THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

1990 Ship Production Symposium

Paper No. 1B-1:
Shipyard Modelling -- Approach to Obtain Comprehensive Understanding of Functions and Activities

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

Report Documentation Page

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
AUG 1990	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
The National Shipbuilding Research Program, 1990 Ship Production Symposium, Paper No. 1B-1: Shipyard Modelling -- Approach to Obtain Comprehensive Understanding of Functions and Activities	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Naval Surface Warfare Center CD Code 2230-Design Integration Tools Bldg 192, Room 128 9500 MacArthur Blvd, Bethesda, MD 20817-5700	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

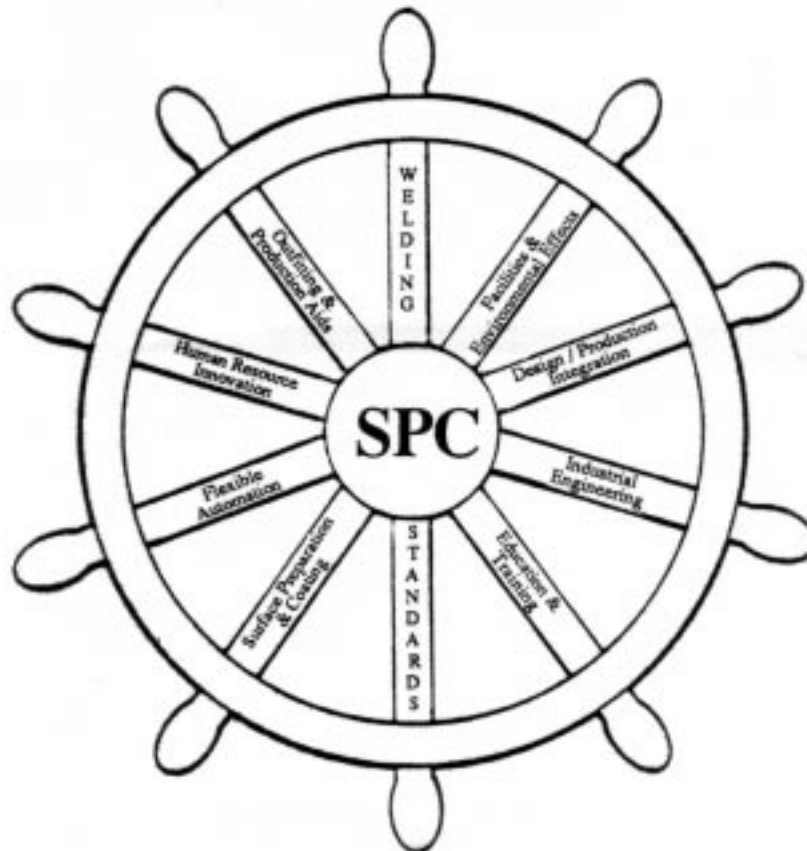| 16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	**SAR**	**21**	
unclassified	**unclassified**	**unclassified**			

DISCLAIMER

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

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM'S

1990 SHIP PRODUCTION SYMPOSIUM

Preparing for the 21st Century: Focusing on Productivity and Quality Management

WELDING

Outfitting & Production Aids

Facilities & Environmental Effects

Human Resource Innovation

Design / Production Integration

SPC

Industrial Engineering

Flexible Automation

Education & Training

Surface Preparation & Coating

STANDARDS

August 22-24, 1990
Pfister Hotel
Milwaukee, Wisconsin

SPONSORED BY THE SHIP PRODUCTION COMMITTEE
AND HOSTED BY THE GREAT LAKES AND RIVERS SECTION OF
THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

S. N. A. M. E.

Shipyard Modelling-Approach to Obtain Comprehensive Understanding of Functions and Activities

1B-1

Joachim Brodda, BREMER VULKAN AG and Bremen Institute of Industrial Technology (BIBA)

NOMENCLATURE

CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CAP	Computer Aided Planning
CASE	Computer Aided Software Engineering
CIM	Computer Integrated Manufacturing
CNC	Computer Numerical Control
DNC	Direct Numerical Control
ERA	Entity Relationship Approach
ESPRIT	European Strategic Programme for Research and Development Information Technology
GRAI	Groupe de Recherche en Automatisation Integriel
ICAM	Integrated Computer Aided Manufacturing
IDEF	ICAM Definition
IT	Information Technology
NIAM	Nijssen Information Analysis Method
NIDDESC	Navy/Industry Digital Data Exchange Specification Committee
PDES	Product Data Exchange Specification
R + D	Research and Development
STEP	Standard for the Exchange of Product Model Data

ABSTRACT

The application of Computer Integrated Manufacure (CIM) to one-of-a-kind heavy engineering industries is one of today's most challenging tasks for the industry and Information Technology (IT) vendors. Because of the complextity of the shipbuilding process, as a typical representative of this kind of Industry, available solutions are not yet satisfactory. Even the basic theory of current CIM sytems does not fit many aspects of requirements for the shipbuilding industry. The application of CIM tools, which are based on ideas of line production and have a strict sequence of all tasks, have very often failed in the past, mainly because of a lack of flexibility. Therefore, basic work needs to be performed, starting with a detailed analysis of today's situation and leading to a careful development for the real requirements of tomorrow. This paper deals with the problems resulting from the exceptional nature of shipbuilding for the application of CIM elements. The approach chosen for modelling of the production process, illustrated by some examples from actual Reseaarch and Development (R+D) projects, is described. An evaluation of the benefit of structured shipyard modelling and a look at complementary R+ D actions concludes the paper.

INTRODUCTION

Heavy industries, concerned with "one-of-a-kind". production, are typically described through combined workshop manufacturing and remote construction site assembly, and have not yet fully benefited in the application and use of modem information technologres.

The design and manufacturing of large multi systems intergrating products (ships, offshore structures, plants, factories) is a complex and long term activity covering a whole range of possible engineering and working activities. The manufacturing, process can be subdivided mainly into three parts: fabrication using standard and non-standard raw materials; the prefabrication of modules, including pre -assembly with other prefabricated or purchased products; and the final outfitting activities. In this complex manufacturing process, all production activities can normally be found at one production site.

The manufacturing process is construction site oriented with its signification cant amounts of specialized workshop production. The typical overlapping of design, planning and manufacturing means that, compared to mass production with line character, there has been a delay in the development of tools for these more complex requirements.

To come to a CIM solution in this kind of industry, a lot of additional basic work is required which can nevertheless be set up based on common standardization of definitions and rules.

Over the past ten years the shipbuilding industry has not been slow in adapting the latest Computer Aided Design (CAD) techniques. Similarly, although the use of numerically controlled (NC) equipment,, e.g. for flame cutting, is commonplace. In this context there is already some computerized intergration of CAD and Computer Aided Manufacturing (CAM). Some links are also existing between CAD and Computer Aided Planning (CAP) and Production Planning and Control (PPC) Systems through the generation and completion of bills of materials.

However, the majority of systems in use are mostly 'island' solutions which are supporting work in special application fields. Below the level of PPC-Systems the information flow is mainly paper based, or on a person-to-person level.

Before starting into the development of ideas for CIM applications, the need for a detailed analysis of the resent situation of one-of-a-kind production in genera and shipbuilding in particular is evident. The analysis should cover different viewpoints of the process, such as manufacturing functions, process planning and control functions, organizational aspects, resources and information links. The use of formalised modelling methods even for analysis purposes provides a good basis for the development of requirement for the future system, i.e. an architectural reference model. This model defines the complete set of functionalities, single activities and interrelations required for the production process. CIM elements and in particular also the remaining manual tasks as intergrated elements can be identified or defined on the basis of this reference model.

Organizational changes, the development of CIM elements, and the specification of interfaces as main element can be prepared. Any changes with respect to the today's situation can be documented.

Models based on common descriptive languages therefore provide a good opportunity for the discussion between system users and system developers. The more complex the task, and the less clear activity sequences are, the more important the use of formalised modelling techniques is. The original shipbuilding process combined with its manifold external dependencies represents a challenging production process to be described.

THE CHARACTER OF SHIPBUILDING

The shipbuilding process has been chosen for a number of principal actions within European R + D. As reference products of one-of-a-kind manufacturing ships provide good opportunities for basic investigations. Compared with mass production, significant differences can be identified as:

-- tremendous influence on design and manufacturing by the customers;

-- complex , complicated and multi-stage production process with high interdependencies;

-- combined manufacturing principles at one site;

-- use of universal equipment;

-- craft skills are of vital importance for the assembly process;

-- long term order throughput;

-- character of products under contract changes;

-- significant overlapping of design, planning and manufacturing;

-- hostile working environments;

-- final product definition only after contract signing possible;

-- decisions with high relevance must be taken on basis of uncertain, stochastic information;

-- product value is very high;

-- order throughput times are very long;

-- product size in volume and weight is very high.

In spite of being incomplete, this list gives some major reasons for the difficulties in the utilization of advanced information technologies for shipbuilding which are originally designed for mass production.

Some of the points will be illustrated in the following.

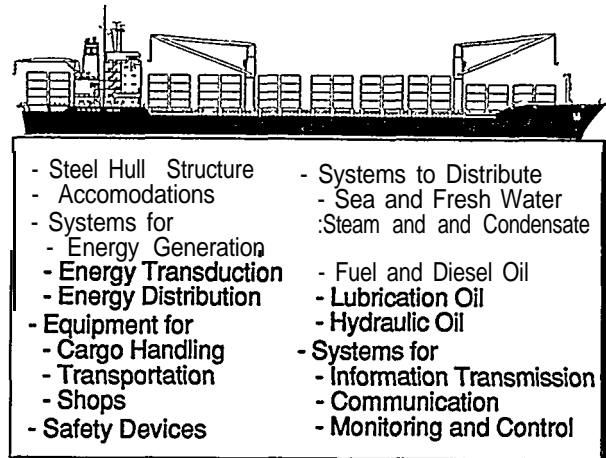| - Steel Hull Structure | - Systems to Distribute |
- Accomodations	- Sea and Fresh Water
- Systems for	:Steam and and Condensate
- Energy Generation	
- Energy Transduction	- Fuel and Diesel Oil
- Energy Distribution	- Lubrication Oil
- Equipment for	- Hydraulic Oil
- Cargo Handling	- Systems for
- Transportation	- Information Transmission
- Shops	- Communication
- Safety Devices	- Monitoring and Control

'Figure 1:   Ships-Multi Systems Products [10]

Ships, as unique and ambitious technical objects, contain numerous and different technical systems (Figure 1). These different systems require a related number of various skills and manufacturing principles. Different types of ships require different loads in typical work trades which can lead to considerably divergent loads. Figure 2 shows an example of the loads for four typical ship types. Depending on the type of shipyard - with high or low level of self-fabrication of parts and components - this also effects the collaboration with subcontracters or suppliers. Even in case of specialization of a few ship types the flexibility of work trades and equipment must be kept. Therefore all facilities of the shipyard have to be designed for the widest range of products allowing nearly the same level of productivity and quality for the different production cases. In this context it is understandable that for shipbuilding all activities working towards an optimisation and integration of designing, planning, manufacturing, and assembly are of vital interest. Especially, methods and tools for planning, monitoring and control of the uncertain process must be a matter of special consideration.

During the preparation of offers for customers the design office must be able to provide information of high accuracy for the calculation of required material, needed resources, different loads of
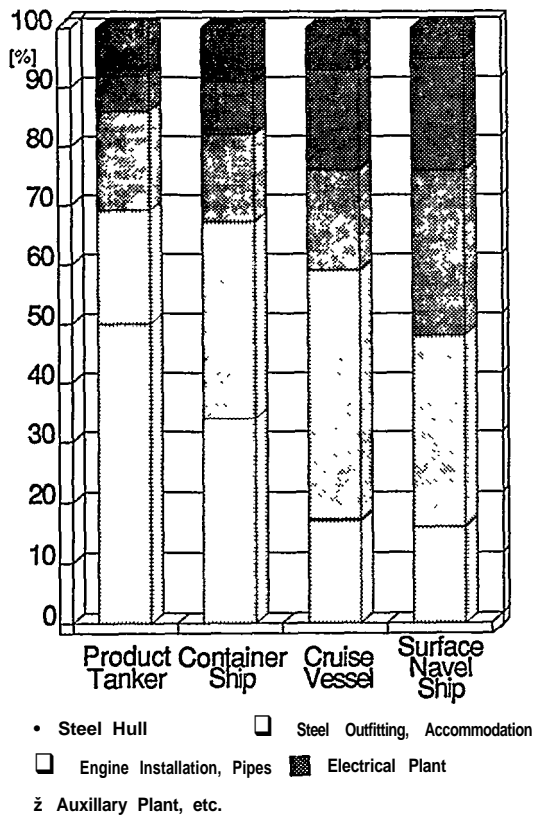
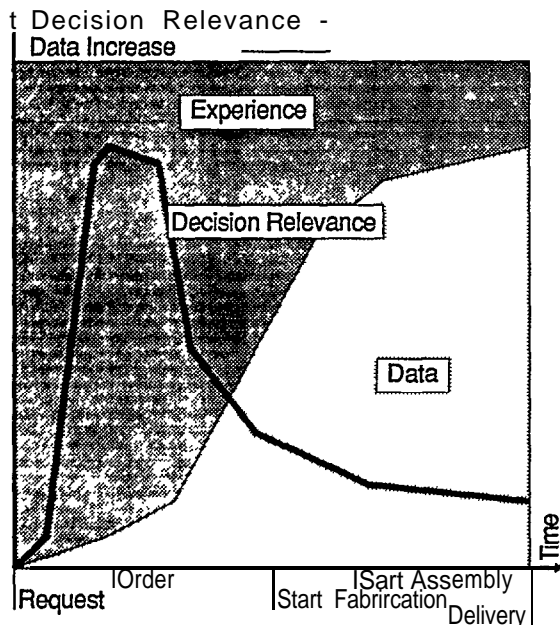Figure 2: Different Ship Types Workload Distribution for Main Work Trades [10]

worktrades and time schedules. In this early stage of a potential order, decisions have to be made on the basis of forecasted figures which are of importance for the whole order throughput time. The preliminary design, without any detailed definition of the product, provides the more or less uncertain basis for those forecasts and decisions. The success or failure of an order for a company therefore depends highly on the skill and knowledge of the decision-making people who compensate for the lack of information in this early stage of a customers request with their experience.

Not only in this initial phase must missing data be compensated for by experience, but even in the production phase, mainly in the assembly process, workers make decisions about construction and design solutions, e.g. the routing of pipes. Therefore, ship, or compareable objects in size and complexity, do not necessarily need a 100% description by data. As long as a certain level of experience can be held at shipyards, the maximum level of data can be limited. Nevertheless, today's situation does not seem satisfactory. Therefore, one of the tasks to be performed is to find out the suitable level of data to be produced by advanced information technologies and the maximum gap to be levelled through human experience in the different stages of the order throughput. Figure 3 illustrates this coherence.

A reason for the need to balance the lack of data through experience can be seen in the significant overlapping of the different order throughput phases. Figure 4 shows this overlapping compared with the situation in mass or series production. Because some
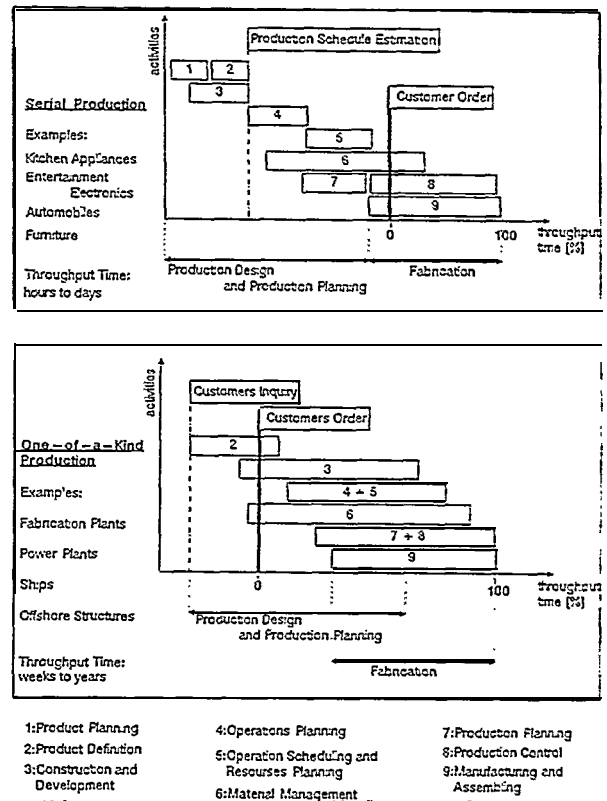

Figure 3: Decision Relevance Compared with Data

Figure 4: Different Overlapping of Main Activities for Serial Production and One-of-a-Kind Production

activites have to start before the required data has been produced, the 'realtime' generation of working instructions such as 'what to do' and 'how to do it' is required. Those working instructions very often are produced by the shop floor responsible without consulting the design office and higher level planning instances. The trust in the self responsibility and experience of these people by the company must be high. In spite of the danger this system naturally contains, advanced organizational principles, highly supported by modern information technologies, should carefully consider this flexibility of today's system as an asset of today, as well for tomorrow. Therefore a future (CIM) system must consider even the human role as an eminent element of the process.

The initial phase of the contract, i.e. the preliminary design, bases all calculations on the functional structure of the ship. The product will be designed from the system point of view. Constructional groupings (e.g. ballast water system) normally are approved structures of the product traditionally grown or tailor made for particular shipyards. This functional view of the system "ship" provides a good structure for different tasks in design and pre-calculations (functional structure). Because of the separate consideration of all constructional groups, resources, loads, and possible due dates, for this potential order can be calculated on this basis and preliminarily mapped into plans, cost centers and financial planning (cost/ quantity structure). Based on manufacturing capabilities and and constraints (e.g. lifting capacities,, space) the ship will be divided into manufacturing specific structure) which provides the backbone for the bills of material for structure and further scheduling purposes (Figure 5).
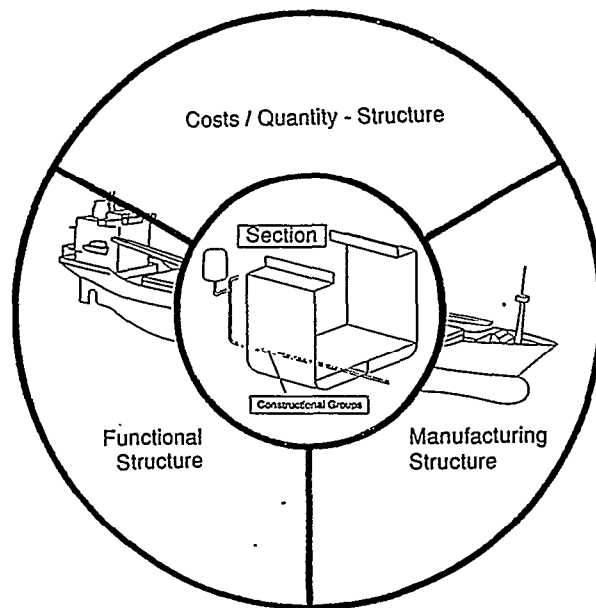

Figure 5:   Threefold view on the Product Ship [BIBA]

Modern ship production techniques, like building big blocks with high quantities of pre-outfitting before assembling the ship within drydocks, defintely need a suitable manufacturing structure. With
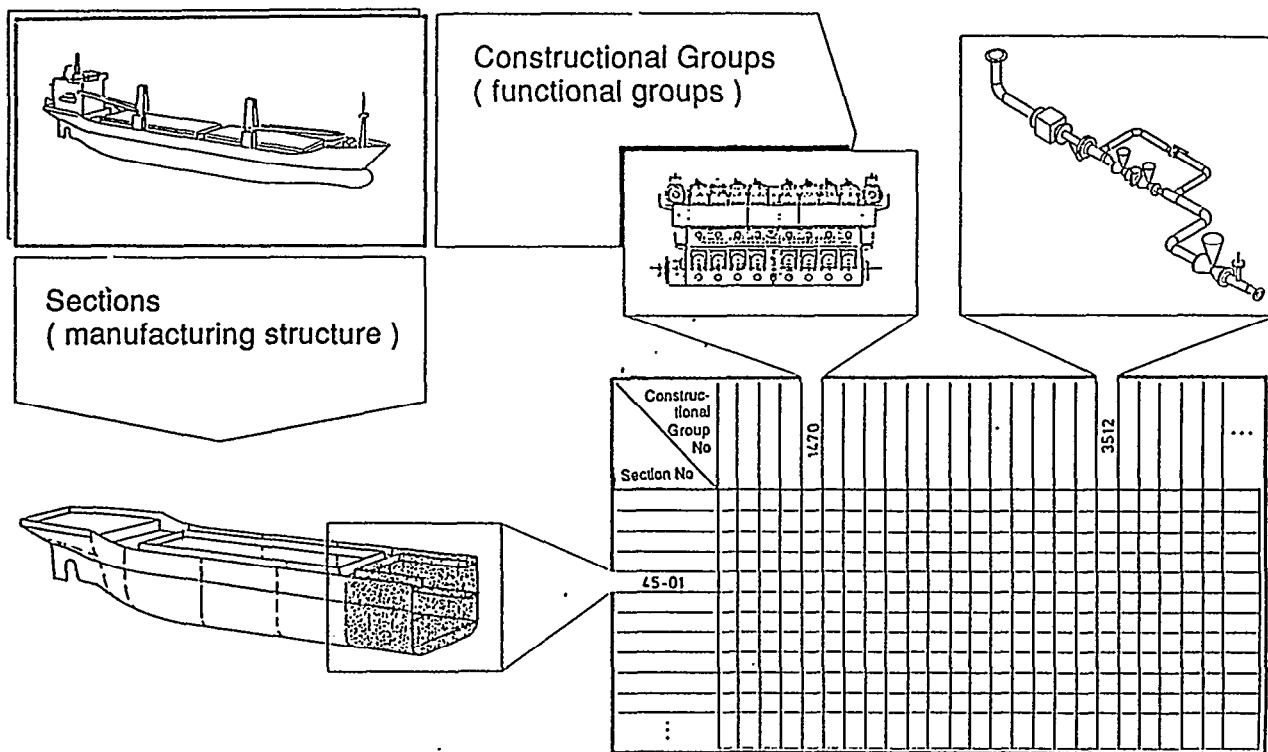

Figure 6:   Integration of Manufacturing Structure and Functional Structure [BIBA]

the ongoing subdivision of the ship body the functional groups must be subdivided similarly and distributed to related blocks and sections (Figure 6). This means the related bills of material, job cards and other planning documents must be merged in a suitable way which creates difficulties for conventional planning methods and tools.

The intention to extend the level of preoutfitting and to reduce the time spent at the final building place by the object makes it more important to think about the right structures and their interlinkages.

The different stages of the shipbuilding process can be subdivided into 7 levels (Figure 7). An additional stage for section or unit conservation should be considered between levels 3/4 or 4/.5. Because of the growing size and weight of the different objects between levels 2/3 there is usually a point during steel assembly where a transition is necessary from "moving product to process" to "moving process to product". Therefore levels 0, 1 and 2 can be performed following workshop production principles. On the other hand, levels 3 to 6 are mainly performed at construction sites. Figure 8 defines the different manufacturing principles. The three main parts of the production system - the working object, the worker and the production equipment - are defined as fixed or movable. In case of construction site manufacturing, the working object is fixed, at least for a certain time. All equipment and workers have to be moved to it. The main shipbuilding processes can be easily identified as belonging to this kind of manufacturing principle. Different pre-fabrication processes for steel and outfitting trades (e.g. pipes, sheet metal, accomodation) can be identified as workshop or even line production oriented processes (Figure 9).

0 = Working Objekt
W = Worker   ○ fixed
P = Production Equipment   ₀ movable

Figure 8:   Definition of Manufacturing Principles

Figure 9:   Assignment of Manufacturing Areas to Manufacturing Principles
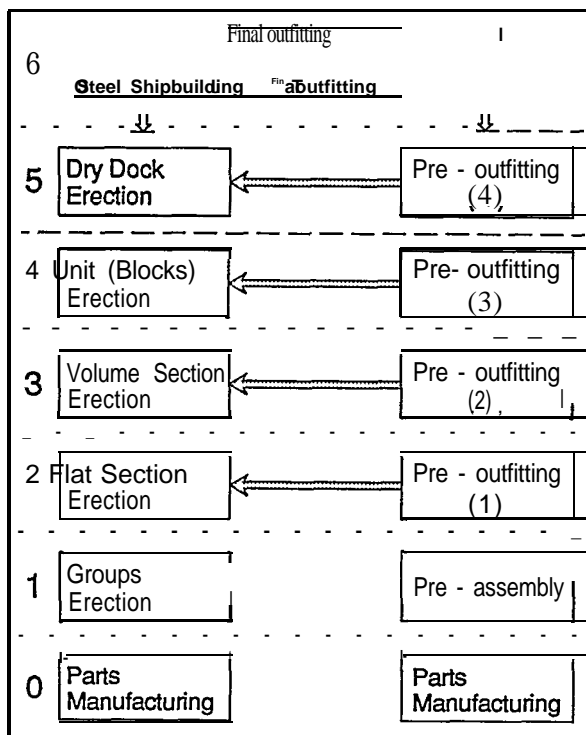
Figure 7:   Levels of the Shipbuilding Process

These workshop or line production oriented tasks accompany the erection/construction site oriented processes throughout the whole construction time. Advanced shipyard concepts try to group those workshops closely around the related outfitting locations. For instance, Bremer Vulkan AG implemented the so called Workshop Oriented Ship Production Technology (WOST) concept which led to significant short cuts and reductions in outfitting costs. The idea was to minimize information links from workshop to the construction site by bringing outfitting intensive blocks under roof, close to the workshops.

This concept was realized for the engine room section and the superstructure. The highly pre-outfitted blocks then can be transferred to the dry dock by a gantry crane. After integrating the blocks into the hull as a final step of ship erection, the ship can be launched immediately.

Nevertheless some major tasks remain on remote construction sites. Because of hostile evironments, uncertain planning basis, unforeseeable changes through late delivery of material or weather influences, the monitoring and control of the production process is relatively difficult. Major reasons for these difficulties can be seen in communication problems of central planning instances with remote working people.

However the described character of the shipbuilding process shows some differences to other industry's. At least it provides some reasons for the need of some exceptional requirements and the need for adapted CIM theories and tools which are not yet satisfactorily provided by scientists and vendors.

MEANING OF CIM FOR SHIPYARDS

The integration of computers into the physical manufacturing process and all related management functions. for heay engineering industries in general and for shipbuilding in particular , is a very challenging task. First the question must be answered what computer integration means for this type of industry. It should be considered that 80% of the working hours or even more today are manual assembly tasks which can't be controlled by NC devices. This number will not significantly change within the near future. Therefore the industry highly de ends on the skill, the self-responsibilty and the flexibility of its working personnel on the shop floor. Many naturally existing deficits in craft manufacturing can be solved through improvements in organization, facilitating, and better support for the handling of material and layout improvements.

Naturally all possibilities for manufacturing automation should be considered. Solutions for the fabrication, e.g. of steel parts, are commonplace. For low level assembly tasks, mainly in the field of welding of subassemblies, some promising tools are available. Nevertheless investments in these tools comprise some difficult calculable risks and require corporate decisions. Beyond the question of how it is useful to mechanize or automate physical manufacturing processes, the generation and use of information for technical and management purposes must be carefully investigated. A process which depends highly on decisions made by experience needs improvements in information provision. Developments in this field are major objectrves of CIM approaches for shipbuilding.

CIM approaches should always be seen as an overall company strategy, giving more answers for "Integration" than just for "Computers" and "Manufacturing". In this context, the definition of clear corporate strategic targets for CIM is a must for every single company. Functions and activities of the manufacturing process have to be considered as having very close and manifold links to all other necessary tasks. This is particularly important to solve the integration aspect of CIM. However, it is essential for CIM to cover the whole range of company manufacturing activities. Partly implemented 'island solutions' or small groups of integrated systems might have improved the productivity of single company departments. However, the benefits of an overaℲℲ integration are greater than those from the sum of 'island solutions'.

The one-of-a-kind nature of the product (ships), including the related special demands for manufacturing process and management, lead to some extended and exceptionel requirements for CIM. Because of individual differences between companies and a relatively small market for IT vendors, combined with complex function for suitable software elements, many of these requirements couldn't be satisfied in the past. The man-machine interfaces are an es ecially imortant factor in the existing craft skilled & dominated industry and will remain so in the future.

Thinking about movements towards CIM or even Computer Integrated Enterprise (CIE) the following field seems to be important in the future.

1. Consequent use of 3D-CAD-systems with complete substitution of physical engineroom models.

2. CAM systems with complex links to CAD for NC path generation and simulation e.g. Computer Numerical Controlled CNC) or Direct Numerical Controlled (DNC) weldingrobots for first to third stage assembly).

3. Integrated Computer Aided Engineering (CAE) and CAD systems allowing stage wise operations planning (for calculation purposes and manufacturing planning).

4. PPC combined with decentralised worktrade oriented control centers to serve three different levels of planning accuracy.

5. Object oriented production progress devices using user friendly data capturing

6. Communication technology for external links and internal fixed, temporary and movable requirements.

7. Neutral data base datastructure, and data base management concepts for product data, factory data and process data.

8. New concepts for data presentation to people in the yard (e.g. in the field of progress monitoring).

9. Knowledge Based Systems (KBS) especially for rescheduling purposes.

The hope for develo ments and improement in all these different IT fieℲls are natural y based on open systems and neutral data storage concepts. In particular, shipbuilding and similar heavy engineering industries will definitely benefit from these approaches. It is doubtful whether individual, temporary or 'closed solutions can ever be gained from one-off product manufacturing.

To ensure that all single applications will fit into the whole CIM infrastructure in the shipyard, an overall CIM strategy must be found. Understanding the enterprise is essential before the future architectures can be developed. Existing system strutures have to be modelled in a compact and comprehensive form. Because of the natural interest to use general approaches it is necessary to think strategically and in long terms. Conventional, manual and intuitive approaches of today are not satisfactory in this context. Especially, the coordination of physical processes with information systems regarding hierarchical communication often exceed human imagination because of their complexity. Therefore, formalized techniques should be applied to analyse existing enterprize functions, information/data structures, organization and resources. The development o f n e w structures leading to a reference model or future CIM applications should be based on the same techniques utilizing existing elements of the original structure. This approach provides a common language for the participating architects, users, experts, non-experts and iT developers from the beginning, and throughout the whole develo ment period. The model also provides a good basis or testing, simulation and cost-benefit-analysis of intended changes compared with the existing system.

The performance of methods and tools to be utilized should further allow mapping the processes globally and on detailed levels. At east the definition, specification and design of soft- and hardware should be supported. A three level approach to come to an implementation specification (Figure 10) follows in principle the particular derivation process of ESPRIT, project 66 ESPRIT is the "European Strategic Programme for Research and Development in Information Technology." The objective of this project was to design an Open System Architecture (OSA) for CIM and to define a set of concepts and rules to facilitate the building of future CIM systems.

The (future) reference model should be defined through careful analysis with transformation of the as IS situation combined transformation and development into an ideal 'should be' scenario. The comparison with possible and available organizational and IT solutions lead, at least through intermediate stages, to an integrated implementation specification. The reference model updated through the implementations taken provides a basis for continued research and definition of an advanced CIM design.

MODELLING APPROACH

Several methods and tools for the different enterprise modelling tasks have been developed in the past. Those tools are often based on Computer Aided Software Engineering (CASE) tools and are utilized for the different modelling tasks. Because of the requirements of shipbuilding, including lots of decisions based on experience, and because of the special interest in the planning and control sector, the EsPRIT Project No. 2439 ROCOCO (Real Time Monitoring and control of construction Site Manufacturing) decided to follow the GRAI (Grou de Recherche en Automatisation Integriel) approach for modelling and methods. The ROCOCO project is lead by Bremer Vulkan AG and involves 4 more major
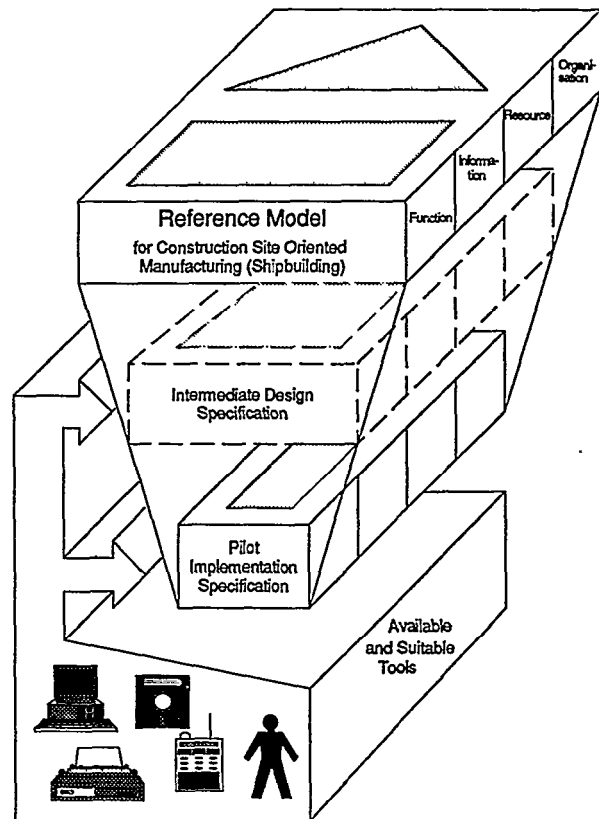
Figure 10:   Three Level Approach for Factory Modelling

European shipyards (Chantiers de L'Atlantique, Fincantieri, Eleusis Shipyard, Masa Yards). At least 11 partners from Europe comprising research institutes, universities and IT vendors beneath the shipyards are forming the consortium.

To provide the basis for the tool development tasks, and as a major part of the project, a reference archrtecture customized to the intended application area must be developed.

Following the GRAI a preach the structured reference model will be subdivided into three sub-sytems (Figure 11). The operational sub-system describes the physical manufacturing (and design) functions and has the role of transforming, raw materials (and design orders) into end-products (and technical data).

The decision sub-system, also called the production and design management sub-system aims, to control the operatronal sub-system in order or reach the economic targets while taking constraints into account (Figure 12) The information sub-system links the two previous sub-systems and aims to supply and memorize the information, restitute and process it. From the various applicable methods and approaches IDEF 0 (see next subchapter) has been choosen for the operation sub-system and GRAI for the decisional sub-system. For the informational sub-system an Entity Relationship Approach (ERA) has to be applied. The

decision for a particular tool for information modelling has not been finally taken. Tests with several tools (e.g. IDEF 1 or the Nijssen Information Analysis Method (NIAM)) in context with other projects are under way.
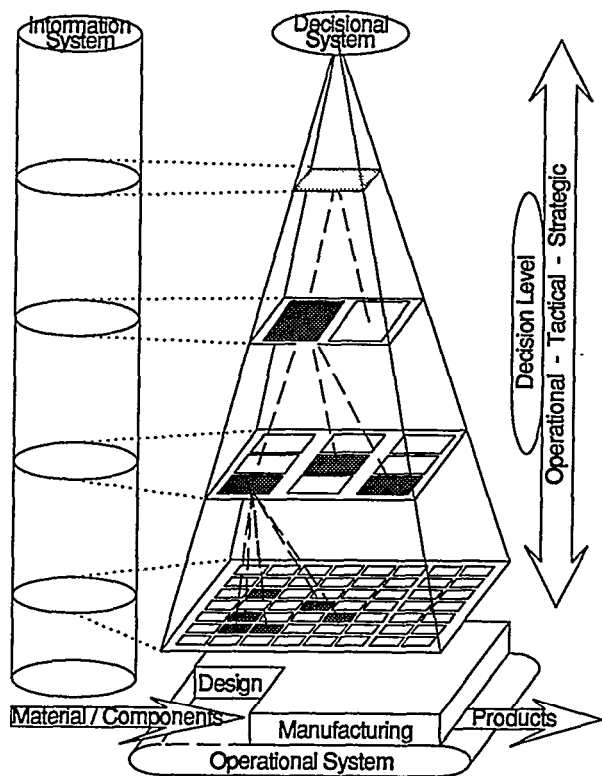
Figure 11:   Reference Model-GRAI Approach [6]
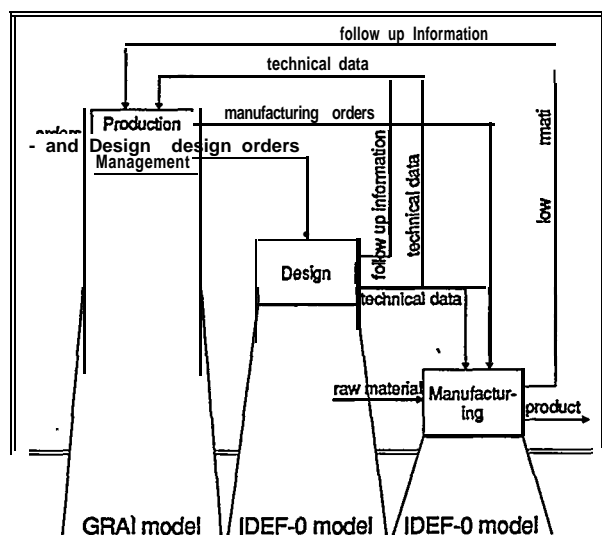
Figure 12:   Assignment of Methods to Sub-Systems

Originally the methodology has its roots in the US Air Force Program for Integrated Computer Aided Manufacturing (ICAM). This program identified the need for better communication and analysis between the people involved in improving manufacturing productivity. To satisfy that need the ICAM program developed the IDEF (ICAM DEFinition) methods to address particular characteristics of manufacturing.

The approach was to use the methods to produce models which would provide a basis for defining where changes to the manufacturing process would result in improvements to manufacturing productivity.

IDEF comprises three modelling methodologies which   graphically characterize manufacturing. IDEF 0 is use   to produce a "functional model", which is a structured representation of the functions of a system and of the information and objects which interrelate those functions. IDEF 1 is used to produce an "information model" which represents the structure and semantics of information within the system. IDEF 2 is used to produce a "dynamic model" which represents the time varying behavioral characteristics of the system.

IDEF 0, which has been applied here,. consists of techniuse   for performing system analysis and a graphical language for applying these techniques. The graphical language is limited to a set of basic components with which the analyst or designer can compose structures of any size. These basic components include boxes and arrows.

The IDEF 0 diagrams in a model are or organized in a hierarchical and modular "top-down" fashion showing the breakdown of the system into its component parts. Application of IDEF 0 starts with the most general or abstract description of the system to be produced. If this description IS contained m a single "module," representedby a box, that box is broken down into a number of more detailed boxes, each of which represents a component part. The component parts are then detailed, each on another diagram. Each part shown on a detail diagram is again broken down, and so forth, until the system is described to any desired level of detail. Lower level diagrams (children), then, are detailed breakdowns of higher level diagrams (parents). The place of each diagram in a model is indicated by a "node-number", derived from the numbering of boxes. The boxes within the diagrams represent functions or activities in the hierarchy named by verbs connected by arrows representing the relationship (objects, information) labeled with nouns.

Figure 13 maps the application of the methodology for the ROCOCO project. Two different diagrams of the same level showing the same activity boxes describe first the material flow and second the information flow. This approach has been chosen for the ROCOCO project to keep the diagrams simpler. The lowest level   diagrams are clear-cut single activities describing all inputs, outputs, controls and resources (material and information related). This gives a complete figure for these single activities and can be considered as kind of generic modelling elements forming the basis for the future definition of other models. A textual explanation diagram behind the original diagram gives the opportunity for additional comments.
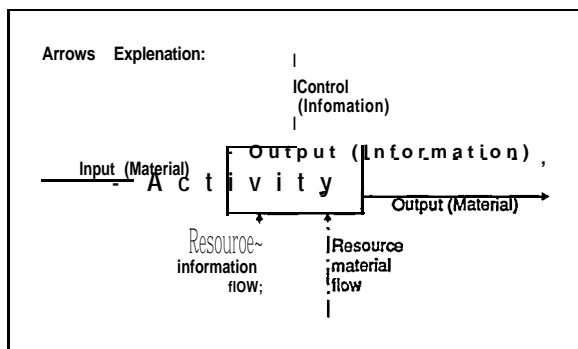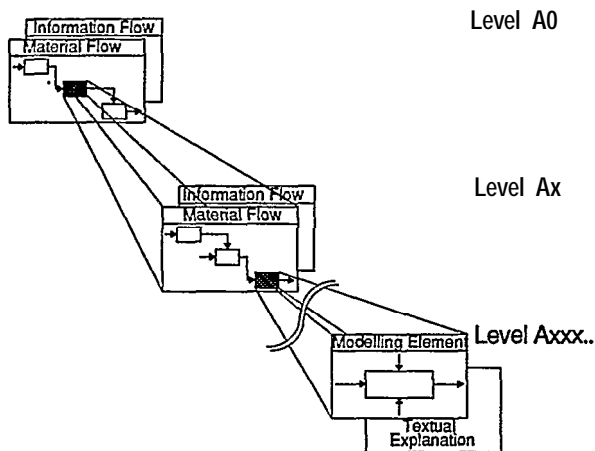
Figure 13:   IDEF 0 - Structure Explanation [6]

Figure 14:   GRAI Method - Structure Explanation
              [V]

GRAI   Methodology

        The GRAI methodology has been developed by
the GRAI Laboratory 0f Bordeaux University/France
for the model considers processes. The GRAl
conceptual   considers a   management
(decisional) system as a hierarchical structure. This
decisional system consists of decision activity centers as
part of the company's management functions. Decision
frames connect different decision activity centers of
different levels. At least three main decision levels are
common and the lowest level corresponds to the real
time shop floor level. Besides the decision frames,
information links ensure information exchanges
between decision activity centers. These elements and
concepts will be combined and realized in a "GRAI
Decision Activity Grid." GRAI Grids give a
hierarchical representation of the whole structure of
decision activities in a Production Management
System. In a matrix format functional criteria are used
     identify production   management functions
(columns). Decision time horizons combined with
decision updating cycles criteria are used to identify
decisional levels (rows). This leads to the definition of
decision time horizons considered for the decision and
a revision period (if any) as a time interval for decision
verification. Decision activity centers as building blocks
*of the Grid, are the intersections of the functional
columns and the time dependent levels.

        Full line arrows within the Grid represent
decision links between different decision activity
centers. In a working production management system a
decision link leads always from a higher level to a
lower level or it is used to connect two centers on the
same level, but never from a lower level to a higher
level. Broken line arrows represent information links
connecting decision centers without restrictions.

        After the most important Decision Activity Grid
two more Grids can be defined. The intersections of
functions and levels in the Information Grid contain
the result of the related decision activity. The Resource
Grid provides information on persons, groups,
departments or tools responsible for the related
decision activity. Therefore it also considers
organizational aspects.

        The decision activity centers of the GRAI Grid
will be decomposed into so called GRAI Nets. GRAI
Nets give a more detailed descrition of the various
activities with the decision activity center. This
description includes the interrelations with other
decision activity centers. Additionally , because of the
importance of decision activities, variables,. objectives,
and rules can be identified and expressed.

        Figures 14 and 15 give some more explanations
on the GRAI methodology as used within the
ROCOCO project. Within this context the following
definitions should be considered:

decision frame   -   constraint for the following decision activity;

decision objective -   aim to be achieved by the decision activity;

decision variables -   variables allowed to be influenced by the decision activity;

decision rules   -   rules to be followed by the decision activity obligatory;

trigger   -   information triggering execution or decision activities;

request   information given on request;

information   -   information given automatically;

address   information address - where from/ where to.
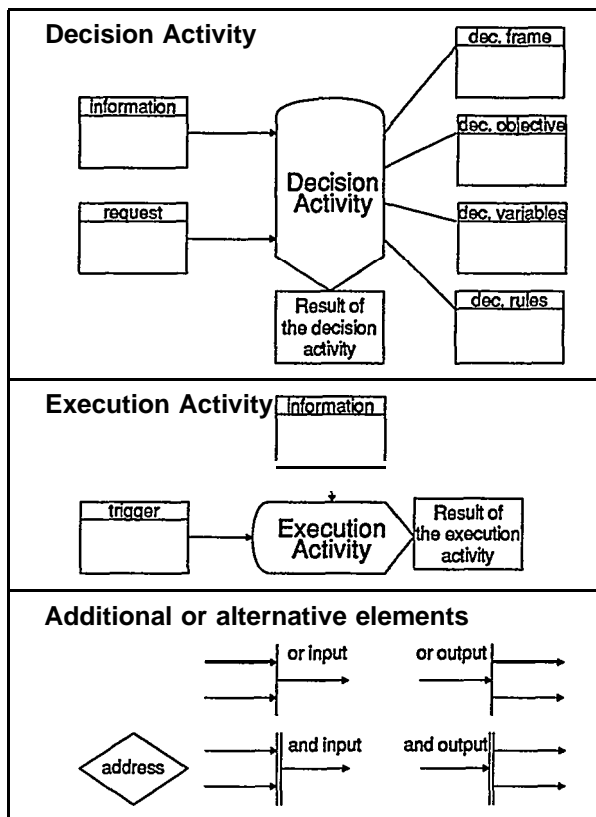
Figure 15:   GRAI Method - Net Elements Explanation [6]

Integrated Methodology

The integration of IDEF 0 and GRAI methodologies follows basically the ideas of ESPRIT Project No. 418 "Open CAM Systems". Even here operational sub-systems, namely the physical manufacturing functions, will be modelled by using the IDEF 0 methodology. The decisional sub-system of the model will be described by the GRAI approach. The principle connection of the two methods is shown in Figure 16. The control arrow is therefore directly or indirectly (via another IDEF 0 box) coming from the GRAI model. The follow up information to the following IDEF 0 box is described with an output arrow. The control and output arrows are labeld with addresses defining the IDEF 0 box/node number or the GRAI Net Reference number.
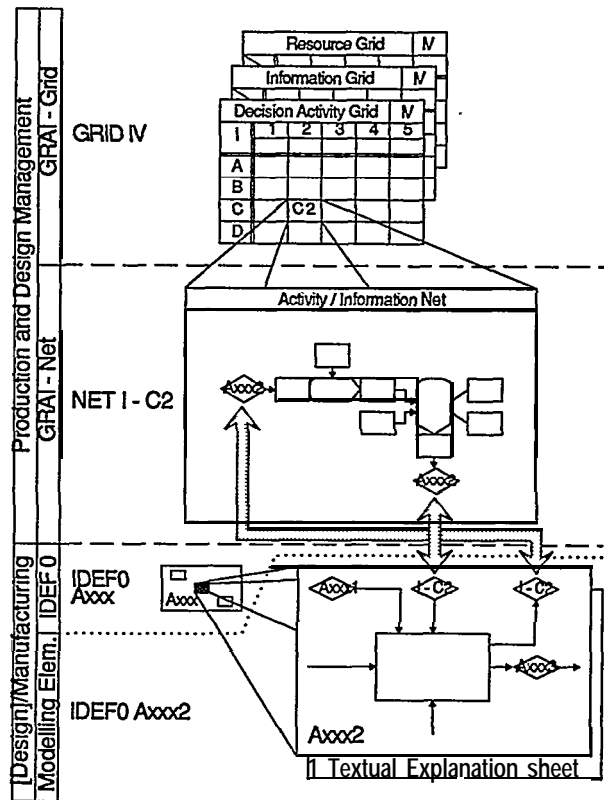
Figure 16:   Linkage of GRAI and IDEF 0 [6]

MANAGEMENT FUNCTIONS MODELLING

The GRAI Grid, developed for one-of-a-kind production management systems, identifies 8 different levels with different management time horizons and periods (Figure 17). Levels A/B/C are for more strategic decisions, levels D/E/F have a more tactical character, and levels G/H should cover the operational tasks. In this context it 1s difficult to define clear figures for horizons and periods for shipbuilding characterized as an unstable production process with many unforeseeable events. Therefore the mentioned can be considered as typical figures, but a r e

Grid I - Centralized Activities

Func-tion H/P	ES External Information	1 Sale Customer Contact	2 Design Quality Planning	3 Purchasing	4 Store Management	5 Operations	6 Time	7 Personnel (Production)	8 Equipment Facilities Workplaces (Production)	9 Personnel (Design)	10 Financial Planning Cost Control	IS Internal Information
One-of-a-kind Production Management System		**Product Management**		**Material Management**		**Planning**		**Resource Management**				**Internal System / Internal Information**
A 10 y / 1 y		marketing corporate product planning						strategic personnel planning	strategic facilities planning	strategic personnel planning	long term financial corporate strategy	
B 5 y / 6 m	y			strategic purchasing planning							strategic finance planning	
C 4 y / event	x y z	evaluation of request, accept orders	specification of product	evaluate ability for purchasing		operations estimation	fictive multi order scheduling	fictive load of main work trade	evaluate required facilities, equipment investments	evaluate required manpower and qualification	evaluation of price quote and financiability	
D 3 y / event [3 m]	y			fix ordering policy, order long lead item		fix budgets (work) for main work trades	multi order scheduling	plan allocation of work to main work trades and sub-contractors	plan investments and allocation of facilities	plan allocation of work to people & subcontractors	fix financing of product	enterprise maintenance and installation
E 2 y / 1 m	x y z	decide technical, financial changes	evaluate technical changes, plan tests and trials	ordering			scheduling for purchasing, design			allocate design work to teams & subcontractors	plan liquidity	
F 1 y / 1 w	x y z	accept quality	plan quality, decide rework	reordering, usage oriented ordering		detailed operations planning	production scheduling	allocate work to specific work trades and sub-contractors	allocate equipment and facilities		cost control	work trades time and attendance
G 1 w / 1 d										dispatch design work to people		
H 1 d / RT			decide on urgent design changes							dispatch urgent design work		

Different Stores and Work trades

x = customer
y = supplier /subcontractor
z = authorities etc.

→ descision frame (contains information relevant for the following decision and a return about the decision making)

– – –▷ Information (needed to carry out decisions, provided automatically or on request)

Figure 17: GRAI Grid Example [6]

IB-1-1

Grid IV - Pipe Installation

		One-of-a-kind Production Management System											Internal System
	Es	1	2	3	4	5	6	7	8	9	10		IS
Func tion	External Information	Product Management		Material Management		Planning		Resource Management					Internal Information
HIP		sale Customer Contact	Quality Planning	Purchasing	Store Management	operations	Time	Personnel (Production)	Equipment Facilities Workplaces	Personnel	Financial Planning		
A 10 y / 1 y													
B 5 y / 6 m													
C 4 y / event													
D 3 y event [3 m]													
E 2 y / 1 m													
F 1 y / 1 w					stock level control	operations planning	production scheduling	allocate to specific work trades and subcontractors	allocate equipment facilities and workplaces				
G 1 w / 1 d					daily balance of delivered material and extracted	complementary operations planning	detailed pipe installation scheduling	dispatch work to teamleaders and subcontractors	allocate workplaces				other work trades time and attendance
H 1 d RT			decide on urgent design changes		incoming material inspection, prepare stock issue		detailed team scheduling	dispatch work to workers,	check workplace occupation				other work trades time and attendance

b descision frame (contains Information relevant for the following decision and a return about the decision making)

x = customer
y = supplier I subcontractor
z = authorities etc.

------▷ Information (needed to carry out decisions, provided automatically or on request)

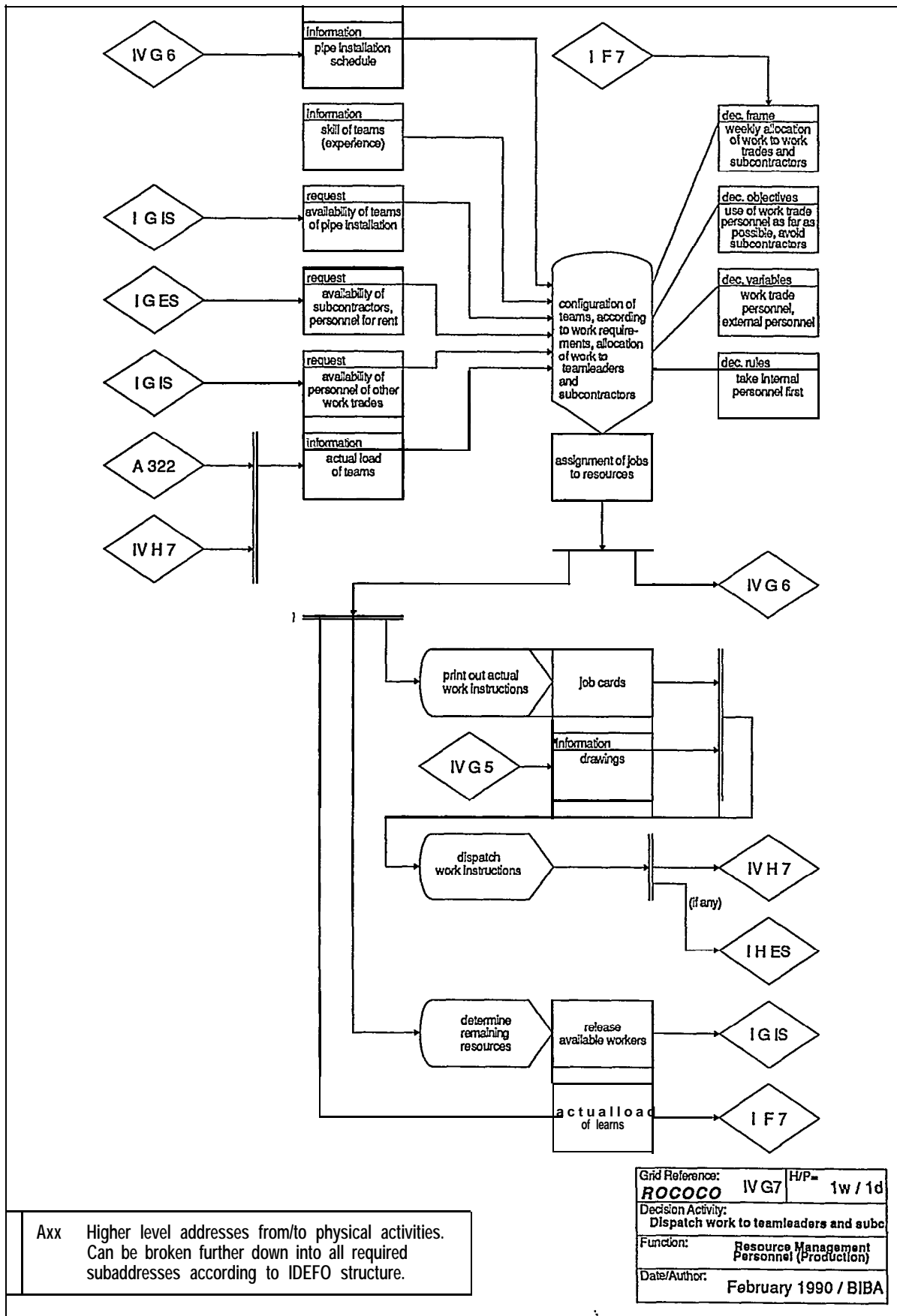Figure 18: GRAI Sub-Grid Example [6]

Figure 19:   GRAI Net Example [6]

very often disturbed by events. The problem is smaller for the low level (operational) planning and resource management activities, i.e. 'nearer' to the physical process.

Four main functions have been considered further, broken down into at least 10 subfunctions (columns). Compared with grids developed for series production, the subfunctions 'customer contact,' 'design. management, 'operations planning,' and 'design personnel management' have to be considered in addition. Even under the other functions several activities have to be mentioned which are of less importance to other industries.

The heavily framed activities in the GRAI Grid are specific for different worktrades, and stores. The decision activity grid for the pipe installation management process (Figure 18), for example, can be overlaid. Combined with another grid for a specific store, a comprehensive grid for one special case occurs. The grid structure is completed through 'shadow' grids comprising the information generated by the activity and the resources responsible for the activity.

The grids should provide a good overview of the most important decision activities. For activity centers of special interest a further detailing through a GRAI Net is required. Figure 19 gives an example related to Grid IV (figure 18), activity coordinates G7. If required, a further break down of the specific decision or execution activity within this Net might be generated.

DESIGN AND MANUFACTURING FUNCTIONS MODELLING

The shipbuilding operational functions have been subdivided into five major subfunctions. Figure 20 shows a part of the IDEF 0 functions and activity breakdowns for outfitting sytems manufacturing

functions. In particular the branch for pipe system related functions has been followed here. Further down, three different functions - running the pipe stockyard, fabricating pipe systems, installing pipe systems - are distinguished. The "pipe system installation" is shown broken down into two more detailed levels, allowing the smallest description of single clear-cut activities (modelling elements).

For the breakdown structure reference No. A 3232, 'To install fabricated pi es,' outlined IDEF 0 diagrams: one for material flow and another for information flow are shown in figure 21 and 22. For example, the presentation of clear- cut activity No. A 32322 is given in figure 23.

MODELLING BENEFITS

Beyond the general benefits already mentioned above under "The need for modelling," modelling actions produce some other positive side-effects for a CIM approach.

An expert team was chosen to represent the key-functions of the company and to describe their working-system from a top-down view throught the analysis phase. One effect of the ensuing discussions was to see the experts learning to recognize and to understand some problems of their colleagues. Because of the 'integration' aspect of the discussion for some of the experts, the consequences of omitted work with no local relevance became more apparent. This is very important for the generation of the future reference model from basically the same team. For the validation of the results proved d through the top-down approach, people in the related lower hierarchical positions, or those having decision responsibilities for single decision activities (GRAI structure), were asked for their view on the working-system. The effect of the involvement of all these people in an analysis and definition procedure is to obtain more acceptance of the approach itself and to limit distrust of future implementation.
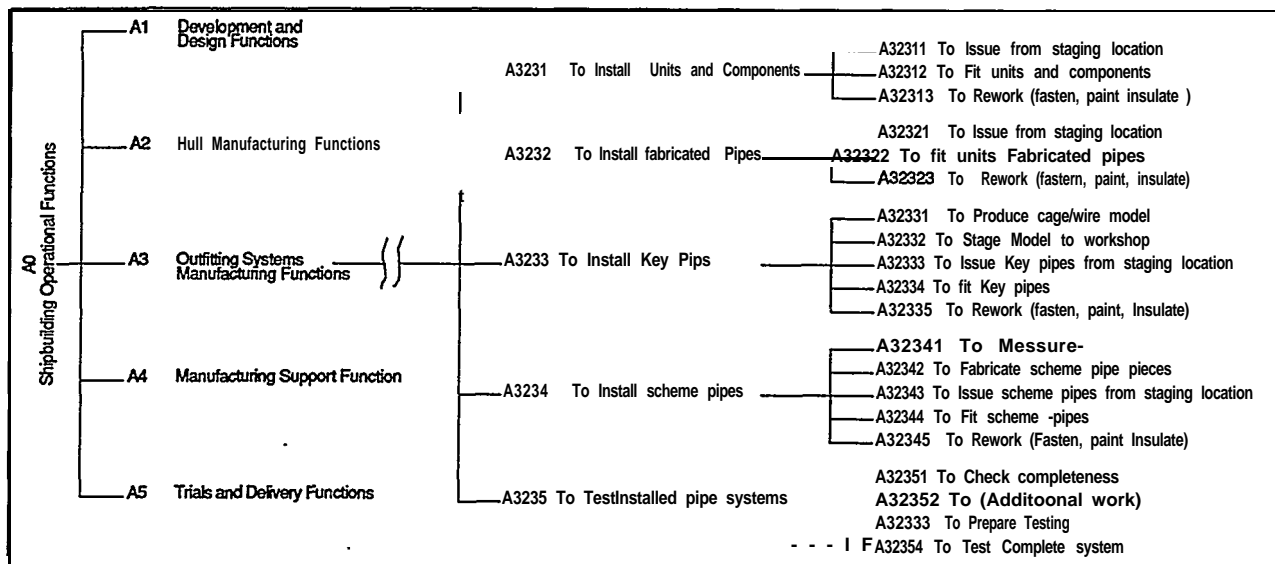
Figure 20: IDEF 0 - Subset of an Exemplary Function and Activity Breakdown Structure [6]

To Extract from Staging Location 1 WOL5

staged fabricated Pipes

extracted fabricated pipes

fittings

craftsmanship

To Fit Fabricated Pipes 2 WOL7

fitted fabricated pipes

rework material

To Rework (Fasten, Paint, Insulate) 3 WOL9

installed fabricated pipes

craftsmanship

craftsmanship

| DDE: A3232 | TITLE: To Install Fabricated Pipes | NUMBER: WOL11 |
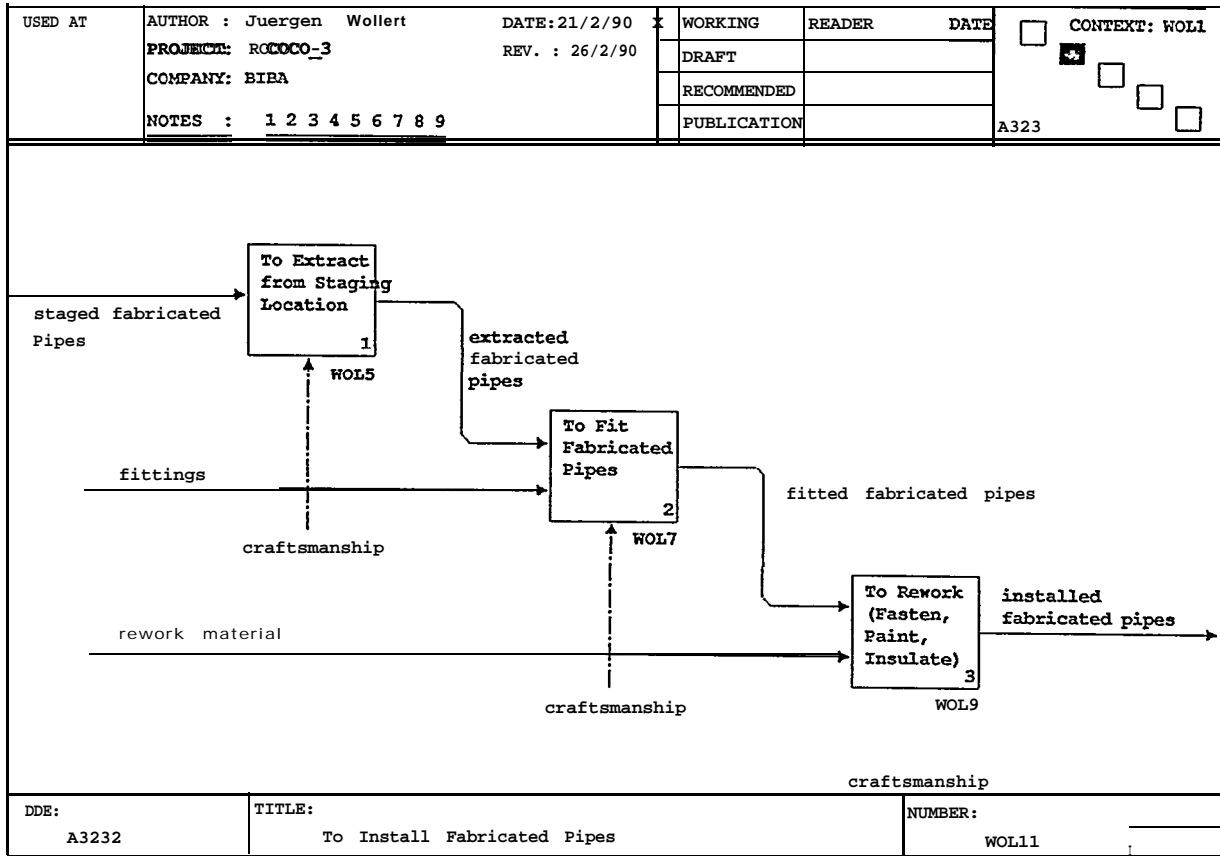
Figure 21:   IDEF 0 Sheet; Example Material Flow

daily workplan

system installation plan

daily fitting plan

daily installation plan

job cards

To Extract from Staging Location 1 WOL13

daily work progress [IV-G6]

worked orders [IV-G5]

worker

i coordinator assistant 'DC-device

To Fit Fabricated Pipes 2 WOL15

daiy work progress [IV-G6]

worked orders [IV-G5]

resource status [IV-G7,H7,H8]

worker

: coordinator :assistant, :DC-device

To Rework (Fasten, Paint, Insulate) 3 WOL17

daily work progress [IV-G6]

worked orders [IV-G5]

resource status [IV-G7,H7,H8]

worker : coordinator assistant, :DC-device

| NODE: A3232F1 | TITLE: To Install Fabricated Pipes (Information Flow) | NUMBER: WOL12 |

Figure 22:   IDEF 0 Sheet;
Example Information Flow

USED AT	AUTHOR : Juergen Wollert DATE:21/2/90	X	WORKING	R E A D E R	CONTEXT: WOL11
	PROJECT: ROCOCO-3 REV.: 27/2/90		DRAFT		
	COMPANY: BIBA		RECOMMENDED		
	NOTES : 1 2 3 4 5 6 7 8 9		PUBLICATION		A3232

```
          | daily          job           system
            fitting      cards           installation
          Plan              I            Plan
             I              I       I
             I              I       I
                            I       I
             ↓              ↓       ↓
        ┌──────────────────────────────────────┐
 issued fabricated pipes ─b│                    │─── daily work progress ---------~
                           │   TO FIT FABRICATED PIPES │─── worked orders -----------+
                           │                    │─── resource status --------c
 fittings ──────────────b│                    │    fitted fabricated pipes
                           │                  1 │
        └──────────────────────────────────────┘
             ⋮          ⋮              ⋮

        worker   : coordinator   craftsmanship
           I     : assistant,
           t     : DC-device      t
           l                      i
                                  i
                                  i
```

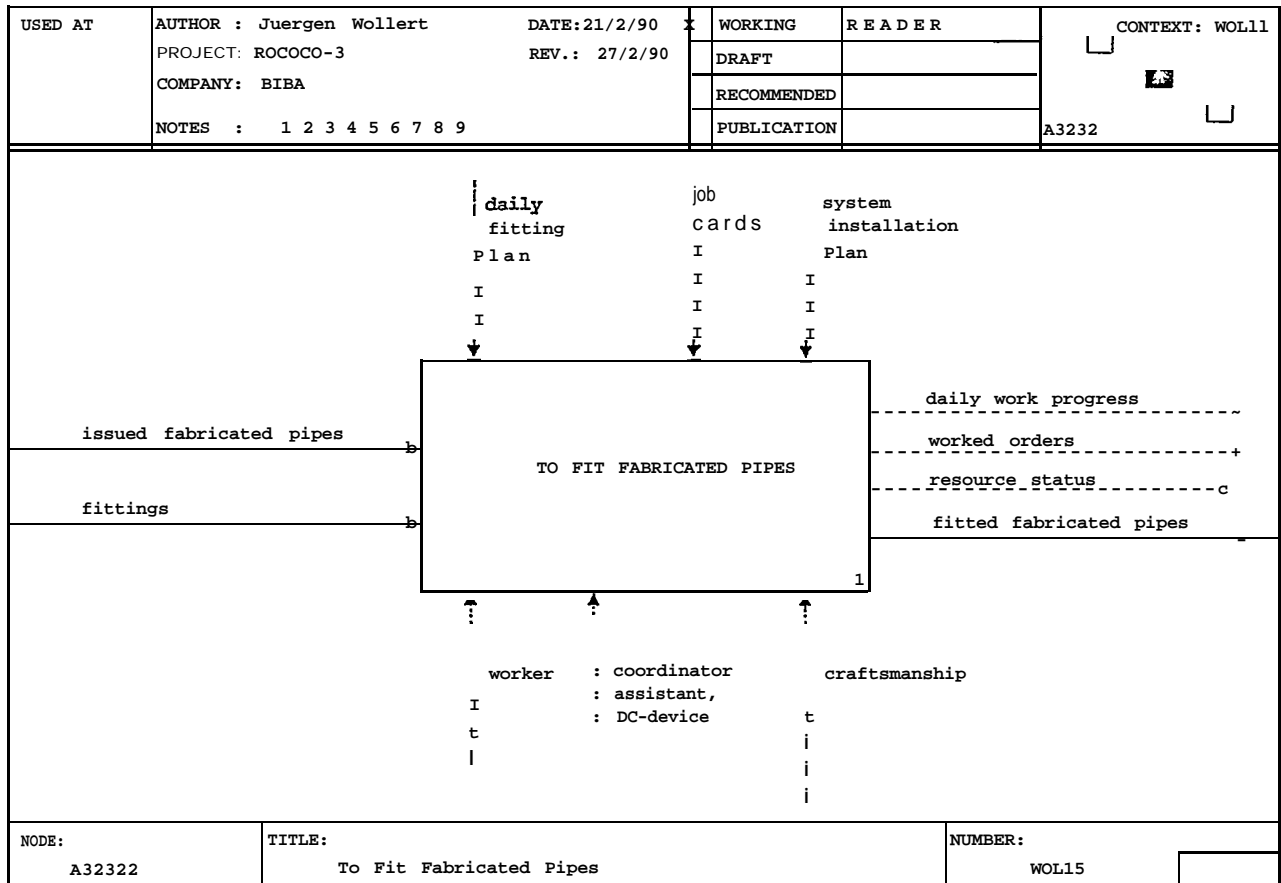| NODE:	TITLE:	NUMBER:
A32322	To Fit Fabricated Pipes	WOL15

Figure 23:   IDEF 0 Sheet; Example
Modelling Element

These analysis should be considered by a company before using external consultant. The formulation of CIM for every single company must be found internally by the company's key personnel. External help should be limited to experts for the formal application of the method or for the development of solutions for specified questions. The initiative should always be taken by the problem owner - the company. Then, modelling approaches keep what they promise and offer their full benefits.

COMPLEMENTARY ACTIONS

The European shipbuilding industry is realizing, more and more, the challenge of CIM. Through the consideration of European R + D programs, the collaboration between major shipyards grows more permanent.

Considering CIM as a threefold problem of:
    functionality of software (CAD, CAM, PPC etc.);

2.   data storage (structure, accessability, data bases etc.); and

3.   communication networks and communication (user) inter-faces;

lots of different projects have recently been launched.

These projects are too numerous to refer to individually. However, two representative projects dealing with modelling in a similar context should be mentioned.

ESPRIT Project Nr. 2010 'NEUTRABAS
(Neutral Product Definition Database for Large Multifunctional Sytems).

The objective of this project is to develop standardized methods for the storage and exchange of data defining shipbuilding and ocean engineering products. The work is based on standardized interface formats such as "Product Data Exchange Specification" (PDES) and "Standard for the Exchange of Product Model Data" (STEP) and will define the principles of application oriented reference models relating to complex maritime products.

It is also expected that the project will provide a valuable contribtuion to international standardization in the area of data exchange technologies. Contacts to other groups such as the Navy/Industry Digital Data Exchange Standards Committee (IDDESC) in the United States have been already established.

ESPRIT Projekt No. 3143 'FOF
(Factory of the Future Production Theory)

The project is dealing with the develop ment of new production philosophies and a designer's workbench for the development of CIM in production systems, especially for 'one-of-a-kind' products. The project is running under the framework of ESPRIT research actions. The consortium comprises 7 well established universities and research institutes. The group feels it necessary to look for alternative ideas to theory of F.W. Taylor. The shortening of product lifecycles and the trend towards individual products makes it necessary to think about more suitable solutions for the future compared with those for mass production. After other effected products (planes, computers), ships play an exemplary role in this project.To understand the real differences in the manufacturing principles of the effected industry and compare these with series production (e.g. automotive industry), it is a goal of the project to model exemplary and comparable production activities utilizing the same methods.

The results, at least generally, promise some answers for principle questions and as well for the applicability of CIM within the shipbuilding industry.

CONCLUSIONS

The utilization of diverse modelling methods and tools to specify the system requirements of CIM for the shiproduction process facilitates understandin the manifold and complex interrelations. Method(s) chosen for a 'common language' to describe the 'as is' and the 'should be' situation are very necessary. As a language understandable for IT experts and matter-experts, modeling can bridge the traditional gap between vendors and users. The results are not Just temporary, but also useful for the documentation of the actual situation, for the evaluation and simulation of future concepts, or suitably computerized to manage the implemented CIM elements. This takes the whole modelling a approach to a new and useful dimension. The modeling work leads at least to a living, functional, and informational, organization and resource model for the company. Even though, the work IS just beginning, results are promising and already of / help.

Through the acceptance and motivation of the modelling team and through improvements in modelling techniques and tools, the modelling approach will definitely lead to benefits for the shipbuilding industry.

ACKNOWLEDGEMENTS

The author wish to express appreciation to all collegues of the ROCOCO project and the Bremen Institute of Industrial Technology (BIBA) for comments and contributions to thus paper. Special thanks go to Jurgen Wollert and Markus Lehne for their advice and to Sieglinde Precht without whose help this paper would not have been possible.

The conclusions and opinions expressed in this pa Paperer are the author's own, and do not necessarily reflect the opinion of any other source.

BIBLIOGRAPHY

1. Barkmeyer, Edward et. al., "An Architecture for Distributed Data Management in Computer Integrated Manufacturing," National Bureau of Standards, Gaithersburg, Maryland 20899, January 1986.
2. Brodda, J., 'EDV-unterstiitzte Stuicklistenverwaltung in der Einzelfertigung," Diplomarbeit 1985, Universit Hannover
3. Bunce, P.G.., 'The Need for Factory Modelling," CIM Europe Conference Proceedinngs edited by CEC DG XIII, 1987
4. Doumeingts, Guy et al., "Design Methodology for Advanced Manufacturing Commuters in Industry 9 (1987) p. 271-296, North Holland
5. "Modelling of Present Situation", ESPRIT Project 2439 (ROCOCO) Report D 11, Consortium Confidential 1989
6. "Preliminary Reference Model", Report D 13, ESPRIT Project 2439 (ROCOCO), Consortium Confidential 1990.
7. 'The Application of CIM to Welded-Fabrication; Industrial Background," "ESPRI'I Project 595, Technical Report - Vol. 1,1989.
8. "The Application of CIM to Welded-Fabrication; Systems Analysis Methodology," ESPRIT Project 595; Technical Report - Vol. 2, 1989
9. 'The Application of CIM to Welded Fabrication; Definition of User Requirements," ESPRIT Projekt 595 ESPRIT Project 595 - Technical Report - Vol. 3,1989.
10. "A Primer on Key Concepts and Purpose of the Open System Architecture for Computer Integrated Manufacturing," ESPRIT Project 688, AMICE & APT, 1987.
11. Kerlen, H., "Methoden und Verfahren der Schiffbaufertigtung - Ziele und Aufgaben fur die 90er Jahre," Jahrbuch STG, Bd. 79,1985.
12. Malloni, J.S.; Nusinow, S., "An Engineering/Manufacturing Enterprise Integrated Information Control System," ICCAS 1985 Conference Proceedings, Shipyard Operation and Ship Design V, EDITED BY P. Banda, C. Kou, G. di Frlippo, North Holland 1985.
13. McLean, Charles R.., "Information Archrtecture of the Automated Manufacturing Research Facility (AMRF)," National Bureau of Standards, Gaithersburg, Maryland 20899,1986.
14. Reed, A.W.; Brodda, J.; Marzi, J., "ROCOCO-Project Overview; in ESPRIT-Section Computer Integrated Manufacturing: Results and Progress of the ESPRIT Projects 1989, edited by CEC DG XIII, November 1989.
15. Roboam, M.; Doumeingts, G.; Zanettin, M., "Study of Manufacturing Systems, Need of Integrated Methodology: in EsPrit '88. Putting the Technology to Use. Part 2, p. 1442 - 1461, edited by CEC DG XIII, Elsevier Science Publishers B.V., 1988.

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

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

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

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