource Planning and Scheduling

TRACKING NO: 40

REQUIREMENT: Order Generation and Tracking

STATE OF DEVELOPMENT Available on the market and proprietary versions

DESCRIPTION: Capability for generating and tracking ordering of material (both purchased and in-yard manufactured) with the following features

- Automated attribute data in the product model
- Purchase order generation using bill of material input (order number, start date, completion date and routing instructions)
- Specific lead times (including set-up and run times; these may be) standard lead times or automatically estimated; may be on-demand) generated)
- Feedback on actual lead times and when purchase has actually taken place

POTENTIAL BUSINESS BENEFITS: Enable effective management of material ordering processes in order to be a low cost provider and increase margin on sales.

GENERAL AREA: Operations Management

DETAIL AREA: High-Level Resource Planning and Scheduling

TRACKING NO: 41

REQUIREMENT: Performance Measurement
STATE OF DEVELOPMENT: Available on market and proprietary versions
DESCRIPTION: Provide system generated management reports that provide key performance indicators that illustrate if the production processes are within their historical control limits. This information is to be based on data generated at the workstation level.

POTENTIAL BUSINESS BENEFITS: Enable effective magement of production processes in order to be a low cost provider and increase margin on sales.

GENERAL AREA: Operations Management
DETAIL AREA: High-Level Resource Planning and Scheduling

TRACKING NO: 42

REQUIREMENT: Production Status Tracking and Feedback
STATE OF DEVELOPMENT: Conceptual stage
DESCRIPTION: Tracking and feedback for project management (not cost recovery tracking). Considered are labor and material costs for fabrication, steel assembly and installation. This method is simplified compared to cost recovery method. Interim products are considered.

POTENTIAL BUSINESS BENEFITS: Enable effective management of production processes in order to be a low cost provider. Also, enable better understanding of underlying costs of processes in order to develop more effective bids on new work and to help gain market share.

GENERAL AREA: Operations Management
DETAIL AREA: High-Level Resource Planning and Scheduling

TRACKING NO: 43

REQUIREMENT: **Inventory Control**

STATE OF DEVELOPMENT **Available on the market and proprietary versions**

DESCRIPTION: **Provide capabilities for controlling and tracking inventory, including the following features:**

- **identify location of inventory by warehouse or production storage site**
- **Identify specific storage locations (bins) within a warehouse/ storage site**
- **Identify status e.g., (on-hand, in-inspection, in-transit, rejected)**
- **Show program ownership or company stock**
- **Provide transactions for contract transfers, movement of stock, adjustments of inventory, receipts and issues**
- **Provide tools for cycle counting to determine inventory accuracy**

POTENTIAL BUSINESS BENEFITS: **Enable effective management of production processes in order to be a low cost provider and increase margin on sales.**

GENERAL AREA: **Operations Management**

DETAIL AREA: **High-Level Resource Planning and Scheduling**

TRACKING NO: **44**

REQUIREMENT: High Level Planning and Scheduling
STATE OF DEVELOPMENT: Proprietary versions
DESCRIPTION: Generate high level planning and scheduling information, including:
- Labor requirement profiles
- "B" level schedule information, including labor estimates, crew size estimates, and duration estimates

Estimates may be based on rules, definitions, and historical production data.

POTENTIAL BUSINESS BENEFITS: Increases margin on sales by the following:
- Improved decision making through availability of dependable, up-to-date information, thus reducing risk
- Improved operational efficiency
- Reduced manual labor

GENERAL AREA: Operations Management
DETAIL AREA: High-Level Resource Planning and Scheduling

TRACKING NO: 45

REQUIREMENT: Development of Production Packages
STATE OF DEVELOPMENT Proprietary versions
DESCRIPTION: Development of production packages to support steel and outfit fabrication and assembly. This is tied to "order generation."

POTENTIAL BUSINESS BENEFITS: Increases margin on sales by the following:

- Reduced costs to kit material
- Improved kit accuracy (proper material)
- Increases productivity of shop workforce through better understanding of job definition
- Provides feedback mechanism for process improvement

GENERAL AREA: Operations Management
DETAIL AREA: Production Engineering

TRACKING NO: 46

REQUIREMENT: Development of Unit Handling Documentation
STATE OF DEVELOPMENT: Proprietary versions
DESCRIPTION: Automated development of unit handling (lifting, bracing) sketches or documents for decision support.

POTENTIAL BUSINESS BENEFITS: Reduced engineering and design labor hours and vastly improved cycle time, decreasing costs and increasing margin on sales

GENERAL AREA: Operations Management
DETAIL AREA: Production Engineering

TRACKING NO: 47

REQUIREMENT: Parts Nesting
STATE OF DEVELOPMENT Available on the market
DESCRIPTION: Nesting of parts for structural plate, shapes and sheet metal. Included is consideration of tools to support material management associated with nesting, such as linear automation, xy automation, and xy specific. These tools may be rules or manual intervention.

POTENTIAL BUSINESS BENEFITS: Reduced engineering and design labor hours and vastly improved cycle time, increasing margin on sales.

GENERAL AREA: Operations Management
DETAIL AREA: Production Engineering

TRACKING NO: 48

REQUIREMENT: Development and Issue of Work Orders and Shop Information
STATE OF DEVELOPMENT Proprietary versions
DESCRIPTION: Development and issue of work orders and shop information.

POTENTIAL BUSINESS BENEFITS: Increases margin on sales by means of:

- Increases control of operations, which should reduce expediting and help maintain adherence to schedule
- Increases accountability of workers to meet schedules and produce quality work
- Reduces need for rework
- Increases productivity
- Increases quality

GENERAL AREA: Operations Management
DETAIL AREA: Production Engineering

TRACKING NO: 49

REQUIREMENT: Material Management

STATE OF DEVELOPMENT: Prototype testing (parts are proprietary versions and on market)

DESCRIPTION: Material management to ensure on-time availability in support of production, including:

- Order statusing
- Feedback loop
- Yard stock material management (including material status)
- Long lead time material procurement (makes use of EDI and CAD information)
- Direct material stocking, including consideration of receipt processing at delivery to shipyard and basic order agreements between shipyard and vendors
- Interfaces with bill of materials (such as the bill of materials generated in the CAD product model)
- Obtaining and processing vendor furnished information through electronic means (EDI)
- Processing and tracking of purchase orders
- Support of tendering, including inquiry, history, and tracking and and validating vendor proposals

POTENTIAL BUSINESS BENEFITS: Takes advantage of inputting data one time to a product model, and using the data in various ways, resulting in:

- Reduced manual labor
- Reduced errors
- Increased speed in development of bills of materials and in material procurement

Increases margin on sales.

GENERAL AREA: Operations Management

DETAIL AREA: Purchasing/Procurement

TRACKING NO: 50

REQUIREMENT: Provision of Planning and Scheduling Information to Shops
STATE OF DEVELOPMENT: Conceptual stage (non-shipbuilding software on the market)
DESCRIPTION: Provision of planning and scheduling information to shops, including:

- Drawings
- Schematics
- Lofting information
- Work instructions
- Ship location reference marks
- Welding reference lines
- Machine setup instructions
- Part marking instructions

POTENTIAL BUSINESS BENEFITS: Enable effective management of production processes in order to be a low cost provider and increase margin on sales.

GENERAL AREA: Operations Management
DETAIL AREA: Shop Floor Resource Planning and Scheduling

TRACKING NO: 51

REQUIREMENT: Work Order/Work Station Tracking and Control

STATE OF DEVELOPMENT: Available on the market and proprietary versions

DESCRIPTION: Work order and work station tracking and control including:

- Integrated with product model and other systems
- Establishes shop priorities across programs (i.e., multi-ship, not single ship capability)
- Provides shop dispatch list that is priority driven
- Provides for controlled release of work to production
- Provides for tracking of orders through use of statuses
- Real time progress reports for use in shift turnover and other briefings (not currently available on the market)
- Agent based approach (not currently available on the market - initial development)

POTENTIAL BUSINESS BENEFITS: Enable effective management of production processes in order to be a low cost provider and increase margin on sales.

GENERAL AREA: Operations Management

DETAIL AREA Shop Floor Resource Planning and Scheduling

TRACKING NO: 52

REQUIREMENT: Detailed Capacity Planning for Shops and Areas

STATE OF DEVELOPMENT: Available on the market and proprietary versions

DESCRIPTION: Detailed capacity planning for shops and areas, including:

- Inclusion of business process considerations
- Approach based on finite capacity
- Multi-programs (i.e., multi-ship, not single ship capability) conflict resolution
- Floor agents (human or computer-based)
- Interactive tools
- Approach based on finite capacity
- Consideration of process lane layouts
- Consideration of machine sequencing

POTENTIAL BUSINESS BENEFITS: Enable effective management of production processes in order to be a low cost provider and increase marginon sales.

GENERAL AREA: Operations Management

DETAIL AREA: Shop Floor Resource Planning and Scheduling

TRACKING NO: 53

REQUIREMENT: Collect and Calculate Costs for a Major Assembly
STATE OF DEVELOPMENT: Available on the market and proprietary versions
DESCRIPTION: Collect and calculate total labor and material direct costs for a major assembly. This is tracking and feedback for project management (not cost recovery tracking). Considered are labor and material costs for fabrication, steel assembly and installation. This method is simplified compared to cost recovery method. Interim products are considered.

POTENTIAL BUSINESS BENEFITS: Enable effective management of production processes in order to be a low cost provider and increase margin on sales.

GENERAL AREA: Operations Management
DETAIL AREA: Shop Floor Resource Planning and Scheduling

TRACKING NO 54

REQUIREMENT: Datacentric Architecture
STATE OF DEVELOPMENT Available on the market
DESCRIPTION: Datacentric architecture of software:

- Each data item is present in only one place in the product model
- Intelligent attributes (e.g., part numbering and data states)
- Structure, outfitting, and other data in a single, integrated database
- User may define item numbering scheme
- Topically associativity of structure and outfit
- All items are logically and physically connected

POTENTIAL BUSINESS BENEFITS Improves market share and margin on sales through:

- Efficient control over design and manufacturing database entities
- Rapid revision of existing designs
- Reduction of span times for creation of new design
- Simplified configuration management of design details
- Immediate, accurate communication between shipyard and sub-contractors and suppliers

GENERAL AREA: Umbrella
DETAIL AREA: Umbrella

TRACKING NO: 55

REQUIREMENT Computer-Automated as Well as Computer-Aided

STATE OF DEVELOPMENT Initial development

DESCRIPTION: Software is computer-automated as well as computer-aided:

- Robust and flexible data interrogation and reporting tools (e.g., drawings, BOMs, cost estimating and schedule impact information to designers)
- Decision support tools (e.g., integration with simulation tools)
- Capability to develop and use Standards (e.g., for design and for processes)
- Uses knowledge, rules and expert system reasoning approaches

POTENTIAL BUSINESS BENEFITS: This capability will enhance a shipyard's ability in the areas of market size, market share and margin on sales by

- Increasing speed of developing variations on designs that Will meet customer's desires for costed-out and engineered options from which to choose
- Decreasing uncertainty while increasing speed in developing proposals and optimizing existing designs within tight delivery schedules

GENERAL AREA: Umbrella

DETAIL AREA: Umbrella

TRACKING NO: 56

REQUIREMENT: Interoperability of Software
STATE OF DEVELOPMENT Initial development
DESCRIPTION: Software is interoperable (i.e., capable of object linking and embedding among different applications (e.g., spreadsheet, word processing), especially without need for platform-resident applications.

POTENTIAL BUSINESS BENEFITS: Increases speed and ease of use of software as well as enhancing enterprise-wide integration. Bottom line results should enhance accuracy and delivery times, assisting shipyard to increase market size, market share and margin on sales.

GENERAL AREA: Umbrella
DETAIL AREA: Umbrella

TRACKING NO: 57

REQUIREMENT: Open Software Architecture

STATE OF DEVELOPMENT Initial development

DESCRIPTION: Open software architecture: CAD/CAM/CIM systems utilize an operating system common to other needed applications. Modular applications (plug and play) for upgrade of technology.

POTENTIAL BUSINESS BENEFITS: Open architecture should enhance the ability of various shipyards, vendors and owners to exchange data and files, making it easier to integrate teaming arrangements. This can improve the team's market share and margin on sales through increased response times, ability to develop variations from which a customer can select the most suitable design, and ability to refine existing designs.

GENERAL AREA: Umbrella

DETAIL AREA: Umbrella

TRACKING NO: 58

REQUIREMENT: Accessible Database Architecture
STATE OF DEVELOPMENT Available on the market
DESCRIPTION: The database architecture is accessible (open):
- Capability for user to modify to reflect changing needs of user
- Ability for enterprise-specific data and relationships to be entered into database

POTENTIAL BUSINESS BENEFITS: The user's ability to access data enables that data to be reused in other applications (rather than regenerating the data), thus saving time and decreasing errors. Increases margin on sales.

GENERAL AREA: Umbrella
DETAIL AREA: Umbrella

TRACKING NO: 59

REQUIREMENT: Remote Networking Capability
STATE OF DEVELOPMENT Available on the market
DESCRIPTION: Capability for remote networking to support world-w-de project participants and to communicate across organizational boundaries.

POTENTIAL BUSINESS BENEFITS: This capability should enhance ability of various shipyards, vendors and owners to exchange data and files, making it easier to integrate teaming arrangements. This can improve the team's market share and margin on sales through increased response times, ability to develop variations from which a customer can select the most suitable design, and ability to refine existing designs.

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GENERAL AREA: Umbrella
DETAIL AREA: Umbrella

TRACKING NO: 60

REQUIREMENT: Full Data Access (Read Only) to All Project Participants
STATE OF DEVELOPMENT Available on the market
DESCRIPTION: Full data access (read only) to all project participants. There is no preconception about "need to know."

POTENTIAL BUSINESS BENEFITS: Because all participants have access to all of the project data, any question for which data exists as an answer can be answered for the participants. This saves the participants from having to determine who has authority to certain desired data and then gaining authority to share the data. Participants Will not be tempted to guess at or estimate data that they can easily access. Thus, projects may be carried out more quickly and with greater accuracy increasing market share and margin on sales.

GENERAL AREA: Umbrella
DETAIL AREA: Umbrella

TRACKING NO: 61

REQUIREMENT: Assignment of Data Ownership
STATE OF DEVELOPMENT Proprietary versions
DESCRIPTION: Data ownership is assigned to particular project participants for change control. There is a broadcast/mail/notify method to announce changes to all project participants.

POTENTIAL BUSINESS BENEFITS: Assignment of data ownership increases management structure within the design team while (if Full Data Access, Requirement 86, is available) maintaining flexibility. The owner of the data is responsible for the data, which should decrease errors caused by uncertainties of data development authority and increase the efficiency of a design effort. This can improve a design team's market share and margin on sales through increased response times, ability to develop variations from which a customer can select the most suitable design, and ability to refine existing designs.

GENERAL AREA: Umbrella
DETAIL AREA: Umbrella

TRACKING NO: 62

REQUIREMENT: User-Friendliness
STATE OF DEVELOPMENT: Prototype testing
DESCRIPTION: Software is user friendly, having characteristics such as the following:

- Program and graphical user interface are oriented to facilitate "natural" user needs and preferences
- Multi-path approaches for use (not rigid sequences)
- Irons
- Hesitate help at icons
- Robust enough to support discoverability for safely learning software capabilities
- Seamless integration among program modules
- Minimal learning curve requirements (e.g., same look and feel among modules and applications)

POTENTIAL BUSINESS BENEFITS: User friendliness decreases training time and enhances efficiency of new and experienced users of an application. This can improve a design team's market size, market share and margin on sales through increased response times, ability to develop variations from which a customer can select the most suitable design, and ability to refine existing designs.

GENERAL AREA: Umbrella
DETAIL AREA: Umbrella

TRACKING NO: 63

REQUIREMENT Enterprise Product Model
STATE OF DEVELOPMENT Available on the market
DESCRIPTION: The enterprise product model includes

- 3-D Model of product (e.g., ship)
- Model of project (including work instructions and processes)
- Physical plant (facility) model (including resources, processes, and constraints)
- Tools to support the modeling, utilization and implementation
- Data navigator

POTENTIAL BUSINESS BENEFITS Allows shipyard to achieve a true Integrated Product Data Environment (IPDE). As technology becomes cost effective to implement, this capability Will improve market size, market share and margin on sales.

GENERAL AREA: Umbrella
DETAIL AREA: Umbrella

TRACKING NO: 64

REQUIREMENT: Integration With Simulation
STATE OF DEVELOPMENT Available on the market
DESCRIPTION: There is integration with simulation for IPPD.

POTENTIAL BUSINESS BENEFITS: Simulation (electronic mock-up) can reduce the need for the development of a physical mock-up. Many benefits can be realized in the areas of planning and assembly sequencing. Simulation allows production workers to visualize complex CAD models and then work with designers and planners to develop more cost-effective designs. Increases market share and margin on sales.

GENERAL AREA: Umbrella
DETAIL AREA Umbrella

TRACKING NO: 65

REQUIREMENT: Information Management
STATE OF DEVELOPMENT Available on the market
DESCRIPTION: Tools for information management, including:
- Document retrieval
- Shared access
- Integrated with office automation

POTENTIAL BUSINESS BENEFITS: Many advantages may be found in managing configuration of design and changing documents through electronic vaulting concepts, including check in/out, access control, versioning and revisioning. Files, documents and drawings can be logically grouped together and managed, thus saving time in carrying out these functions manually. Increases margin on sales.

GENERAL AREA: Umbrella
DETAIL AREA: Umbrella

TRACKING NO: 66

REQUIREMENT: Scalability
STATE OF DEVELOPMENT: Prototype testing
DESCRIPTION: The software has scalability capabilities, in which features that may not be needed in some business environments can be omitted seamlessly and without economic consequences. For example, configuration management may be present for naval designs and omitted for commercial designs.

POTENTIAL BUSINESS BENEFITS: Helps reduce span time in the development of proposals and price quotes, and provides faster, more accurate and lower risk analysis of new designs. Increases market share and increases margin on sales.

GENERAL AREA: Umbrella
DETAIL AREA: Umbrella

TRACKING NO: 67

REQUIREMENT: Transportability
STATE OF DEVELOPMENT Initial development
DESCRIPTION: Software is transportable the code is platform independent.

POTENTIAL BUSINESS BENEFITS: Allows the shipyard flexibility in the selection and upgrade of hardware and the ability to add additional processors. Increases margin on sales.

GENERAL AREA: Umbrella
DETAIL AREA: Umbrella

TRACKING NO: 68

REQUIREMENT: Configuration Management
STATE OF DEVELOPMENT Available on the market
DESCRIPTION: Tools for configuration management, include
- triggers messaging via ownership (work flow) and feedback loops
- availability of on-line status
- locations of objects in the workflow
- control and accurate definition of work processes

POTENTIAL BUSINESS BENEFITS This will become practical for commercial shipyards as implementation and cultural rests decline, and production processes are defined more accurately. Will increase margin on sales.

GENERAL AREA: Umbrella
DETAIL AREA: Umbrella

TRACKING NO: 69

REQUIREMENT Compliance With Data Exchange Standards
STATE OF DEVELOPMENT Prototype and proprietary versions
DESCRIPTION: Compliance with standards for data exchange by programs such as product model programs, focused technical applications (e.g., stability analysis programs), management programs, costing programs, scheduling programs, and production simulation programs. Initial standards may be set within a shipyard or within a project team comprised of several shipyards and vendors and other members. These initial standards would be useful only within the team. Ultimately, international data exchange standards will be set, through initiatives such as STEP in collaboration with ISO. International standards would enable universal compliance.

POTENTIAL BUSINESS BENEFITS Enable the formation of efficient teams of shipyards, vendors, design firms and other organizations through easy exchange of design and production data among team members.

GENERAL AREA: Umbrella
DETAIL AREA: Umbrella

TRACKING NO: 70

APPENDIX B

APPENDIX B - THE JAPANESE CIM STUDY

B.1 General

The Japanese Ship and Ocean Foundation (SOF) conducted a Shipbuilding Industry Computer Integrated Manufacturing (SICIM) study in 1992. This study bears similarities to the NSRP CAD/CAM/CIM project, and provides insights into the selection and definition of CAD/CAM/CIM requirements. Also a comparison of the NSRP study to the SOF study provides a high-level (i.e., not at the level of individual requirements) check for completeness of the NSRP approach. The Japanese study was documented, and has been translated [3](It should be kept in mind while reading this section that [3] is a draft translation of the original Japanese document).

B.2 Description of Requirements-Related Issues

The SOF study expanded upon the results of a similar Japanese effort carried out between 1989 and 1991, and aimed at developing a product model approach to ship design and production. The SOF study envisioned SICIM eventually being used to coordinate all shipbuilding activities, including (p. 52):

- sales
- development
- design
- procurement
- manufacturing
- inspection
- materials
- communication between shipyard divisions
- facilitating the decision-making process

Further, the SOF study, which encompassed both design and manufacture aspects of shipbuilding envisioned that the ultimate SICIM system would assist in:

- solving problems inherent in product development
- shortening production time
- providing a flexible response to changing demand
- maintaining a high level of technology
- addressing an aging work force
- addressing a lack of skilled workers

The SOF study views design and production process information as keys to the success of an SICIM system and is as important as information describing the ship itself (p. 125).

The SOF SICIM system is based on a product model integrated with 15 application subsystems. The 15 application subsystems maybe viewed as software modules, and may be described as follows (pp. 116-119)(some retitling and interpretation have been carried out for clarification):

1. Fabrication Production Management: Uses rule-based techniques and historical production data to develop construction, erection and fabrication schedules.
2. Desire Management. Develops and tracks the design development schedule, ensuring that designs are produced in a timely manner in order to support production.
3. Project Information. Involves development of plans and arrangements drawings. An automated approach is used so that changes maybe incorporated easily.
4. Resistance and Powering. Consists of resistance and powering calculations based on initial hull values with updated calculations to reflect design changes.
5. Hull Structural Desire. Comprises structural calculations of the hull, including the midship structural calculation. The results are used to support stress calculations and for submittal to regulatory bodies. Information is available in three formats: structural arrangement, structural materials and structural parts.
6. Outfitting Equipment Listing. Lists all ship's oufit from the contract specification.
7. Outfitting Equipment Arrangement. Addresses the arrangement of all ship's outfit, including working spaces, engine room and accommodations. Develops equipment bill of materials for use by purchasing. At the system level the design process is assisted by a rule-driven feature.
8. Distributed Systems Desire Addresses distributed systems (e.g., duct, cabling and piping) design, based on machinery arrangement and hull size. Assembly information is produced for piping and ducting.
9. Painting Desire Deals with structure and outfit painting design (dry film thickness, number of layers and paint name).
10. Steel Plate Processing. Defines the type and quantity of steel plate, and development of NC and robot information for cutting shaping, assembly and welding.
11. Build Strategy. Develops section, unit and block divisions, set-up of sequence of operations for fabrication and erection, development of detailed piece part and subassembly diagrams, and production of preliminary build schedule.
12. Qualitv Program. Develops quality specifications in the form of a manual and records the accuracy information during construction.
13. High-Level Scheduling. Develops a milestone schedule to support the contract delivery date of the ship within the constraints of the shipyard facility (manufacturing resources).
14. Short-Term Scheduling. Involves time spans between one day and one week at the level of individual persons and individual NC machines. Feedback is provided, based on actual production progress, and this is fed to the high-level schedule.
15. Material Control and Tracking. Defines material needs and provides reports, and tracks material from arrival at the warehouse to process and assembly areas.

The SOF study observed that it is important to examine how the SICIM system wiIl change the design and production process. In particular, the study recommended a detailed analysis with regard to production planning and management issues (p. 53). The expected results of implementing SICIM are anticipated by the authors of the SOF study to be of a magnitude even greater than for implementing CAE, CAD and CAM systems (p. 78).

Thus, the SICIM is viewed not simply as a computerized way to carry out business using today's processes, but rather the introduction of fundamentally new processes. This in turn reflects on the SICIM software requirements, which must be tailored with the new processes in mind. This is of course an interactive process of refining the software and the processes which that software supports.

B.3 Comparison of SOF and NSRP Approaches

In contrast to the SOF application systems, the NSRP developed a number of product and process areas. These are not meant to be application systems, linked to a CIM product model, but rather a way to view the process of designing and producing a ship. The SOF and NSRP approaches are somewhat different, but in many ways remarkably similar. The NSRP product and process areas, with short descriptions, areas follows

1. Conceptual/prelimilnary Desire. Addresses the initial design stages for anew vessel in which general characteristics and basic system requirements are defined.
2. Functional Design. Involves the second stage of ship design. Primary structure scantlings and compartment layout are defined in functional design, along with system diagrams for distributed systems. Primary space arrangements (machinery spaces, cargo and handling layouts, etc.) are also developed during functional design. For the purposes of this evaluation functional design also includes "transition" design, in which initial design and outfitting zones are defined.
3. Detailed Desire. This is the design stage in which the detailed structural and systems design occurs; detailed calculations, systems integration and interference checking are performed; and the detailed product model is developed. For the purposes of this evaluation, detail design also includes the development of production-ready documentation, including bills of materials, fabrication and assembly level drawings, and sketches.
4. Fabrication Processes. Includes all processes associated with part fabrication, including leveling/straightening, marking, cutting, bending and forming machining process, casting and forging.
5. Joining and Assembly Processes. Includes all types and stages of joining and assembly, all types of welding and other thermal-joining methods, mechanical-joining methods and adhesives. Stages include subassembly, assembly, block erection, and post erection installations.
6. Surface Treatment and Coating. Includes all preparatory and fish work Preproduction priming, blasting and cleaning methods (sand, shot, water, solvents), residue collection and cleanup, painting finish painting and part painting are all considered.

7. Material Control. Incorporates all aspects of material tagging for identification% moving, kitting, palletizing storing and disposal. Includes both hardware and software used to support material handling and tracking issues.
8. Testing/Inspection. Includes the areas of weld inspections by dye penetrant and other NDT means, visual and optical inspections, pipe hydro test, ventilation pressure drop tests, compartment tightness and strength tests, compartment completion inspections, and grounding and EMI tests.
9. High-Level Resource Planning and Scheduling. Includes overall build strategy development, major milestone level planning, block production and erection schedules, test and inspection schedules, trials and delivery, facilities planning and scheduling, engineering planning and scheduling training and qualification issues.
10. Production Engineering. Addresses the interface between design and production. Includes all detailed planning, definition of work packages, development of product work breakdown structure, interface between CAD and CAM and design related production support.
11. Purchasing/Procurement. Covers all areas of material ordering, procurement and supplier relations. Includes interfaces with bill of materials systems and cost estimating, long lead time material ordering, obtaining and processing vendor furnished information, and processing and tracking of purchase orders.
12. Shop Floor Resource Planning and Scheduling. Covers planning and scheduling issues not included in high level planning and scheduling. Issues include shop floor and process lane layouts, equipment and personnel scheduling, detailed planning work order development, labor and/or cost control, job statusing, machine sequencing and shop capacity planning.
13. Qualitv Control and Assurance, SQC. Includes all aspects of quality control and assurance starting in design, through productin, including development of dimensional tolerance information and reference line systems, distortion control, dimensional data gathering in production statistical process control and statistical quality control.
14. General. Includes umbrella areas such as bill of materials, cost information, responses to shop floor disruption accuracy, high level planning customer requirements, part numbering, error detection, shipyard-vendor relationships, robotics, continuous improvement processes, data backup and recovery, shop floor feedback production automation, and process and tools documentation.

Tables B-1 and B-2 cross reference the elements of both approaches, first from the SOF perspective and then from the NSRP perspective. As is the case for the above descriptions of the SOF Application Systems, which must be viewed as approximate, the cross-referencing is approximate. With that limitation in mind, the following observations may be made

- The number of elements are nearly equal 15 for SOF and 14 for NSRP.
- There is close correspondence for the elements of Painting Design/Surface Treatment and Coating, and Materials Tracking/Material Control, and fair correspondence for the elements of Assembly and Processing/Joining and Assembly Processes.
- There is no NSRP equivalent to the SOF element of Design Management.

- There is no SOF equivalent to the NSRP element of Purchasing/Procurement.
- The SOF Quality Program element is addressed in four NSRP elements.
- The NSRP elements Functional Design, Detailed Design, Material Control, High-Level Resource Planning and Scheduling and General are each addressed by more than one SOF element.
- The SOF approach places more emphasis on managing, planning and scheduling than does the NSRP approach.

B.4 **Indicated Additional Requirements**

From the above, it is concluded that the following additional requirements would enhance the NSRP approach

1. Design Management (under NSRP Detailed Design, using approach from SOF Design Management) - Develop and track the design development schedule, ensuring that designs are produced in a timely manner in order to support production (included in Requirement 10).

2. Schedule Development (under NSRP High-Level Resource Planning and Scheduling, using approach from SOF Fabrication Production Management) - Computer-aided schedule development should make use of rule-based techniques and historical production data (included in Requirement 45).

Table B-1
For SOF Application Systems,
The Corresponding NSRP Product and Process Areas

SOF Application Systems	NSRP Product and Process Areas
1. Fabrication Production Management	9. High Level Resource Planning and Scheduling
2. Design Management	(Not Addressed by NSRP Approach)
3. Project Information	2. Functional Design
4. Capacity Design	2. Functional Design
5. Hull Design	3. Detailed Design
6. Outfitting Equipment Listing	3. Detailed Design
7. Outfitting Equipment Arrangement	3. Detailed Design
8. Distributed Systems Design	2. Functional Design
9. Painting Design	6. Surface Treatment and Coating
10. Steel Plate Processing	5. Joining and Assembly Processes
11. Build Strategy	5. Joining and Assembly Processes 10. Production Engineering
12. Quality Program	7. Material Control 8. Testing/Inspection 13. Quality Control and Assurance, SQC 14. General (Accuracy, Error Detection, Continuous Improvement Program)
13. Mid-Term Scheduling	9. High Level Resource Planning and Scheduling
14. Short-Term Scheduling	12. Shop Floor Resource Planning and Scheduling
15. Materials Tracking	7. Material Control

Table B-2
For NSRP Product and Process Areas,
The Corresponding SOF Application Systems

NSRP Product and Process Areas	SOF Application Systems
1. Conceptual/Preliminary Design	3. Project Information
2. Functional Design	3. Project Information 4. Resistance and Powering 8. Distributed System Design
3. Detailed Design	5. Hull Structural Design 6. Outfitting Equipment Listing 7. Outfitting Equipment Arrangement
4. Fabrication Processes	10. Steel Plate Processing
5. Joining and Assembly Processes	11. Build Strategy
6. Surface Treatment and Coating	9. Painting Design
7. Material Control	12. Quality Program 15. Material Control and Tracking
8. Testing/Inspection	12. Quality Program
9. High-Level Resource Planning and Scheduling	1. Fabrication Production Management 13. High-Level Scheduling
10. Production Engineering	11. Build Strategy
11. Purchasing/Procurement	(Not Addressed by Japanese SICIM)
12. Shop Floor Resource Planning and Scheduling	14. Short-Term Scheduling
13. Quality Control and Assurance, SQC	12. Quality Program
14. General	6. Outfitting Equipment Listing 12. Quality Program

APPENDIX C

APPENDIX C - CITATIONS RELEVANT TO REQUIREMENTS

This appendix presents citations of professional papers and reports that provide further insight into the CAD/CAM/CIM requirements. Numbers in parentheses refer to applicable requirement numbers. Figure C-1 shows the relationship between citations and requirements in matrix form (not all requirements have relevant citations).

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(Overleaf: Figure C-1, Relationship Between Citations and Requirements)

The matrix may be used to identify citations that are relevant to certain requirements: enter the left-hand column with the requirement number, move along the row applicable to the requirement, noting the boxes that are filled in. For each filled-in box, move upward and note the citation number.

How to Obtain the Citations

4th International Marine Systems Design Conference .-
National Shipbuilding Research Documentation Center
Marine Systems Division
Transportation Research Institute
University of Michigan
2901 Baxter Rd.
Ann Arbor, MI 48109-2150
Telephone: (313)936-3125
Fax: (313)936-1081
Email: Doc.Center@umich.edu
URL: http://www.umich.edu/-umtrimsd/docctr/docctr.htm
(Citation Numbers: 50-54)

8th International Conference on Computer Applications in Shipbuilding, Bremen Germany, Sept. 5-9, 1994
Berry Rasmussen Reklam AB
Fosidedalsvaegen 13
S-215 65, Molmoe
Sweden
(Citation Numbers: 1-44)

American Association for Artificial Intelligence
Menlo Park, CA 94025-3442
USA
Telephone: 415-328-3123
Fax: 415-321-4457
Email: info@ aaai.org
Url: http://www.aaai. erg/
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(Citation Number: 45)

REQUIREMENTS AND CITATIONS MAPPING

CITATION NUMBER (1–82)

REQUIREMENT NAME AND NUMBER	
Concept/Preliminary Design Engineering	1
Reusable Product Model Definitions	2
Develop Initial Build Strategy, Cost and	3
Class/Reg Body and Owner Compliance	4
Connectivity Among Objects	5
Tools to Dev Std Parts, Endcuts, Cutouts, etc.	6
Automated Documentation	7
Detail Design Engineering Analysis Tools	8
Design for Fabrication, Assembly and Erection	9
Linkage to Fabrication Assembly and Erection	10
Automatic Part Numbering	11
Interference Checking	12
Linkage to Bill of Material and Procurement	13
Weld Design Capability	14
Coating Specification Development	15
Definition of Interim Products	16
Consideration of Dimensional Tolerances	17
Context-Sensitive Data Representations	18
Processes to Cut/Form Structural Plates and	19
Documentation of Production Processes	20
Information Links to Production Work Centers	21
Piece and Part Labeling	22
Creatn of Path/Process Prgrms for NC Mach	23
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Simulation of Fabrication Sequences	25
NC Programs for Joining and Assembly	26
Automated Subassembly/Assembly Processes	27
Programmable Welding Sta and Robotic	28
Locations Marking for Welded Attachments	29
Definition of Fit-Up Tolerances	30
Control of Welding to Minimize Shrinkage and	31
Programming for Automated Processes	32
Definition of Fit-Up Tolerances for Block	33
Capab for Mall Pick Lists, Marshalling, Kitting	34
Tracking of Piece/Parts Through Fabrication	35
Comm of Staging and Palletizing Reqts to	36
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High Level Development of Build Strategy	40
Order Generation and Tracking	41
Performance Measurement	42
Production Status Tracking and Feedback	43
Inventory Control	44
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Development of Unit Handling Documentation	47
Parts Nesting	48
Dev and Issue Work Orders and Shop Info	49
Material Management	50
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