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State-of-the-Art report on:

The Automation and Integration of Production Processes in Shipbuilding

by:

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Glossary

2-D	Two Dimensional
3-D	Three Dimensional
AI	Artificial Intelligence
ANSI	American National Standards Institute
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAP	Computer Aided Planning
CE	Concurrent Engineering
CEPS	Competitive Engineering & Production in Shipbuilding
CESA	Committee of EU Shipbuilders' Associations
CFD	Computational Fluid Dynamics
Cgt	Compensated Gross Tons
CIM	Computer Integrated Manufacturing
CNC	Computerised Numerical Control
COREDES	Committee of R&D in European Shipbuilding
CSG	Constructive Solid Geometry
D	Deliverable Item (plus reference number)
D.xx	Deliverable Item No xx
DB	Data Base
DG	Directorate General
DIN	Deutsches Institut für Normung
DoF	Degree(s) of Freedom
Dwt	Dead weight tons
EC	European Commission
ECU	European Currency Unit
EDM	Electronic Document (or Data) Management
EEA	European Economic Area
EI	Environment Institute
EPD	Electronic Product Definition
ERP	Enterprise Resource Planning
ESPRIT	European Strategic Programme in Research in IT
EU	European Union
FCAW	Flux Cored Arc Welding
FCW	Flux Cored Wire (welding)
FEA	Finite Element Analysis
FP	Framework Program (research)
FSW	Friction Stir Welding
G ..	Giga: a billion units of ..
Gt	Gross tons
HMI	Human-Machine Interface (same as MMI)
HPCN	High Performance Computing and Networking
HTML	Hyper-Text Machine Language
HW	Hardware
ICIMS	Intelligent Control & Integrated Manufacturing Systems
ICT	Information and Communication Tools
IFR	International Federation of Robotics
IGES	Initial Graphics Exchange Specification
IMO	International Maritime Organisation
IPR	Intellectual Property Rights
ISIC	International Standard Industrial Classification
ISIS	Institute for Systems, Informatics and Safety
ISO	International Standards Organisation
IT	Information Technologies
JRC	Joint Research Centre
k ..	Kilo: a thousand units of ..
LAN	Local Area Network
M ..	Mega: a million units of ..

M.xx	Milestone No xx
m.xx	Month No xx from the start of the project
MAG	Metal Active Gas (welding)
MCAW	Metal Core Arc Welding
MIG	Metal Invert Gas (welding)
MIF	Maritime Industries Forum
MMA	Manual Metal Arc (welding)
m-m	Man-month
MRP	Material Requirements Planning
MS	Microsoft
NC	Numerical Control
NFS	Network File System
NIST	National (US) Institute for Standards and Technology
NoE	Network of Excellence
NURBS	Non-Uniform Rational B-Splines
OCR	Optical Character Recognition
OO	Object Oriented
PDM	Product Data Management
PRODIS	Product Development and Innovation in Shipbuilding
QA	Quality Assurance
QC	Quality Control
R&D	Research and Development
RDB	Relational Data Base
RIT	Remote Inspection and Tele-operation
ROBMAR	ROBotics for the MARitime Industry
ROTIS	Remotely Operated Tanker Inspection System
ROV	Remotely Operated Vehicle
RTD	Research & Technological Development
SAW	Submerged Arc Welding
SoA	State of the Art
SS	System Specifications
SW	Software
T ..	Tera: a trillion units of ..
TF-MSF	Task Force "Maritime Systems of the Future"
TPPS	Technology of the Production Processes in Shipbuilding
USA	United States of America
WAN	Wide Area Network
WP	Work Package
WWW	World Wide Web (Internet)

Executive Summary

Maritime sector has been and will continue to be of strategic importance for Europe, due to the nature of its economy, topology, history and tradition [3]. Shipbuilding is a key maritime industry which has contributed significantly to Europe's maritime past and which is strategic for its maritime future. It is also a considerable source of employment. In the global market economy of today, EU shipbuilding and other related industries, in order to stay competitive, are faced with an urgent need for profound changes towards:

- The drastic reduction of the costs and lead times, imposed by the over-capacity in production and the consequent fierce international competition. This need has become even more urgent from the recent events in the Southeast Asia and from the upcoming cease of all subsidies to the EU shipbuilding industry.
- The achievement of a sustainable shipbuilding process, part of a sustainable "quality shipping".
- The assurance of the highest possible quality standards, necessary for a safe and environmentally friendly navigation.

The achievement of these goals requires drastic changes in almost every aspect of the planning, designing, building and maintaining the European commercial fleet.

As what shipbuilding is concerned, the most promising field for the improvement of its overall efficiency is, according to the maritime industries Master Plan [3], [7], production (incl. design) technology. Novel technologies (like laser welding etc), the automation and robotisation as well as the integration of the design and fabrication processes can lead to a much increased productivity and transform shipbuilding from labour intensive to a technology intensive sector.

JRC-ISIS has undertaken the study on "the Automation and Integration of Production Processes in Shipbuilding; State-of-the-art Report" (AIPS), in support to the activities of the DG "Enterprises". The key objectives are:

- To identify the technologies in which investments are likely to be more productive in increasing the competitiveness of the European shipyards.
- To identify the actions and measures that are more appropriate in order to enhance the necessary R&D efforts.
- To identify sectors from which shipbuilding can profit in terms of technology transfer and the actions that would help developing the necessary synergies.

Traditionally, shipbuilding has been identified with those operations and processes related with the transformation of sheet metal to steel hulls. These operations essentially consisted in marking and cutting the sheet metal prime material in elementary building pieces the assembly of which, in various stages (panels, sub-blocks, blocks, sections), finally yielded the complete steel hull. Thus, three basic classes of processes could be distinguished:

- Sheet (or profile) metal treatment processes
- Fitting and assembling (nowadays mostly by welding)
- Handling (moving and positioning the various blocks and sub-assemblies)

Maximising the efficiency of shipbuilding essentially meant:

- Assuring the most cost-effective acquisition of the necessary prime materials and components,
- Optimising each one of the processes stated above and
- Planning the whole sequence of operations in such a way so as to ensure a seamless flow of material and an optimal utilisation of the available resources

Automation in shipbuilding has been applied almost exclusively in steel construction, in particular in cutting and welding. Nevertheless, especially in what concerns most of the big European yards, the relative importance of the steel shaping and assembling has decreased substantially. Shipbuilding nowadays encompasses a range of

processes and activities much broader than shaping and assembling sheet metal steel. Activities, such as finishing and outfitting become increasingly important.

In what concerns steelwork, new cutting and welding technologies (i.e. laser welding) look promising in assuring high quality even when large deck areas are constructed from thin plates or sandwich panels. Their introduction nevertheless requires radical re-thinking of the whole steelwork chain.

The role of CAD/CAE has traditionally been that of enhancing the various phases of the design process and assuring shorter lead times to the planning and the start of the production activities. Nowadays, in view of the increasing complexity of the production operations and, consequently, the planning requirements and the stringent lead times to market, CAD/CAE tools are rapidly acquiring the role of the integrator between the 'traditional' design phases the planning and production processes.

The first parts of the steel production, that is marking, cutting, conditioning and assembling the steel plates and profiles into 2D blocks, are done today with very small manning and it is unlikely that any considerable gains are achieved through further research. On the contrary, the problems in welding of 3D block assemblies are quite extensive, because the structures are complicated, and the repeatability of the structures is very low. The production is more one-of-a-kind type than serial or similar. Although some shipyards have advanced robotized systems, the mechanisation of welding processes seems more attractive than automation, due the considerably lower investment costs. The same holds true for the pre-erection and erection phases. The need for massive investments in novel "intelligent" systems for automating such one-of-a-kind operations cannot be justified by the meagre gains in terms of overall productivity. As the European shipyards tend to build more outfitting intensive ships, more effort and research in steelwork automation is not likely to be of high priority. Even where the automation technology exists, it is not necessarily economical considering the high investment costs.

Steel construction apart, the degree of automation of the other processes is from non-existent to very limited. The major area for automation in the outfitting is the pipe workshop. High degree of prefabrication means that major part of pipes is being manufactured in workshops. Bending of pipes and welding of flanges can be automated with relatively small effort and this has been already done to some extent. Good planning and efficient design – production integration is needed in order to maximise pipe pre-fabrication.

In the other areas of outfitting automation is not an easy task, although the advantages to be derived could be significant. Standardisation and modularisation of ship systems, integration and good planning rather than automation are regarded as the ways to increase productivity in outfitting, possibly through subcontracted activities.

The main reason for which the largest part of shipbuilding processes are not yet automated lies in the very nature of the shipbuilding operations coupled with the fact that the robotic market has been almost entirely dominated and tailored to the large volume automotive and commodities industry. In fact:

1. Almost none of the shipbuilding operations are exactly repeatable; at best they are similar. Many operations are performed only once or at most a very limited number of times.
2. Many of them, especially the assembly operations, involve very important payloads, in terms of mass, volume and cost. The accessibility can also be quite difficult.

These two facts mark a clear cut with the robotics and automation technologies as applied in the large production volume industries like automotive or commodities manufacturing.

In such conditions (i.e. one-of-a-kind operations), the most important performance criteria of a manipulating robotic system are the ease of path planning and the operational flexibility. Autonomy in the execution of certain tasks is a must for ensuring the above stated characteristics.

Integration of the right sensorial information in a supervisory control type scheme can permit the autonomous execution of many low-level tasks with two important consequences:

- (a) The human operators of robotic manipulators could be concentrated in high level activities (such as planning and supervision) instead of performing low level tasks (such as collision avoidance, precision positioning etc).
- (b) "Small" variations in the work-pieces or in the working environment could be dealt without any need of reprogramming off-line automated or robotised facilities.

The low-level tasks that could be executed autonomously include:

- Obstacle avoidance;
- Adapt to the execution of "similar", not exactly repetitive operations;
- Corrections for work-piece or workspace "inaccuracies"

Task autonomy cannot be achieved but through novel "intelligent" control schemes integrating sensorial systems. It implies the use of data fusion, hard real time computing, autonomous mission execution etc., techniques that are far from being established in the environment of manufacturing or engineering industries (see next paragraph) but are used extensively in some military, deep-sea, space and other "high tech" applications. Specially in heavy robotics, when manipulating large and heavy loads, new tracking techniques compensating or bypassing the inevitable mechanical inaccuracies are required for reliable precision positioning and handling.

An additional factor to consider is that most heavy robotics/handling installations in shipbuilding and other heavy industries are tailored made, often by the final user himself. This prohibits the amortisation of the cost for the introduction of technologies such as stated above. The already high development cost is further augmented because of the inherent safety and reliability requirements implying extensive testing and validation procedures and the big and expensive experimental facilities needed for the experimental demonstration, testing and validation procedures.

For all these reasons, at short term, the margin for improvements in productivity through R&D investments the robotisation / automation of the shipbuilding production processes is very small, especially at individual shipyard level. On the contrary, at long term, a strategic R&D plan should be formulated permitting the introduction of all the necessary technologies for the efficient robotisation / automation of the one-of-a-kind operations in shipbuilding and in other heavy industries.

Prior to construction, every vessel must be designed, the construction operations must be planned, the automated machines must be programmed and the timely delivery of prime materials and equipment must be assured. These activities involve the generation and manipulation of enormous amounts of information. The availability of potent information and communication tools has increased significantly the amount of information to be "managed". Maintenance of consistent and updated information as well as a seamless information flow across the shipbuilding activities are vital for the efficient realisation of each shipbuilding project. The extreme diversity, in terms of contents, users, use and forms, of the information necessary for the various design and production stages make this task quite a difficult one.

A particularity of the shipyards, in relation to other engineering industries, is the fact that it is quite seldom that the machines, assembly lines or workshops will have to produce exactly the same work piece. Virtually every vessel constructed, even if from the same series, differs somewhat from each other.

An additional complication is that even when the nominal geometry of two or more blocks are the same, due to thermal distortions, actual geometry may vary quite a bit. Besides the particular assembling or machining problems this might cause, this gives rise to a problem relative to the gradual deterioration of the model(s) of the vessel assemblies or sub-assemblies, relative to the actual situation. One way to deal with the problem is to perform extensive shrinkage calculations and update the

CAD models with frequent measurements. Nevertheless, this is not always as simple as it might seem.

Up till some years ago, the shipyards have been largely self sufficient in all disciplines of shipbuilding. All the steel work, outfitting work and even the machining work has been made mainly by the yard's own personnel. Occasional work subcontracting has been necessary to even out the peak loads, but this has been minor part and done normally under shipyard's supervision.

However, workload distribution among various disciplines can vary significantly in different ship types. The ever-increasing importance and complexity of the outfitting work requires many specially trained personnel for limited periods of time whose handling is, for the shipyard, difficult and not cost effective. Hence, most advanced shipyards have moved to using extensively subcontractors. These are not contracted only on a time base but also as suppliers capable of turnkey systems deliveries. Examples are that of the HVAC systems and the prefabricated cabins. Production of the cabins is happening at the factory, where it can be standardised in close resemblance to a series production. This gives also possibilities for a certain level of automation.

Standardisation and modularisation of ship systems and subassemblies is seen today as the key to rationalise production, shift work out of the ship in the workshops, where it can be performed in a more comfortable and controlled environment.

Today, experts speak about "assembly" yards, where the shipyard has the sole role of assembling the hull and perform selected parts of the outfitting. This development makes the integration process much more difficult than it would have been in a case where everything was done inside the yard. On the other hand, successful completion of ship project with extensive subcontracting sets new challenges for the standardisation and integration of the processes.

The operational principle of the assembly yard sets special requirements to the integration of processes. The design and production is not happening anymore in the limited area inside the shipyard fences. Instead the work can be done far away from the yard even in other countries.

The shipyard is de-facto the coordinating body for all these activities. This means efficient flow of vast amount of information in all its forms to all the users, as indicated in the paragraphs above. Even more important, the distributed and in a variety of different formats information must be kept constantly concise and updated.

Most shipyards today are conscious that, at short-medium term, the best way to increase their productivity is through an efficient production planning and a rationalisation of all the production and design processes. They are also conscious that these goals cannot be achieved but through integration, making the maximum out of modern information and communication tools.

In fact most large shipyards use large common databases; they have PCs and workstations connected by LANs and have good Internet connections to many of their suppliers or subcontractors. Their CAD system is connected and can download data to cutting machines and T-beam stations. Nevertheless, CAD/CAE tools are still being seen mainly as design tools that, occasionally, provide data to CIM systems, logistics, planning departments and subcontractors. Instead CAD/CAE tools need to be seen mainly as the integrating backbone of each shipbuilding project. Although some timid steps have been taken towards that direction, there is a lot to be done yet.

Conclusions:

The shipping world is relatively conservative in technology thinking. The investments, be it for ordering a ship or purchasing new production technology, are considerable and everybody tries to minimise the economical risks. However, the major EU shipyards have taken up the challenge imposed by the modern global market

economy and the particular shipbuilding market situation of today and are changing fast.

Very high level of automation as such is not of the highest priority in the development list of the shipyards. The nature of shipbuilding, which is one-of-a-type production with few series-production features, makes efficient and cost-effective automation difficult. The diminishing portion of steel construction, which is technically the easiest target for automation, makes investments on further automation even more questionable.

Outfitting work is still at the beginning of the automation process. Here, it is the sub-contractors that are likely to develop new production technologies. Automation is likely to be developed for workshop or subcontracted activities.

At short-medium term, the major productivity gains in EU shipbuilding can be achieved through rationalisation of work phases, good planning and integration rather than automation. The concepts of *product model* and *process simulation* can serve as a backbone for the integration of new construction strategies (standardised components, modular outfitting etc), of highly concurrent engineering and production, methods and of efficient supply chain management tools.

At long term, basic and long-term R&D should be encouraged in order to permit the introduction of all the necessary technologies for the efficient robotisation / automation of the one-of-a-kind operations in shipbuilding, construction and other heavy "one-of-a-kind" industries.

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1 Introduction

1.1 Origins of the AIPS study

Maritime sector has been and will continue to be of strategic importance for Europe, due to the nature of its economy, topology, history and tradition [3]. Shipbuilding is a key maritime industry which has contributed significantly to Europe's maritime past and which is strategic for its maritime future. It is also a considerable source of employment.

Nevertheless, in the global market economy of today, EU shipbuilding and other related industries, in order to stay competitive, are faced with an urgent need for profound changes. The ultimate goals are:

- The drastic reduction of the costs and lead times, imposed by the over-capacity in production and the consequent fierce international competition. This need has become even more urgent from the recent events in the Southeast Asia and from the upcoming cease of all subsidies to the EU shipbuilding industry.
- The achievement of a sustainable shipbuilding process, part of a sustainable "quality shipping".
- The assurance of the highest possible quality standards, necessary for a safe and environmentally friendly navigation.

The enlargement of the Union with five new member states, some of which have a considerable shipbuilding industry, is another factor to be considered.

1.2 Scope of the AIPS study

The purpose of the present state-of-the-art study is:

An overview of the technology of the production processes used in shipbuilding (TPPS), more in particular related to their automation and their integration, in view of a competitive and sustainable European shipbuilding industry.

The key objectives of this report are:

- To identify the technologies in which investments are likely to be more productive in increasing the competitiveness of the European shipyards.
- To identify the actions and measures that are more appropriate in order to enhance the necessary R&D efforts.
- To identify sectors from which shipbuilding can profit in terms of Technology Transfer and the actions that would help developing the necessary synergies.

The study moves along two main lines:

1. State-of-the-art in shipbuilding technology
2. State-of-the-art in related R&D

As requested in the invitation to tender, the report addresses all the activities related to the construction of the vessel as well as its main components (hull, propulsion etc). Some indicative topics on which the study focuses are:

- Computer Aided Design and Engineering
- Computer Integrated Manufacturing
- Automation and mechanisation of production
- Integration of the shipbuilding processes
- Heavy robotics & handling
- Novel cutting and welding technologies
- Component and system modularisation
- Influence of novel vessel designs to shipbuilding
- Employment issues
- Environmental issues
- Safety issues

It encompasses all the EU countries plus some of the new member states and, wherever possible, provides information on US, Japan, Korea and China.

1.3 Implementation method

The methodology with which the AIPS study has been conducted is summarised as follows:

1. The current shipbuilding methods, techniques and practices were outlined
2. A comprehensive, qualitative breakdown of shipbuilding (including design, planning, management, etc.) has been performed.
3. Out of the experience of the contributors to this study and consultations with various relevant professional bodies a list of organisations and/or persons playing a major role in at least one of the items (technologies, techniques, activities) above were identified, covering as completely as possible the above-mentioned breakdown structure.
4. Surveys of the organisations identified above were performed. They included visits on-site and/or interviews with relevant personnel. Although no unified questionnaires or forms were compiled during or following these visits and/or interviews, "survey guidelines" were issued. A list of the shipyards and other organisations surveyed is given in Annex A.2.
5. Following these surveys as well as other relevant literature and web searches, each AIPS contributor submitted a report on its pre-defined area of responsibility (see [2]).
6. Finally, the results of the surveys were synthesised in a concise report (present document) meeting the objectives of the study.

The surveys have covered the four distinct groups, which have been identified as the main groups of *players* in shipbuilding technologies:

1. The 'demand' part: organisations performing, supervising or managing shipbuilding operations
2. The 'supply' part: industries and companies, suppliers of equipment, services and technology
3. The 'regulatory' part: IMO, classification societies, flag etc.
4. The R&D part: laboratories, universities and other R&D performers working in fields related to or of strong potential interest to shipbuilding

The approach and the method of survey for each of these target groups has been distinct, reflecting their particularities.

Events (meetings, workshops etc.) related to shipbuilding or other related sectors have been exploited as well as the structure and the events of the ROBMAR [6], CEPS [8], PRODIS [31] and other related networks. In particular, work done in the frame of the CEPS and PRODIS networks on the state-of-the-art in Engineering and Production and on Product Development tools has not been duplicated but, where applicable, it has been included in the present study.

A particular mention should be made to the CESA Working Group on Co-operation (see Annex A.5), which allowed the participation of F.Andritsos at the meetings and visits of the group and provided to the AIPS study all the material collected and compiled by the group in a "Production Technologies Catalogue".

As what R&D is concerned, the main source of information was the study by BMT and other partners on behalf of DG III (now DG ENTERPRISE) on the current EU member states RTD activities with reference to shipbuilding (including marine equipment, shipping and marine resources), the final report [29] of which was issued in February 2000. An additional source of information has been the direct experience of many of the AIPS contributors on many relevant R&D projects.

It has been to our intention to co-operate closely with DG ENTERPRISE E.6, having frequent meetings, answering any particular demands as they are raised and re-directing the study in real-time, if required.

The implementation of the AIPS study has been divided in four main tasks as follows:

- #1 Detailed work-plan for the study
- #2 Outline of the current shipbuilding methods, processes & practices
- #3 Outline of the current R&D effort for technologies associated with the automation and integration of key shipbuilding processes
- #4 Synthesis and conclusions

Following the AIPS proposal, the detailed plan for the AIPS study [2] had foreseen the following activities:

- (i) Perform a first, qualitative breakdown of shipbuilding.
- (ii) Identify the activities (or clusters of activities) that are of major interest for the present study.
- (iii) Identify those organisations/persons that will give a major contribution to the survey, possibly through contracts with JRC. Specify the contribution of each contributor / contractor.
- (iv) Formulate the questionnaires for each of the 'target' types of the survey.
- (v) Perform the surveys
- (vi) Analyse the results and synthesise the conclusions in a concise document

Following the initial work done in the frame of task #1, we realised that, during the last years, there have been a significant numbers of inquiries, surveys and statistics on shipbuilding. Most of these, either as results or as raw data, have been made available to AIPS. So, further surveys through questionnaires or forms to be compiled were judged unnecessary.

It has been decided, rather than just providing yet another compilation of tables and statistics, to take advantage of the surveys as well as of the existing data, the experience of the contributors to the AIPS study and the valuable contribution of relevant thematic networks and associations and try to analyse and answer directly the main questions at which the AIPS study aims at (as listed in section 1.2 above).

In performing the planning of the study care has been taken so as to cover:

- All regions of interest (i.e. EU regions, new member-states, etc)
- All basic types of technology and equipment relative to shipbuilding (i.e. welding, cutting, handling, IT, etc)
- All fields of R&D directly related to shipbuilding (i.e. new materials, laser welding, etc).
- All activities related to shipbuilding operations (i.e. construction, planning, management etc)

1.4 Report structure

Essentially, the object of the present study can be broken down to:

- The automation of each of the generic shipbuilding processes (including design, planning etc.);
- The integration, mainly through appropriate CAD/CAE tools of the design, planning and production processes;
- The R&D relative to the core technologies relative to the automation of each production / design process and to their integration.

The present state-of-the-art report is structured as follows:

The section 2 below gives a brief definition of the main terms used in the rest of the report.

Section 3 deals with the context of the AIPS study. It intends to give an overview of the main generic arguments (shipbuilding processes, robotics & automation, CAD/CAM/CIM) of the present study in their context, trace the interrelations and delineate their potential as well as their limitations.

Section 4 deals with the generic shipbuilding process. It presents the shipbuilding process breakdown structure as well as the information flow diagram. It presents some typical shipyard layouts and tries to outline the inter-relations of the various processes and production phases.

Section 5 deals with the state-of-the-art and/or best practices of each of the production processes as identified in section 4, in respect to their robotisation / automation. In particular, it tries to identify the owners and users of these state-of-the-art technologies or techniques.

Section 6 deals with the state-of-the-art and/or best practices in design, production planning and logistics.

Section 7 deals with integration of the various production processes through the use of computerised tools. More in particular it addresses the issue of interfacing and integrating the various CAD/CAE to the CIM and logistic tools as well as the production practices and procedures.

Section 8 deals with the current status, at European, national and, where possible, at international level of the R&D activities relative with the core technologies of the production and integration processes identified at the sections 5 to 7.

Section 9 analyses the effect of the automation of the production processes and their integration to the competitiveness of the EU yards vi-a-vis their Far Eastern counterparts.

Finally, section 10 attempts to draw some useful conclusions relative with the contractual aims of the AIPS study (see section 1.2 above). Namely: the identification of the technologies in which investments are likely to be more productive in increasing the competitiveness of the European shipyards, the actions and measures that are more appropriate in order to enhance the necessary R&D efforts and the actions that would help developing eventual technology transfer.

2 Terms & definitions

Care has been taken so that the terms and definitions used in the current report are in concordance with internationally accepted standards such as:

- International Standard Industrial Classification of All Economic Activities (ISIC): Details, as well as an index for all classified economic activities, can be found at <http://www.un.org/Depts/unsdold/class/isicmain.htm>. When possible, revision 3 compatible classification is used, otherwise revision 2.
- International Federation of Robotics (IFR)
- International Organisation for Standardisation (ISO), <http://www.iso.ch/>

As the whole section 4 is dedicate to shipbuilding processes, including design and planning activities, no specific shipbuilding terms will be defined here.

2.1 Robotics

2.1.1 Industrial robots

According to ISO 8373, a Manipulating Industrial Robot is an automatically controlled, re-programmable, multipurpose manipulator, programmable in 3 or more axes, which may be either fixed in place or mobile, for use in industrial automation applications.

Industrial Manipulating Robots are classified [10] by:

1. Industrial branches: according to International Standard Industrial Classification (ISIC), rev.3, some 24 industrial branches are specified. Among them there is no specific entry for Shipbuilding or Maritime Industry. Shipbuilding robots could be classified under one of the following categories:
 - Manufacture of other metal products, except machinery & equipment (No 28) or
 - Manufacture of other transport equipment
2. Application areas: 24 main areas (IFR classification). Among the, of special interest for the current report are:
 - Welding (No 160), further broken down in arc, spot, gas, laser welding (161 to 164) and others (169)
 - Special processes (No 190), further broken down in laser and water jet cutting (191 and 192) and others (199)
 - Assembling (No 200), further broken down in mechanical attachment, inserting/mounting/cutting, bonding, soldering, handling for assembly operations (201 to 205) and others (209)
3. Type of robot: the classification is done by:
 - (a) Number of axes (3, 4, 5 or more)
 - (b) Type of control:
 - Sequence-controlled / playback point to point: Binary operation (i.e. start/stop), no programmed control of the trajectory in between
 - Trajectory operated / continuous playback: 3 or more controlled axis motions specifying a time based trajectory
 - Adaptive: robots provided with sensory¹, adaptive² or learning³ control
 - Tele-operated
 - Not classified

¹ Motion or force is adjusted according the output of an external sensor

² Control system parameters are adjusted from conditions detected during the process

³ When experience from previous cycles is used automatically to change the control parameters or algorithms

(c) Mechanical Structure

- Cartesian & gantry
- SCARA: robot with 2 parallel rotary joints to provide compliance in a plane
- Articulated: robot with at least 3 articulated joints
- Parallel: robot with concurrent prismatic or rotary joints
- Spherical & cylindrical

The definition of the industrial robots, such as presented above, does not include the concept of autonomous performance of even low-level tasks or operations. This concept is fundamental for the robotisation of critical, one-of-a-kind operations such as the ones found in typical shipbuilding environments. IFR envisages autonomy only for the recently introduced category of *service robots*.

2.1.2 Service robots

There is no strict, internationally accepted definition for service robots, specially in what distinguishes them from manipulating industrial robots and other type of equipment. According to a preliminary definition by IFR, service robot is a robot which operates semi or fully autonomously to perform services useful to the well being of humans and equipment, excluding manufacturing operations. Often, but not always, service robots are mobile.

According to the above definition, some manipulating industrial robots, when operating in non-manufacturing environments, could be classified as “service robots”. Several robots, operating in a manufacturing environment but in non-repetitive operations and possessing some degree of autonomy, cannot be classified either as manipulating industrial robots or as service robots.

2.2 Automation / mechanisation

According the Webster dictionary “automation” is a coined word having no precise, generally accepted technical meaning but widely used to imply the concept, development or use of highly automatic machinery or control systems. Automation is generally accepted as the technology concerned with the application of complex mechanical, electronic or computer based systems in the operation and control of production / manufacturing. It includes:

- Automatic machine tools for processing work-parts;
- Automatic materials handling systems;
- Automatic assembly machines;
- Continuous-flow processes;
- Feedback control systems;
- Computer process control systems and
- Computerised systems for data collection, planning and decision making to support manufacturing activities

In what concern the metalworking industries and the shipyards in particular, automated production systems can be classified in three basic types:

- Fixed automation: fixed sequence of processing operations (i.e. transfer lines)
- Programmable automation: programmable sequence of processing operations (i.e. NC machine tool)
- Intelligent automation: Some degree of autonomy / self-adaptability

The Mac-Graw Hill Encyclopaedia quoted the Harvard Business Review proposal of 17 levels of mechanisation according the power and control sources, as shown on Table 1 below.

Table 1: Levels of mechanisation, Harvard Business Review, source: Mac-Graw Hill Encyclopaedia

INITIATING CONTROL SOURCE	TYPE OF MACHINE RESPONSE		POWER SOURCE	LEVEL	LEVEL OF MECHANIZATION
From a variable in the environment	Responds with action	Modifies own action over a wide range of variation	MECHANICAL (Non manual)	17	Anticipated action required and adjusts to provide it
				16	Corrects performance while operating
				15	Corrects performance after operating
		14		Identifies and selects appropriate set of actions	
		13		Segregates or research to according measurement	
	Responds with signal	12		Changes speed, position, according to measurement signal	
		11		Records performance	
		10		Signals pre-selected values	
		9		Measures characteristic of work	
		8		Actuated by introduction of work piece or material	
From a control mechanism	Fixed within the machine		7	Power tool system remotely controlled	
			6	Power tool program control	
			5	Power tool fixed cycle	
			4	Power tool, hand control	
From man	Variable		3	Powered hand tool	
			2	Hand tool	
			1	Hand	
			MANUAL		

Self-correcting actions are on levels 12 to 17 while the “automatic” operations are found on the levels 5 to 8. A scale of mechanization-automation specific to shipbuilding, similar to the one proposed by the Harvard Business Review (Table 1 above), does not exist as yet. Such a generally agreed scale would be desirable for monitoring and benchmarking purposes.

Automation of a shipbuilding sub-process or operation can imply:

- Connection to a ERP programming tool
- Input material selection & flow
- Material positioning and clamping
- Interfacing CAD data to off-line programming
- Off-line programming of the trajectory and sequence
- Connection to a data-base of welding, cutting etc procedures
- Off-line programming of the parameters (gas rates, velocity, current)
- Start and stop parameter and ramp automatic start and stop adjustment
- Sensors to monitor excursions from predefined limits (shrinkage, weld gap aperture)
- Programming for self-adjustment to variations detected

- On line quality control (record of parameters, warning or inspection systems, marking)
- Tool exchange and cleaning automated systems
- Cleaning and finishing as needed
- Material output
- Material output classification and routing

By the term “mechanisation” we refer to the *assistance*, which is provide to the operator, usually by servo-mechanical means, in order to alleviate him in the most tedious parts of his job. Sometimes, this assistance can involve quite complicated and expensive equipment as in the case of *robot-assisted* operations. The fundamental difference of *mechanisation* as compared to *robotisation* or *automation* lies in the fact that, although some auxiliary operations might be automated or robotised, the operation as such is performed manually.

Typical examples of mechanisation are:

- Automatic feed of the electrode during a welding operation
- Servo-assisted handling of the tubes, wires or the entire welding machine through gantries, hanging pantographic mechanisms etc.

Often, the terms “semi-automated” and “mechanised” are used indiscriminately. In fact, there exist many overlaps in what in the use of terms like *automation*, *mechanisation*, *semi-automation*, *robotisation*, *robot-assisted operations* etc.

2.3 Computer Aided Design, Engineering and Manufacturing

CAD (Computer-Aided Design) refers to the use of computer and digital technology to support the preparation of engineering designs, typically limited to geometry only.

CAD / CAM (Computer-Aided Design / Computer-Aided Manufacturing) refers to the integrated use of computer and digital technology to support the entire design-to-fabrication cycle of a product.

CAE (Computer-Aided Engineering) refers to the use of computer and digital technology to support basic error checking, analysis, optimisation, manufacturability, etc., of a product design. Finite element analysis (FEA) is one example of CAE.

CE (Concurrent Engineering) refers to a systematic approach to creating a product design that considers all elements of the product life cycle from the conceptual design to the disposal of a product, and in so doing defines the product, its manufacturing processes, and all other required life cycle processes such as logistic support. *Concurrent engineering* means shortening the engineering process cycle introducing parallel engineering processes instead of sequential processes.

CIM (Computer Integrated Manufacturing) refers to the use of computer and digital technology to completely integrate all manufacturing process with engineering design.

Communication Protocol refers to a defined communication format that contains the control procedures required for the data transfer across the link interfaces, and to and from the user's application programs. A set of rules that specify how data communication is to take place over a network. governing the format, timing, sequencing and error control of exchanged data.

EPD (Electronic Product Definition) refers to the concurrent creation, management, sharing, and reusing of electronic product information in a collaborative environment throughout a product's life cycle and across a distributed value chain.

EDM (Electronic Document Management) refers to a combination of automated and operator-invoked processes that allow the capturing, storage, retrieval, display, routing and maintenance of information comprising electronically stored documents.

Extended Enterprise: The seamless integration of a group of companies and suppliers.

IGES (Initial Graphics Exchange Specification) is an American standard for exchanging CAD data, started by the American National Standards Institute (ANSI) back to 1979. The Current version is IGES 5.3. The next version will be IGES 6.0.

Parametric Modelling refers to a type of CAD model that relates the geometry of different elements of a product so that when one element is changed, the geometry of the rest of the product changes as well.

PDM (Product Data Management) refers to the management of all engineering manufacturing data for a product to control its entire development cycle.

Product Data refer to all engineering data necessary to define the geometry, the function, and the behaviour of an item over its entire life span, including logistic elements for quality, reliability, maintainability, topology, relationship, tolerances, attributes, and features necessary to define the item completely for the purpose of design, analysis, manufacture, test, and inspection.

Product Model is a data model that contains the functions and physical characteristics of each unit of a product throughout its complete life cycle (from requirements specification to disposal).

STEP (Standard for the Exchange of Product Model Data - ISO standard 10303) is the international data description standard which will provide a complete unambiguous, computer-interpretable definition of the physical and functional characteristics of a product throughout its life cycle.

Virtual Prototyping is a software-based engineering discipline that entails modelling a mechanical system, simulating and visualizing its 3D motion behaviour under near real-world operating conditions, and refining / optimising the design through iterative design studies.

VR (Virtual Reality) refers to a class of systems (hardware and software) made to build a high-end representation of reality.

3 Context

3.1 Towards a competitive & sustainable shipbuilding

3.1.1 The changing yard

The shipbuilding market is characterised by an over-capacity in production, mainly in the sector of merchant vessels, which has caused dramatic price reductions (from 15% to 30% over the 1998 prices) in particular for the steel intensive vessel types which are fabricated in Korea (tankers, bulk-carriers, VLCCs, etc.). The actual shipbuilding capacity is around 21 Mgt while the newbuildings in 1999 accounted for 16.4 Mgt. This unbalance is bound to worsen during the next few years, [30].

The principal reason for the unbalance between shipbuilding offer and demand has been the substantial increase of the Korean shipbuilding capacity, mainly during the period 1994-1996. As a result of the Korean expansion, all the major shipbuilding areas (Japan in particular) accused significant losses. In EU the situation of the shipbuilding sector is critical as the increased demand for luxury cruise vessels and the weak Euro cannot but just compensate for the losses towards Korea.

The situation of the shipbuilding market has accelerated the trend of EU shipyards towards building vessel types with high technical content and specialised know-how. Typical examples are the containerships, LNG, LPG and product tankers, dredgers, luxury cruise vessels and ferries.

Apart from the shift towards more complex types of vessels, we must note the increasing complexity of every vessel type because of:

- Increased performance requirements in every operational field: speed, safety, emissions, manning, comfort, cargo & passenger handling etc.
- More stringent environmental and safety regulations
- Better design and building tools that allow better products even in conditions of lower profit margin

Moving to more complicated ship types sets a totally different level of requirements for the shipyard and surrounding infrastructure. The focus is shifted from the pure steel construction towards extensive outfitting work. As the complexity of a vessel increases the portion of the steel work diminishes significantly. In a modern passenger cruise vessel the outfitting work can represent up to 80% of the total work the steel work being 20%. Material costs become also a dominant factor in ship pricing.

Another important change concerns the design activities (including planning and management), which become increasingly important both in terms of volume and cost as well overall impact to the shipbuilding project. For a modern passenger vessel, can easily represent over 10% of the total project cost [44].

The very short delivery times, imposed by the fierce competition and the rapidly evolving market, emphasise even more the need for efficient design, planning and management. Indeed, in many cases, the time from contract to delivery of even a very complicated vessel, such as a cruise liner, can be shorter than 30 months.

In the past, shipyards have been largely self sufficient in all disciplines of shipbuilding process. All the steel work, outfitting work and even the machining work has been made mainly by the shipyard's own personnel. Occasional work subcontracting has been necessary to even out the peak loads, but this has been minor part and done normally under shipyard's supervision.

However, workloads can vary significantly across various disciplines in different ship types. Also the complexity of certain outfitting work requires a lot of highly skilled personnel for limited periods of time. From the shipyard's point of view handling this is difficult and not cost effective. Due to this reason most of the advanced shipyards have moved towards the extensive use of subcontractors. These are more and more requested to provide systems and turnkey deliveries.

Today the experts speak about “assembly” yards, where the shipyard may assume the sole role of assembling the hull and selected parts of the outfitting while a significant part of the added value is produced by external personnel. This development makes the automation and integration process much more difficult than it would be in a case where everything is done at the yard.

Nowadays, successful completion of complicated ship (such as modern high-speed ferries or big passenger vessels) in a concurrent engineering and production environment sets new challenges for the standardisation of components and integration of the production processes.

3.1.2 The changing ship

There has been tremendous development in most kinds of ships since the early eighties. The size of ships has progressively increased as well as speed. Increased safety together with higher capacity and efficiency requirements have led to application of new design configurations and technology, at a rate never seen before in the shipbuilding world.

In terms of hull forms, the tendency has been towards higher capacity, which has meant bulkier ships, above and under waterline, towards higher block coefficient. Another clear tendency has been towards higher speeds especially in ferries, containerships and high value cargoes. Average contract speed for ships above 1000 gt has increased by about one knot within the last 15 years. For some special ship types, such as container feeder ships, ro-ro ships and ferries the increase has been several knots. At the same time also the main dimension ratios have changed remarkably, the length-beam ratio has decreased, in some cases even below 5 and the beam-draught ratio has increased: for example for ro-ro passenger ferries from 3,0-3,5 up to 4,5-5,0.

Up to the end of the 70's the hull forms were typically defined by using hull form series, such as Series 60, Taylor, BSRA and similar. Today these series are no more used and, typically, hull form designs are based on reference vessel(s) or are defined and faired using CAD programs.

Cruise vessels have also developed rapidly during the last twenty years. The increase in vessel size is impressive. 85,000 gt has for a long time been the upper limit of cruise vessel size. The first mega size cruise vessel was the 101,353 gt Carnival Destiny delivered in 1996. The total number of such mega cruise vessels, built or on order by the end of 1999, was 9.

Ro-ro's and ro-ro passenger ferries have today two clearly different families:

- Conventional high displacement ferries with Froude number around 0,30 or below and
- High displacement fast ferries with Froude number clearly above 0,35, reaching today already 0,40 or even above

Catamaran designs and pods and water jet propulsion allow innovative designs waiving the constraints of the monohull-propeller limitations.

Increased competition, however, will always put the focus on the cost effectiveness of any investment. Any drastic innovation in the vessel design, structures or materials has inherent risks on long time performance (fatigue, corrosion, vibrations. etc). Efficient lifecycle analysis is required for the cost-analysis of any new configuration or solution.

The issue is to maximise the efficient revenue generating space at minimised investment and running costs, taking into account system availability and environmental impacts. These items have to be clarified and their impact on the lifecycle economy of the vessel has to be calculated before any major decision can be made.

New products and innovations are introduced and completely new machinery and ship configurations are developed for efficiency and economical reasons.

Considering cost efficiency we end up with four items:

1. Space,
2. Weight,
3. Power
4. Equipment (materials)

The efficient area and volume of the vessel compared with the total area and volume is a good indication of revenue generating capability and costs. Weight is directly related to building and fuel costs. Installed power onboard relates to the efficiency of hull, propulsion system and power generation. Equipment and materials are cost related either directly or indirectly (through required man-hours).

3.1.3 Shipbuilding, fundamental sector of a sustainable EU shipping

The maritime sector has been and will continue to be of strategic importance for Europe, due to the nature of its economy, topology, history and tradition [3]. Shipping in particular has played a major role in almost every aspect of the European life and is, to a great extent, responsible for its present welfare. The EEA (European Economic Area) ship owners controlled a fleet, which, in January 1998, represented 190.6 M gt, corresponding to 38.5% of the world fleet.

The shipbuilding industry in Europe (EU plus Poland and Norway) is in third place, behind Japan and Korea, in terms of tonnage built and equalled Japan in first place as far as order book is concerned (1998 data). Europe's shipbuilding is world leading in complex, high-tech ship constructions, particularly passenger ships (cruisers and ferries), containerships, LNG and LPG tankers, etc. European equipment manufacturers represent over 2,500 SMEs. During 1997, shipbuilding and related suppliers employed a work force of about 200,000 persons, delivering merchant ships and equipment with a value of around 17 G€.

Over the past couple of decades, European shipbuilding has declined dramatically in terms of orders, closures of yards and the consequent loss of skilled workers; in 1976, shipbuilding and related industries employed some 500,000 workers. European shipbuilding, as we know it, cannot survive such losses in its skill base.

Shipbuilding is a key maritime industry, which not only has contributed significantly to Europe's maritime past but also is strategic for its future. In the global market economy of today, in order to stay competitive, shipbuilding industries are faced with an urgent need for profound changes. This need has become even more urgent from the recent events in the Southeast Asia and from the upcoming cease of all subsidies. The enlargement of the Union with five new member states, some of which have a considerable shipbuilding industry, is another factor to be considered. In the long run, European shipbuilding cannot assure its future but by:

- The achievement of a competitive and sustainable shipbuilding, integral part of a sustainable shipping industry.
- The assurance of the highest possible quality standards, necessary for a safe and environmentally friendly navigation.

The achievement of these goals requires drastic changes in almost every aspect of the planning, designing, building and maintaining the European commercial fleet. Improvements are to be sought in every stage of the fabrication process, from the conceptual design to the procurement, production, outsourcing management, assembly, fitting, QA etc. Novel technologies (like laser welding etc), the automation and robotisation as well as the integration of the design and fabrication processes can lead to a much increased productivity and have the potential to transform shipbuilding from a labour intensive to a technology intensive sector.

A technology intensive, sustainable European shipbuilding sector is a fundamental, integrating part of a sustainable European shipping, which is, and will continue to be, of strategic importance for the future of Europe.

3.2 Robotics & automation

3.2.1 The world market for industrial robots

In 1997, worldwide robot installations reached the record level of 85,000 units, exactly half of which concern installations in Japan, as can be seen on Table 2 below. This represents an increase of +6.5% over the 1996 figure. Nevertheless, the value of these installations amounts to \$4.8 billion, which represents a reduction of -4% over the 1996 value. The total stock of operational industrial robots was estimated in 1997 at 711,000 units, distributed as shown in Table 3 below, at +6% over the stock of the previous year.

Table 2: Yearly installations of robots for 1996 and 1997; forecasts for 1998 - 2001, from [10]

Country	1996	1997	1998	1999	2000	2001
Japan	38914	42696	47200	50700	55800	61400
USA	9700	12459	11000	12750	14700	16900
Germany	10425	9017	9500	10000	11000	12000
Italy	3331	3692	3900	4100	4400	4700
France	1697	1721	1800	1950	2100	2400
UK	1116	1792	1600	1600	1800	1900
Big 6 above	65183	71377	75000	81100	89800	99300
West Europe - 8 ⁴	3317	3788	4200	4600	5100	5600
East Europe - 5 ⁵	173	184	200	200	200	200
S.E. Asia - 4 ⁶	8624	7038	6700	7000	8100	9300

Table 3: World robot market and total stock of operational industrial robots in 1997, from [10]

Country	Japan	USA	Germany	Korea	Italy + France + UK
Market (billion\$)	2.2	1.1	0.56	0.143	0.44
Stock (%)	58%	11%	9%		

One important consideration, also reflected in the tables above, is that the unit value of robots is falling continuously: in the period 1990 -> 1997 it fell by 21% in the US, 25% in Germany, 5% in Italy and 45% in France. The average unit price on 1997 was \$88,000 at the US and between \$50,000 and \$65,000 in Europe.

3.2.2 Robots by industrial branch

Engineering industries⁷ account for 65% to 85% of all robots worldwide. The motor vehicle industry is the predominant user of robots (except in Japan) while the predominant application area is that of welding. Table 4 below gives an overview of the distribution of operational robots per industrial branch in 4 typical industrialised countries. Complete data can be found in [10], where the statistical data presented here have been taken from.

⁴ Austria, Benelux, Denmark, Finland, Norway, Spain, Sweden and Switzerland

⁵ Czech rep., Slovakia, Hungary, Poland and Slovenia

⁶ Australia, Korea Singapore and Taiwan

⁷ Industrial branches included in ISIC rev.2, Division 38

Table 4: Operational robot stock, added value and robot density per industrial branch in USA, Japan, Germany and Italy for 1996, from [10]

Branch		Total Industry	Process Industries	Engineering	Metal Products	Machine Industry	Electrical Machinery	Transport Equipment	Motor Vehicles	Instruments Industry
	<i>ISIC rev.2 num.</i>	3	3-38	38	381	382	383	384	3843	385
USA	Stock (k units)	71							35	
	Value added (G\$)	1332	753	579	98	150	144	134	85	52
	Empl. (million)	19	11	7.8	1.4	2.1	1.7	1.8	0.96	0.85
	Robot density (units / 10k empl.)	38							369	
Japan	Stock (k units)	400	91	308	20	48	129	106	95	5
	Value added (T yen)	121	66	56	7	15	20	12	10	1.8
	Empl. (million)	15	8.1	6.8	1.2	1.8	2.4	1.2	1.1	0.21
	Robot density (units / 10k empl.)	268	112	453	165	271	550	850	909	235
Germany	Stock (k units)	60	18	42	5	3.6	3.8	29	28	0.7
	Value added (G DM)	789	416	373	76	80	88	90	87	20
	Empl. (million)	7.6	3.8	3.8	0.86	0.99	0.96	0.83	0.85	0.28
	Robot density (units / 10k empl.)	79	48	111	58	36	40	336	343	25
Italy	Stock (k units)	23	3.5	19	4.5	3.1	2.2	9.7	6.8	0.06
	Value added (T Lit)	378	247	131	30	32	24	21	11	6.8
	Empl. (million)	4.6	3	1.6	0.47	0.4	0.3	0.29	0.17	0.09
	Robot density (units / 10k empl.)	51	12	123	95	77	72	329	402	7

From the table above, 2 good indicators on the relative use of robots in each industrial branch can be derived by dividing the robot stock % share of each industrial branch to its:

- % share in the added value to give the robot / value added relative share
- % share in employment to give the robot / employment relative share.

The higher those ratios are the more intensive the use of robots in the industrial branch in question. These two ratios are given per industrial branch and for some selected countries in Table 5 and Table 6 below.

Table 5: Robot / value added share per industrial branch for selected industrial countries, from [10]

Industrial Branch	Total Industry	Process Industries	Engineering	Metal Products	Machine Industry	Electrical Machinery	Transport Equipment	Motor Vehicles	Instruments Industry
<i>ISIC rev.2</i>	3	3-38	38	381	382	383	384	3843	385
USA	1							7.8	

Japan	1	0.4	1.7	0.9	1	2	2.6	2.8	0.9
Germany	1	0.6	1.5	0.9	0.6	0.6	4.2	4.2	0.5
France	1	0.5	1.8	0.2	1.6	0.5	4.7	6.8	
UK	1	0.5	1.8	1.4	0.4	0.6	4.8	9.3	0
Italy	1	0.2	2.4	2.1	1.4	1.3	6.6	8.8	0.1
Sweden	1	0.3	1.8	2.3	0.9	0.9	3.6	4.5	0

Table 6: Robot / employment share per industrial branch for selected industrial countries, from [10]

Industrial Branch	Total Industry	Process Industries	Engineering	Metal Products	Machine Industry	Electrical Machinery	Transport Equipment	Motor Vehicles	Instruments Industry
ISIC rev.2	3	3-38	38	381	382	383	384	3843	385
USA	1							9.7	
Japan	1	0.4	1.7	0.6	1	2.1	3.2	3.4	0.9
Germany	1	0.6	1.4	0.8	0.5	0.5	4.5	5.1	0.3
France	1	0.5	1.7	0.2	1.2	0.5	4.3	6	
UK	1	0.6	1.5	0.9	0.3	0.5	4.4	8.3	0
Italy	1	0.2	2.4	1.9	1.5	1.4	6.6	8.1	0.1
Sweden	1	0.3	1.7	2	1	0.7	3.5	4.8	0

Unfortunately, shipbuilding is not a distinct category in the ISIC rev.2 or rev.3 classification. Subtracting the "Motor Vehicles" numbers in Table 4 from the "Transport Equipment" ones could derive an indication on the use of robots on the use of robots in the shipbuilding, train and aeronautic branches together. The Robot / added value and robot / employment relative shares for the transport industries excluding the motor vehicle industries are presented in the Table 7 below⁸.

Table 7: Robot / added value and robot / employment relative shares for the transport industries excluding the motor vehicle ones

Country	robot / value added share	robot / employment share
Japan	1.7	4.1
Germany	4.4	6.3
Italy	4.8	4.8

3.3 Integration tools

The "IT revolution" to which we have assisted during the last decade, has been essentially geared by the rapid progress in two important, complementary fields:

- The micro-technologies necessary for the miniaturisation of electronic and other hardware components, necessary for the realisation of the modern digital computer and telecommunication systems and
- The development and deployment of the open tools and object oriented programming techniques necessary for the development of the complex software environment of the modern distributed but highly integrated systems.

⁸ It must be pointed out that these numbers are only approximate since they have been derived operating on the numbers reported in Table 4, that is with only 2 significant digits

Especially during the last decade, digital computer technology penetrated almost every single aspect of industrial activity. It alleviated humans from many tedious repetitive jobs and provided the backbone for efficient and cost effective performance of operations as diverse as document production to car assembling or high precision component manufacturing.

3.3.1 Computers: from calculations to communications and integration

There is no need to illustrate to anyone the rapid advances of the computer industry during the last years. In many respects, the hardware potential available in a modern laptop computer is superior to any medium-size computer of 10 years ago. In the recent years, the improvement of the average cost / performance ratio has been halved every one and half years. The considerable performance gains obtained in the PC based platforms and the consequent move of many engineering applications towards Windows NT has further improved that figure.

Nevertheless, the most drastic change perhaps lies in the way computer systems are perceived and used:

10 years ago a computer would typically be perceived as a tool for increasing the productivity of a certain process, be it design (i.e. CAD/CAE systems) or production (robots or automation systems), mainly through its ability to perform fast calculations.

10 years from now, a computer is likely to be perceived as an integration tool, component of a broad digital communication system rather like a process productivity enhancing tool.

Today, in what regards the use of computers, EU enterprises are still in the very beginning of a transformation process. The levers of this transformation are:

- The vast amount of technical and commercial information which are available almost in real-time through Internet.
- The new digital communication technologies (LANs, WANs, ISDN, etc.), which make technically possible concurrent engineering, virtual enterprises, and other collaborative forms of working, using cheap, public communication channels.

Important issues to be addressed are of commercial and regulatory aspect rather than technical. They mainly concern communication standards and data security.

3.3.2 Software development & programming techniques

Object Oriented Programming

Object Oriented Programming is the recent answer to the complexity of the software engineering processes. Although the concept of Object is not that new it was the late evolution of languages like C++ and Java that gave to this technique the required tools to apply it.

The concept of Object is based on the idea that this software unit comprises from the data and the routines that are used to process them. This way the degree of access to the data and the permission to alter them is controlled. This is referred as the encapsulation property. Objects represent usually existing physical entities (sensor, mechanism) but also processes or message passing units. Objects can have certain relations among them the most important is inheritance. An object can be described to belong to a certain class of objects inheriting a structure and behaviour from the original class. According to this relation a feature of one object can be inherited to others once those are declared to belong to this group of objects. Other relations among objects can be constructed allowing different levels of interaction. Objects can belong to a number of different groups inheriting thus the characteristics (coherently) of all these groups. This property is referred as polymorphism.

Another basic advantage of the OOP is the possibility to recycle software code. Parts of the same software code in the form of objects can be used in different projects exploiting similarities in the representation of an object. This is possible since

each object can have the same interface and structure that characterises its behaviour in different software packages.

UML

Unified Modelling Language (UML) is a semi-formal semantic meta-language used mainly in OOP, to define the basic modelling concepts of object, class, association, etc. It includes formal well-formedness rules expressed as constraints in the Object Constraint Language (OCL). In addition it provides graphical notation for modelling concepts with 8 different diagram types and 2 predefined domain extensions.

UML combined existing standards developed separately by researchers into a unique by the Object Management Group (OMG) in 1997. In this way UML evolved into a standard tool for analysis and design of object-oriented systems based on extensive experience and best practices. Currently is gaining rapid acceptance (training, tools, books) as a common language in software industry.

UML can be used in many different areas to capture domain-specific concepts and ideas, reflecting the main characteristics of OOP that is :

- encapsulation
- inheritance
- polymorphism / genericity

In addition it offers the means for the description of a system as set of structurally collaborating parts classes and instances.

UML offers the possibility to describe a number of different design views for a system with corresponding types of diagrams, namely:

- Requirements (use case diagrams)
- Static structure (class diagrams): types of objects and their relationships
- Dynamic behaviour (state machines): possible life histories of an object
- Interactive behaviour (activity, sequence, and collaboration diagrams): flow of control among objects to achieve system-level behaviour
- Physical implementation structures (component and deployment diagrams): software modules and deployment on physical nodes.

A number of visual tools based on UML have been developed automatically translating the graphical structures into software frames. The author has then to fill up the created frame with the detailed code. This allows a more effective software construction since the generated structures reflect design choices not to be overwritten in later stages of development.

3.3.3 CAD / CAE

A *model* is a representation of an object or a physical system. Models can be symbolic (i.e. a set of mathematical or logical equations), iconic (i.e. a map), logical (.e. flow chart) or geometric. Designers, engineers or analysts create and use models to define somehow the process the physical realisation of any part, assembly or construction. In addition, models are used extensively to simulate, test or predict the behaviour of objects or physical systems.

Computerised systems, mainly due to their interactive graphic capabilities, have become valuable tools for creating and manipulating geometric and other types of models. Thus, they have contributed in enhancing significantly most of the design phases, leading at much better engineered products much faster. Modern CAD packages also provide interfaces towards CAM systems, thus contributing in the off-line programming of the automated production facilities.

A very important change happening these days concerns in the role that CAD tools play in modern industry: The role of CAD/CAE has traditionally been that of enhancing the various phases of the design process and assuring shorter lead times to the planning and the start of the production activities. Nowadays, in view of the increasing complexity of the production operations and, consequently, the planning requirements and the stringent lead times to market, CAD/CAE tools are rapidly ac-

quiring the role of the integrator between the 'traditional' design phases the planning and production processes.

The design, manufacture and support of a product involve an increasing number of *partners* each one of them requiring different, specialised data and information related to the development of the given product. All of them need to be able to operate efficiently and for that it is vital the ability to share and exchange *Product Data* in a timely manner is critical. Geometry, which has traditionally been the object of CAD/CAM, is only part of the information necessary for the realisation of a product, especially when a product life-cycle approach is considered. Recently, the potential of the IT tools, combined with the new SW development environment, promises to make possible the realisation of a *Product Model* providing a representation of all information associated with the complete product lifecycle including design, manufacture, utilisation, maintenance, and disposal along with the necessary mechanisms and definitions to enable data to be exchanged among different computer systems and environments (see STEP).

In general, the capabilities of the CAD / CAE packages kept pace with the rapidly evolving IT potential with two important trends:

- The move, even for demanding CFD applications, from mainframe platforms to workstations and / or PCs.
- The move from proprietary operating systems towards standard UNIX and, mainly, Windows NT environment.

In what concerns the CAD market, on top of the above trends, we see an important shift of the big software vendors towards new architectures, moving from 2D based drafting to complete 3D and Product Model representations. Some important CAD packages are currently being completely re-written at costs of several thousands of man-years of development work.

The globalisation of the market economy combined with the IT context, as described in the paragraphs above, has created two apparently conflicting trends in the market of the CAD / CAM / CAE products:

- Further concentration of the big CAD / CAE vendors
- Creation and development of many small, home/custom made, highly specialised products

Although there have been significant activities to define standards on CAD data exchange, the interfacing of the various existing CAD programs remains a major bottleneck. Even if the big software houses usually provide ad-hoc translators towards each other's packages, passing data among applications is usually a matter of concern. The situation is much worse in smaller packages.

Nevertheless, this situation is bound to change. The great enabler in the uptake of new standards is the web. With the prevalence of the Internet within the working environment we have the means to move and view data from anywhere to anywhere in the world. With companies like Microsoft, who have recently made a strategic decision to enter the engineering applications market, applying constant pressure to conform, we stand on the brink of a new generation of systems with new architectures built on the concept of integrated platforms.

In shipbuilding, CAD tools are used in every stage of the design process and, partly, in the early production processes. A good overview of the use of the CAD / CAE tools in shipbuilding is found in [25].

3.3.4 Standards

Models, even when representing the same physical object or system can be extremely different from each other depending primarily on the use or the requirements they are supposed to meet but also on the way they were conceived. This is even more so for the computerised models that depend upon also upon the HW and SW platform on which they are visualised, on the particular modelling (CAD/CAE) program used or even on the programming habits of the CAD designer / operator.

Flawless information exchange across different models / applications has always been a major issue.

In the past decades, models used in engineering / industrial applications were mostly CAD, CAM or CAE models, that is mostly graphical representations of some physical object or system. Consequently, the major issue has been that of exchanging / sharing of graphical / geometric information among the various applications. The IGES (Initial Graphics Exchange Specification) standard for exchanging CAD data, started ANSI back in 1979, was the most important response to tackle this issue. Nevertheless, the interfacing of the various existing CAD programs and the flawless exchange of geometric information still remains an important issue. In fact, the problem is so complicated, the requirements (and consequently the methods and techniques used over the time) are so diverse that even the market forces have been unable to impose a de-facto standard (like Microsoft in the office automation applications).

Inevitably, the situation is bound to be much more complicated in what concerns the standards on product models, where information is not only geometric but is supposed to describe all aspects of the product throughout its life-cycle.

STEP (Standard for the Exchange of Product model data - ISO standard 10303) is an international set of standards, still under development, which will be used to describe a product in a neutral format over its complete life-cycle in a hardware-independent way. Several STEP application protocols, specifically oriented to ship design, production and operation, are in preparation. EMSA is the European Maritime STEP Association. In USA the MariStep organisation is quite active, driven by the military industry and IBM and a ProStep organisation. Japan has also a Step Association.

This series of ISO 10303 International Standards provides a representation of product information along with the necessary mechanisms and definitions to enable product data to be exchanged. The exchange is among different computer systems and environments associated with the complete product life-cycle, including product design, manufacture, use, maintenance, and final disposition of the product.

The following are within the scope of ISO 10303:

1. The representation of product information, including components and assemblies;
2. The exchange of product data, including storing, transferring, accessing, and archiving.

Thus, STEP supports not only the exchange of product data, but also its representation for e.g. archiving. The whole life-cycle of a product is in scope, including operation and maintenance.

4 Shipbuilding process break-down

4.1 Shipbuilding today

Traditionally, shipbuilding has been identified with those operations and processes related with the transformation of sheet metal to steel hulls. These operations essentially consisted in marking and cutting the sheet metal prime material in elementary building pieces the assembly of which, in various stages (panels, sub-blocks, blocks, sections), finally yielded the complete steel hull. Thus, three basic classes of processes could be distinguished:

- Sheet (or beam) metal treatment processes (conditioning, marking, cutting, bending etc)
- Assembling (nowadays mostly welding)
- Handling (moving and positioning the various blocks and sub-assemblies)

Maximising the efficiency of shipbuilding essentially meant:

- Assuring the most cost-effective acquisition of the necessary prime materials and components,
- Optimising (in terms of cost and quality) each one of the processes stated above and
- Planning the whole sequence of operations in such a way so as to ensure a seamless flow of material and an optimal utilisation of the available resources (labour, equipment, space and time)

Today, the relative importance (at least in terms of cost) of the steel shaping and assembling has decreased substantially. This is true especially for the big passenger and ferry vessels where EU shipbuilding still holds a considerable share of the market. In fact, due to the ever-increasing requirements in terms of passenger comfort, safety in navigation and environmental concerns, modern passenger and ferry vessels look more and more like huge navigating hotels or big industrial complexes. Shipbuilding nowadays encompasses a range of processes and activities much broader than shaping and assembling sheet metal steel. Less 'traditional' shipbuilding activities, such as finishing and outfitting become increasingly important.

For a variety of reasons (also tackled in section 3 above), the traditional concept of shipbuilding still prevails between in the European shipbuilding industry. Nevertheless, there are concrete signs that this situation is beginning to change.

Another very important change happening these days is in the role that CAD tools play in shipbuilding: The role of CAD/CAE tools in shipbuilding has traditionally been that of enhancing the various phases of the design process and assuring shorter lead times to the planning and the start of the production activities. Nowadays, in view of the increasing complexity of the production operations and, consequently, the planning requirements and the stringent lead times to market, CAD / CAE tools are rapidly acquiring the role of the integrator between the 'traditional' design phases the planning and production processes.

For all these reasons, design, be it basic or detailed, cannot be considered separately not only from production planning but also from most of the individual production processes. Nevertheless, for practical reasons, we distinguish the production from the design & planning activities in terms of the different tools and technologies applied. While production deals with the handling and transformation material objects, design and planning activities have mainly to do with the generation and handling of information. As such, for the purpose of the AIPS study, they are considered as fundamental components of the integration process and the corresponding information flow rather than parts of production process flow.

So, for the purpose of this study, we consider two types / classes of processes:

- (a) The production processes, dealing with material objects and

(b) The information processes, dealing with information

Each one of them being examined in its own context:

- (1) The shipbuilding production process flow scheme, as seen in Figure 1
- (2) The information flow across the shipbuilding activities, as seen in Figure 2.

Although there exist significant variations according to the type of vessel, the size and specialization of each shipyard, these schemes, given in Figure 1 and Figure 2 below give an adequate picture of the generic shipbuilding production process breakdown structure and the corresponding information flow.

4.2 Production processes

By the term “production activities” or “production processes” we mean all the activities that essentially consist in transforming (machining, assembling, handling, transporting etc) material objects. In what follows, the “generic shipbuilding” is broken down to classes of processes hereafter referred as “production processes” or “processes”. Although the meaning and the sequence of these processes can vary according to the type (i.e. tanker, container carrier, passenger ship) and size of the vessel as well as the particular methods and mentalities each individual yard, it can be said that they represent quite well all but the very specialised constructions.

So, the generic shipbuilding production can essentially be broken down in the following production processes:

- P.1 Raw material reception & preparation
- P.2 Marking, cutting & conditioning of steel plates and profiles
- P.3 Fabrication of 2D blocks: welding of flat and shaped sub-assemblies (panels and sub-blocks)
- P.4 Fabrication of 3D blocks in workshop
- P.5 Pre-erection: assembly of 3D blocks and subassemblies into erection units
- P.6 Prefabrication of pipes, supports, modules etc
- P.7 Pre-outfitting
- P.8 Blasting and painting/coating
- P.9 Erection and outfitting in the dry-dock or slip-way
- P.10 Outfitting (incl. piping, wiring, machinery etc.)
- P.11 Finishing & outfitting onboard of the floating vessel
- P.12 Commissioning & sea trials

The processes above are not necessarily sequential. Processes P.6 to P.8 in particular, are performed at various stages of the shipbuilding schedule (see Figure 1 below). In addition, there exist two processes that are performed in support to all of the processes stated above, throughout the shipbuilding activity:

- P.13 Transport & handling
- P.14 Dimensional control & inspection

Another important factor to consider is where each process takes place. In that respect, we can distinguish three classes of processes:

- Processes P.1 to P.7 are generally performed in a workshop with the possibility of support for eventual production lines, semi or fully automated facilities etc.
- Processes P.9 to P.12 are performed out of the workshop, on the dry dock, slipway or in the floating vessel at the dockside.
- Processes P.8, P.13 and P.14 are performed either on the workshop or outside

In general, phases performed in the workshop tend to be much more efficient⁹ than in dry-dock or in the floating vessel (see section 3.1.1). Consequently, there is a tendency to perform as much of the outfitting, coating painting etc as early in the production schedule as possible.

⁹ According to [12], each man-hour of pre-outfitting is equivalent to 1.5-2.0 man-hours of outfitting at the dock

A first schematic representation of the generic production process flow in shipbuilding is given in Figure 1 below. In section 5, each of the above mentioned processes is further analysed, particularly from the automation point of view.

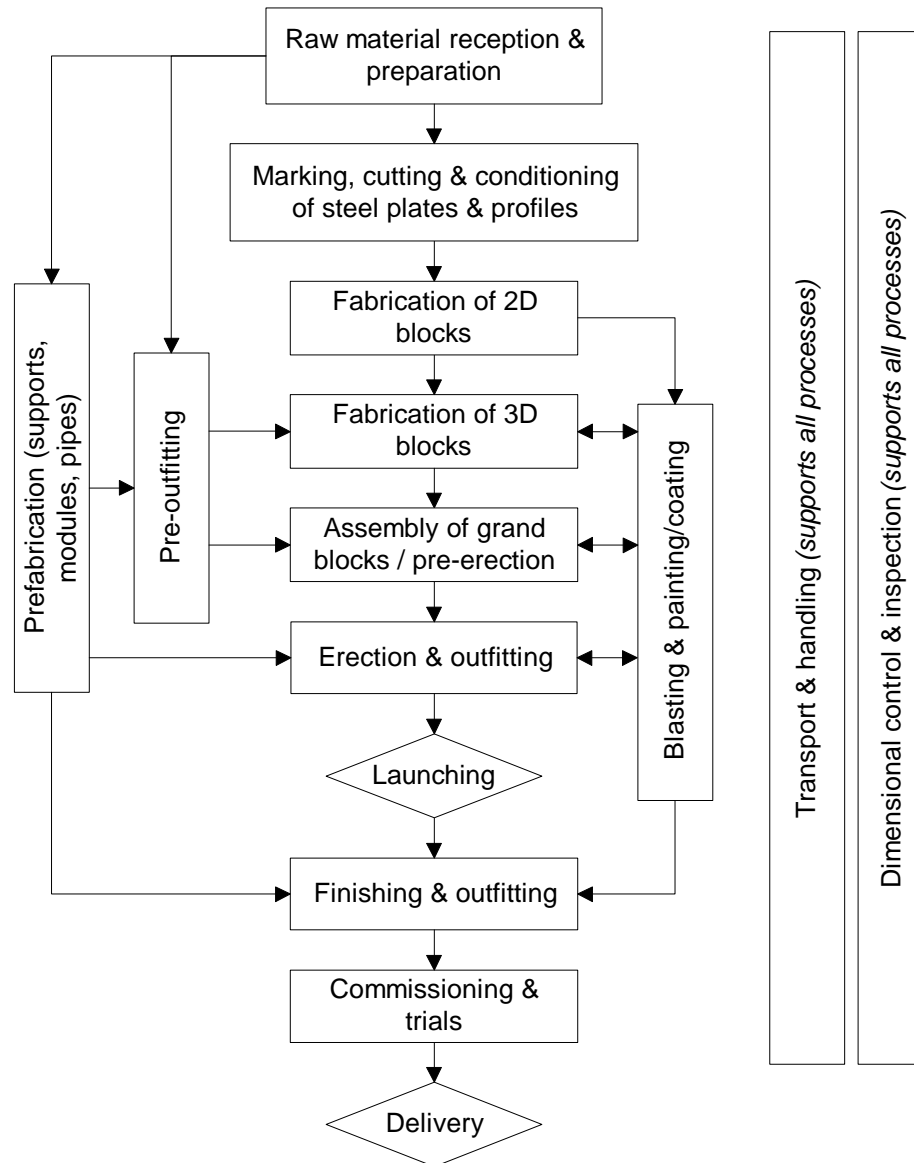


Figure 1: Shipbuilding production process flow

4.3 Information processes

Prior to construction, every vessel must be designed, the construction operations must be planned, the automated machines must be programmed and the timely delivery of prime materials and equipment must be assured. These activities involve the generation and manipulation of enormous amounts of information. The availability of potent information and communication tools has increased significantly the amount of information to be “managed”. Seamless information flow across the shipbuilding activities is vital for the efficient realisation of each shipbuilding project. The extreme diversity, in terms of contents, users, uses and forms, of the information necessary for the various design and production stages make this task quite a difficult one.

In terms of content, information regards entities as different as:

- The vessel as a whole or in blocks, parts, equipment, tubing, circuitry etc
- The yard layout, personnel, facilities and equipment
- Procedures and know-how

The information users are:

- Engineers, naval architects and other specialists
- Welders, automated machine operators and other craftsmen
- The owner and the class
- External subcontractors, equipment and service providers

Information (mostly but not always computerised) can be in a variety of forms:

- 3D models,
- drawings,
- specifications,
- machine tool programming code,
- work-schedules,
- part lists,
- plans and lay-outs,
- inventories etc

In the following paragraphs we identify the main classes of information processes, hereafter referred as “information processes”, in the context of an information-flow scheme (Figure 2) in a generic shipbuilding process. By the term “information processes” we mean all the activities that essentially consist in generating or processing information, essential for the subsequent realisation of one or more production processes as delineated in the section 4.2 above.

The main information processes involved in shipbuilding are:

- I.1 Pre-design
- I.2 Basic design
- I.3 Detailed design
- I.4 Building procedures
- I.5 Production design & planning
- I.6 Programming of automated facilities
- I.7 Warehouse control
- I.8 Outsourcing control
- I.9 Work planning & preparation

A schematic representation of the information flow in the context of the generic shipbuilding production can be seen in Figure 2 below. Fully contoured blocks denote the main information processes, as listed above, while the dotted ones denote the production processes, as delineated in the section 4.2 above.

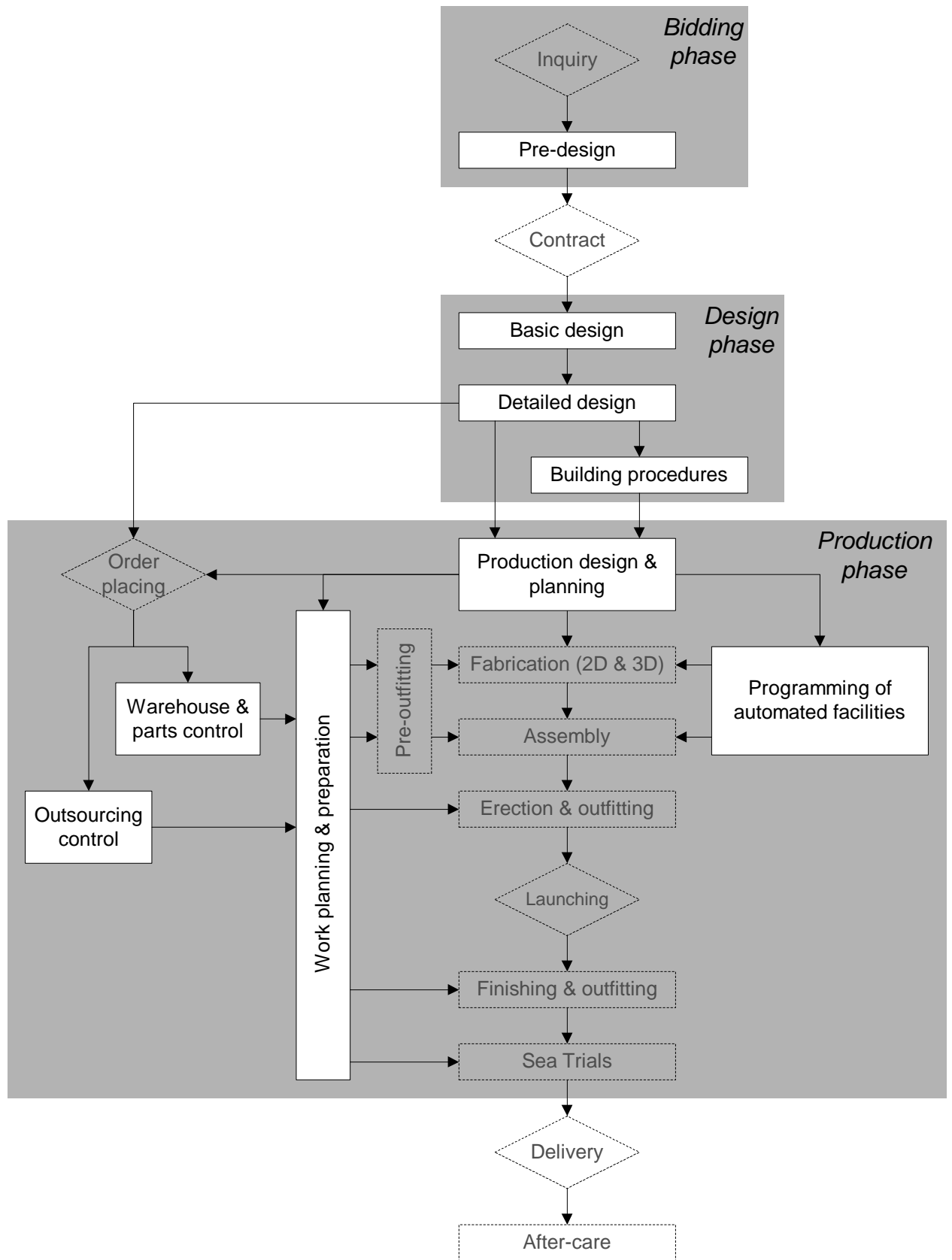


Figure 2: Information flow across the shipbuilding activities

5 Automation of the production processes

In this section we will deal with the automation of each of the processes listed in section 4.2 above (see also Figure 1). The processes of major interest from the automation point of view are the following:

- P.2 Marking, cutting & conditioning of steel plates and profiles
- P.3 Fabrication of 2D blocks: welding of flat and shaped sub-assemblies (panels and sub-blocks)
- P.4 Fabrication of 3D blocks in workshop
- P.6 Prefabrication of pipes, supports, modules etc
- P.8 Blasting and painting/coating
- P.13 Transport & handling
- P.14 Dimensional control & inspection

The state of automation / mechanisation of each one of these processes is outlined in the following subsections. A considerable part of the information presented comes from [32], CEPS State-of-the-Art report on General Production Technology.

Apart from the processes listed above, particular attention is given to the new production technologies such as laser cutting and welding etc. The main reason for that is the fact that most of these technologies cannot be conceived without a significant degree of mechanisation / automation.

5.1 Marking, cutting & conditioning of the steel plates and profiles

5.1.1 De-scaling / priming

Typically, yards are equipped with gantries with magnet or vacuum-beam to put the material on the charging conveyor.

Successive stations are:

- Roller conveyor
- Preheating plant (gas or oil-heated)
- Connection roller conveyor
- De-scaling plant, equipped with SI centrifugal wheel with integrated grit recycling plant
- Connection roller conveyor
- Priming plant, with spraying sensor system controlling paint film thickness, exhaust system with special self cleaning filter
- Drying conveyor with exhaust system
- Roller conveyor
- Marking device
- Discharging conveyor
- Crane with magnet or vacuum-beam for transporting / storing the material

The plants are normally designed to handle plates as well as profiles. Special devices ensure that more than one profile at a time can pass through this line.

The trend today is to minimize the stock (and finance) and avoid local environment issues by ordering the plates and profiles blasted and shop-primed and almost just-in-time (based on reliable supply from the steel mills).

5.1.2 Marking

The following methods are currently in use, usually as an attachment to the cutting device:

- Powder marking
- Inkjet marking
- Plasma arc marking
- Laser marking

Marking in advanced shipbuilding includes

- Contract/construction number
- Plate or part number allowing also traceability from heat /lot number of the plate, lamination direction...
- Position lines for fitting and welding
- Lines for shaping in case of curved plates
- Welding procedure(s) identification and sequence
- Identification of the sub-assembly and block where the part or plate must be fitted

5.1.3 Cutting

The following methods of cutting are in use nowadays for plate and profiles (including bulb profiles):

- Shears: used for straight cuts normally up to 3,000 mm (Nowadays mainly used only in the locksmith's shops)
- Roller shears: Used for straight cuts normally up to 12,000 mm (nowadays being replaced by thermal cutting machines)
- Water-jet cutting: due to its rather poor performance at the moment it is not widely used
- Thermal cutting: basically we can distinguish:
 - Oxy-Fuel cutting
 - Plasma-Cutting
 - Laser-Cutting
 - A combination of the above

Plasma cutting installations are gradually taking over. Underwater plate cutting systems with dual pools (the heads are cutting in one of the pools while the other is pumped out for cleaning, plate conditioning and unloading) provides an automated service to any yard size.

A plate cutting system can be considered complete when it addresses all of the points below:

- Conveyor feed-in and facilities for unloading either plates and small pieces
- Possibility to cut with the bevel for welding
- Integrated marking (identification, part number and block, procedure welding lines, marks for bending).
- Tolerances, change of bevel on contour
- Measurement system /integrated quality control/
- Connection to the CAD system
- Multiple torch for simultaneous cutting
- Protection, insonorisation etc.

Some yards have multiple cutting lines; small yards can benefit of joint installations like in the Nederland, where most cutting is concentrated on two specialised installations, one of them is served just-in-time by the steel mill. The Dutch cutting organisations offer complementary services such digitisation of hard drawings, and generation of CAD information, nesting etc.

5.1.4 Automation / mechanisation

Plate cutting has been one of the first processes to be automated in shipbuilding. Cutting systems are less complex than welding systems and numerical control mechanized equipments have been used since 20 years ago and have been steadily improving since. Indeed, references on robotized shipyard plate cutting systems are about ten times as numerous as welding systems. The TRIBON reference list of 1999 (Table 8 below) gives an idea on the subject.

Table 8: TRIBON robot installations, 1999

Plate cutting	47
Welding	6
Profile cutting	3

The data presented in this section mostly comes from the CEPS survey on *general production technology* [32].

Mechanised surface treatment is implemented at most yards as well as in most of the subcontractors. Mechanised 2D cutting is also fully implemented. Robotized cutting is implemented at 50% of the yards.

Mechanised milling is implemented at 40-50% of the yards together with other edge preparation methods.

Mechanised solutions have been developed and implemented also for the bending and forming of plates in most of the yards.

A number of EU manufacturers offer complete production lines for surface treatment, marking and cutting operations.

The biggest challenge appears to be the assurance of the accuracy and the cut surface quality adequate for the implementation, in the successive production phases, of laser welding techniques.

5.2 Fabrication of 2D blocks

5.2.1 Typical equipment

Basically a typical modern panel production line consists of:

- Roller bed with conveying means
- Clamping (hydraulic, magnetic, vacuum) / tacking portal
- Butt-welding gantry(s)
- Panel turnover arrangement (in some cases)
- Panel turning arrangement (90°) sometimes equipped with a thermal contour cutting machine
- Stiffener pallet
- Mobile Grinding: device for the removal of primer / paint in way-off stiffeners
- Mobile stiffener gantry
- Fillet-welding gantry
- Mobile web gantry
- Web welding gantry
- Lift-off transport station

Depending on the kind of panel, all possible outfitting-elements are installed as well. Before a panel leaves the shop, it must be ascertained that it is within allowable tolerances and the outfitting-elements are in the right location. So, appropriate quality assurance equipment, sometimes including automated optical measuring devices, is also present.

5.2.2 Types of panel lines

The following types of panel lines are found in the shipyards:

Mini panel line, usable for one plate, working area under the portal(s) about 4x20 m²

Normal flat panel line, for panels of 10x10 m², 15x15 m², 20x20 m² or larger, depending on the size of ships, the yard is generally building

Double bottom line, usually following the configuration / sequence:

Station 1: Inner floor plates are placed and welded together

- Station 2: Floor plates are being put on the panel and welded
- Station 3: Longitudinal floors are put in position and welded.
- Station 4: Tank heating pipes and other outfitting elements will be attached.
- Station 5: Already bended shell plates will be put on the floor grid and welded
- Station 6: Lifted off the line onto special means of transport for moving to the ring block section building area.

Curved panel line: There are various stations, sized for the largest anticipated panel. Each station is equipped with a large number of adjustable stanchions. By means of the software the upper point of all the stanchions, if being connected, forms the shape of the curved panel in question. They usually follow the following configuration:

- Station 1: The already shaped plates will be put on them and welded together.
- Station 2: Frames will be put on the plate-field and welded by means of robots.
- Station 3: Secondary members are being put on the panel and welded as well.
- Station 4: As far as practicable outfitting elements will be put on the panel
- Station 5: Lift off the line on special means of transport for moving to the block-building area.

Girder building line, consisting of:

- Crane with beam to put web and girder on the roller – conveyor
- Press roller machine
- Welding robots
- Profile straightening machine
- Discharging conveyor

With the aid of this line the optimum profiles are being produced tailor-made.

5.2.3 Automation / mechanisation

Automation (incl. robotisation) is rather well developed. More or less automated lines are implemented in nearly 50% of the yards.

A number of EU manufacturers offer complete custom-built production lines, more or less automated, using various configurations.

Efficient use of laser welding methods, in order to assure minimum thermal deformations, is still an open issue. There is a number of EC sponsored and national projects on this argument with the active participation of some of the biggest EU shipyards (see section 5.8 below).

5.3 Fabrication of 3D blocks in workshop

3D blocks complex structures consisting of flat panels, 2D sub blocks and curved blocks. Assembly of these units is done, in most of the yards. Mechanised welding is installed in some yards also for closed structures (i.e. electro-gas) while some mechanised solutions have been developed even for dock-area welding.

The building strategy for 3D blocks is designed so as to make the welding in best possible positions, but also maintains possibilities of efficient block outfitting.

Outfitting of 3D- blocks is important part of the modern shipbuilding philosophy. When properly planned, major part of the outfitting can be performed in the workshop, where the working positions are optimal and material handling much easier. After erection of the hull the working conditions are much worse (usually top of the head installations and the transportation of equipment and other materials much more difficult).

High degree of block outfitting means that the steel and outfitting work are parallel activities and interact each other throughout the block assembly period. This sets certain limitations to the automation of block assembly and the practical solutions are not very common today. Principally the same technical solutions as in 2D-blocks can be adapted, but the more complex shapes and the integration with the outfitting limit considerably the practical possibilities.

5.5 Blasting and painting / coating

5.5.1 Blasting

The aim of getting a clean surface (SAE 2,5 Quality - SIS 05590-1967 standard) by means of thorough blasting, can be achieved by various methods:

1. Sand and abrasive blasting is only allowed in closed and ventilated rooms. Not in open air!
2. Copper Slag or other mineral abrasive are only to be used for tanks within the section.
3. Grain size of steel abrasive between 0,3-1,0 mm is used for general blasting.
4. Cut wire or steel shot is used for mechanical shot-blasting.
5. High-Pressure Water-Cleaning 300-2,500 bar pressure.
6. Ice-Particles cleaning is being used only for special tasks.

The steel-blast-material is collected, sometimes under the working floor, is being cleaned / separated and transported back to the silos for being used again.

The complete shop must be constantly "de-dusted" of the dust by means of a very effective ventilation system. The free-blasting workers must wear breathing apparatus.

To reach the different level of a block-section normally a scaffolding system is installed at the walls of the shop and being swung to the unit, for easy access.

In alternative to the classical methods, the "VACU-BLAST" method consists of a unit, which works like a vacuum-cleaner and does not need any de-fuming / de-dusting or fresh air for the operator. This system has one handicap, the cleaned area per hour is considerable less compared to any other method.

Shipyards tend to order the plates already blasted and shop primed. However many yards have invested on installations to clean by blasting and paint block assemblies after all welding (except erection) has been completed. This gives a better appearance and plate protection (shop-primer is destroyed by welding).

5.5.2 Coating / painting

After a thorough cleaning, the block-section is painted / coated in place or after being transported to the coating-shop. As per paint specification, the different layer of paint will be applied, in accordance with the required curing time, by means of the paint spraying method. The shop has to be adequately heated and ventilated.

As shown in Figure 1, page 32, a certain part of the painting / coating has to be done on board as part of the *finishing & outfitting* process. As with every operation on the dockside, it is much less efficient and less healthy than in the shop. That is why shipyards tend to coat and paint as early as possible in the production process. Nevertheless, it is estimated that 20% to 40% of the surface of a modern vessel is painted in the dock area.

The surface to be painted / coated in modern vessels has increased dramatically the last years on almost all vessel types; in particular in those having a double hull structure (150% more than the single hull). The total area to be painted in a typical double-hull VLCC of 300,000 dwt is about 380,000 m².

Painting / coating can be quite an unhealthy work. Painters represent, directly or indirectly (through subcontracting) an important part of the shipyard's working force. According to [36], painters represent more than 20% of the working force of the Hitachi Zosen Ariake works, about the same as the welders.

5.5.3 Automation / mechanisation

Despite the increasing importance of blasting and, particularly, painting / coating activities as well as the increasing difficulties in finding painters, no substantial steps have been taken towards the robotisation of these processes. The only significant relevant work that we are aware of is that in [36] on a *NC painting robot for ship-building*, from the Hitachi Zosen Corporation.

There are a number of RTD projects on robotics, which can be of potential interest for future painting robot applications, like an IMS project on a snake robot, jointly developed by US, Japan, EU and Korea and the OCTOPUS project on the vessel topside cleaning.

5.6 Transport & handling

In addition to the self-explanatory Figure 4 below, two more transport / handling devices need to be mentioned:

- The Dual Walking Beams (DWB) units are individual working machines, completely self-contained. They are working in groups as per load-requirement and are operated by one operator. They are designed for a load of 100 t, 200 t and 400 t per unit. The DWB units can move heavy loads over any reasonable firm and flat ground, without the need of tracks, rails or skids. Crushed gravel is acceptable. They can overcome gaps between quay-wall and barge, cross rail-tracks and move up or down a slope of up to 4 degrees. The maximum load up till now handled by a DWB-system was a complete submarine having a weight of 12,000 t and being transported from the construction-shed to the launching site.
- Air Cushions, as an example those distributed by Aero-Go, US. With the aid of fluid film technology, aero-casters use compressed air or, occasionally, liquids, to actually float heavy loads on a thin fluid film. Individual units of a carrying capacity starting from 0.9 t up to 400 t are available. Coupled together they also can handle even larger loads. The only disadvantage compared to the DWB system is that the floor-surface has to be of a much higher quality.

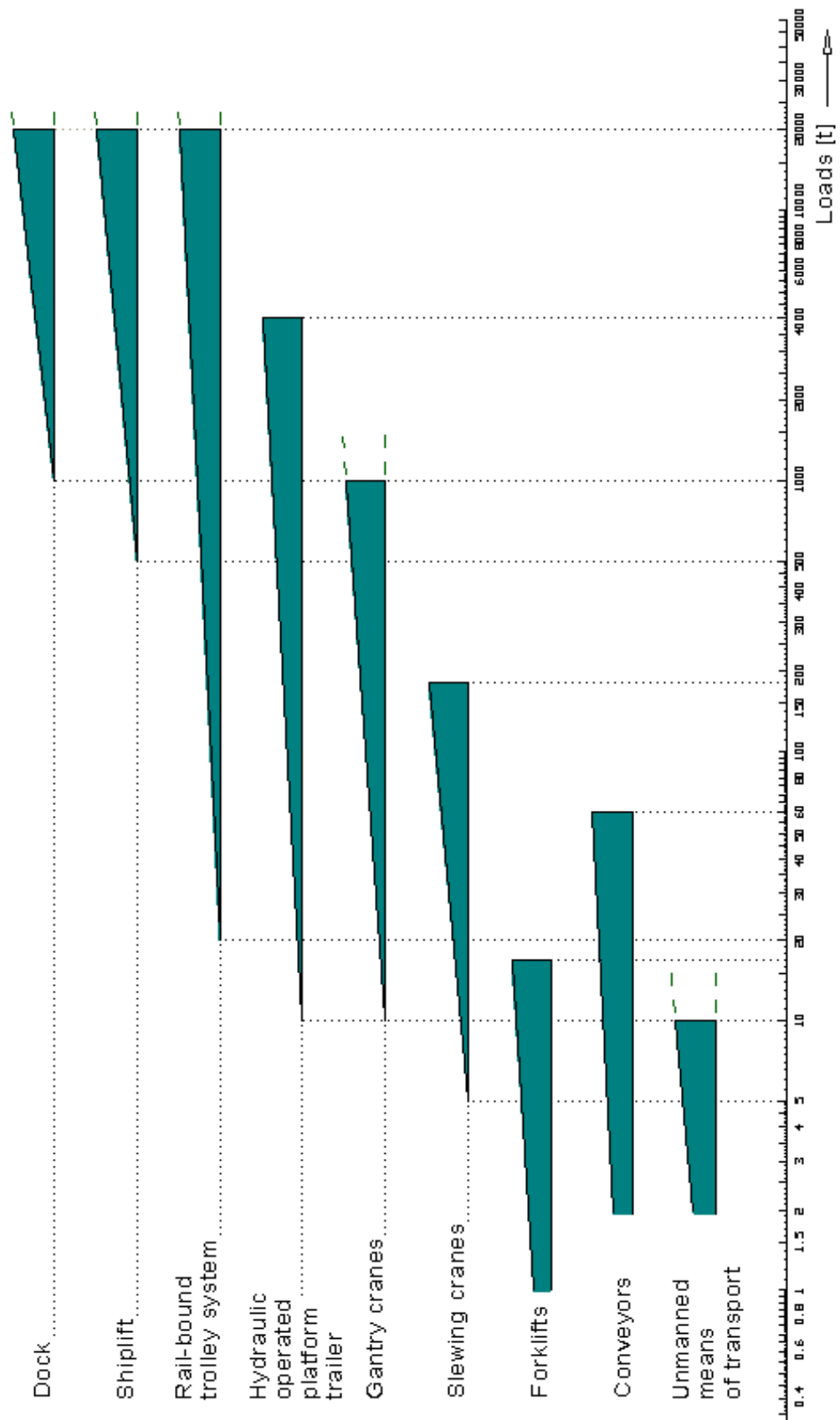


Figure 4: Usual means for handling loads

5.7 Dimensional control & inspection

According to [33], accuracy in production is seen as a main subject where QA/QC concepts can lead to major reductions in production costs. Today's standard concerning accuracy in production seems to be on a good way but some important areas for improvement have been identified.

3-D coordinate measurement techniques are in use at nearly all shipyards. Those who didn't introduce them up to now have these in test or development phases. The local plan/actual data comparison is common on most yards. Those who are not able to do this at present are interested in doing so in the near future.

There is a high interest for R&D in this field. Most shipyards use the measurement results not only for later process improvement but also in the actual ongoing production. The electronic data transfer is already introduced on half of the yards; all others are highly interested in this technology.

5.7.1 Measuring techniques / devices

Tape measuring is the leading method in the various production stages from parts fabrication to subassemblies, including plates, curved plates and profiles, panels and curved panels for nearly 2/3 of the yards.

For measuring sections, blocks and hull assembly less than half of the yards use 3-D co-ordinate measurement techniques, whereas the others use theodolite systems. Some use both systems parallel. Roughly 1/6 of the yards use these systems also for checking panel, curved panel and subassembly tolerance control.

Two yards use stationary photogrammetric measuring both for checking parts (plates) and panel accuracy.

For measuring the flatness the rotation laser is used on very few yards for subassemblies and higher production stages.

The measuring frequency is handled quite differently, spot check or 100% - check seem to be real alternatives, only very few yards have established a systematic approach for the frequency of checks.

5.7.2 NDT methods

The standard manual NDT methods (x-ray, ultra sonic, dye penetration and magnetic particle test) are implemented in every shipyard without exception. The technical standards are sufficient and there is no interest for further development in this field.

However, interest is put on the development of automated testing and verification procedures as well as on online process monitoring systems for welding on stationary plants. Automated test analysis systems are in use only in 1 out of 5 yards. Consequently, the interest for further RTD is rather high.

The use of light materials (aluminium, high-strength steel grades or thermo-mechanically treated steel), and the joining or welding combinations of above, introduce new challenges to prevent fatigue and corrosion failures, this requiring more extensive control in welding and service inspection.

The introduction of lighter sandwich materials that may be joined by gluing or the introduction of laser welding will require the collection of testing experiences on flaw detection on new databases.

The corrosion monitoring of ships' hulls in service where ultrasonic thickness measurement techniques are used, is still subject to new developments (i.e. the resonance method proposed by DNV). Results from thickness measurements are integrated by the classification societies in a ship record from the construction through operation.

5.7.3 Monitoring systems for QC (Shop floor monitoring etc)

Assembly and welding sequence plans are used in almost every shipyard. The same applies to production stage oriented welding standards.

Very few of the questioned shipyards have established any online process data registration system by now, but some activities can be seen in this field.

Manually prepared process data documentation is introduced on almost all yards, the remaining ones are testing whereas product related process data documentation through all production stages is used only on half of the yards, yet few others are interested.

Product related accuracy documentation is already used by 2 yards out of 3. The same goes for the visualisation of measurement results for the workers on the shop floor.

5.8 Welding processes in shipbuilding

5.8.1 General

Welding is by far the most important technology applied in shipbuilding. The weight of the metal deposited by welding in a ship can easily be as much as 3 to 4% of the total steel weight, and the cost of the welding consumable per kg deposited can be more than 10 times the cost of the same weight of steel. Hence, many processes are oriented to as narrow gaps as possible or even in achieving the weld through the fusion of base metal with a minimum deposition of new metal.

Although the deposition rate gives an idea of the capabilities of the basic process, the main cost parameter to consider is the velocity of the overall welding process (in m/s), which depends of the welding position, plate thickness, root size etc.

Table 9: Comparison of welding speed (m / min) for some welding methods, source: Messer IGM 1999

Steel thickness	4 mm	6 mm	8 mm	12 mm
MIG / MAG	1.1	0.9	0.75	0.55
Plasma	0.45	0.35	0.25	-
Laser	20	15	1,2	1,2

MIG = Metal Invert Gas MAG = Metal Active Gas

Table 10: Weld metal consumed between 1975 and 1996, source: ESAB 1999

Welding Method	Western Europe	U. S. A.	Japan
MMA	18 %	22 %	16 %
MIG / MAG Solid Wire	68 %	52 %	53 %
FCW	8 %	20 %	25 %
SAW	6 %	6 %	6 %
Total weight in t	381,000 t	295,000 t	310,000 t

MMA= Manual Metal Arc MIG = Metal Invert Gas MAG = Metal Active Gas
FCW = Flux Cored Wire SAW = Submerged Arc Welding

5.8.2 The main types welding processes

The main welding processes applicable to shipbuilding today are:

Submerged arc welding (SAW) is limited to welds that can be positioned on a horizontal plane. Is used extensively for butt-welding of the plates for the fabrication of the flat panels. With copper backing (or ceramic or powder backing) steel plates up

to 20 mm thickness can be welded in one pass from one side only. Multiple arc tandem-arc, series- arc (3 arc on one pass), magnetic clamping, and procedures using metal powder addition provides highly efficient mechanized systems for different plate thickness. SAW tractors using movable tracks provide an effective automatic welding that can be used also on assembly and erection stages (joining deck or bottom panels) and also on continuous fillet welds (using the beam as guide). SAW welding is also widely used for automatic T section stations

FCAW (flux core arc welding) and MCAW (metal core arc welding) semi-automatic wire processes are now dominant in European shipbuilding and with variations of diameter size, core composition and gas (electrode classification and type) have substituted almost completely the stick electrode (MMA) on production, even many subcontractors still use. Some highly automated yards may still use 20-30% of manual (stick) consumables. Solid wire (MAG) is also used as a low cost consumable with acceptable quality.

Ceramic backing is widely used, to allow one pass welding not only on horizontal position with sub-arc but also on semi-automatic MAG welding in any position at workshop or on assembly or erection on dock. Savings in root grinding for the back pass and/or on the root pass, often eliminating the 180° turn of the block, have proven cost reduction and worsens the potential advantages of robotization.

FCAW is used on mechanised station for fillet welding and robot stations. Some mechanised stations working on 10 m up panels can weld 4 reinforcements at a time from both sides (eight arcs). FCAW is used also on automated egg-crate welding (4 arcs at a time in vertical position) on double bottom assemblies.

Friction stir welding (FSW) has been invented and patented by The Welding Institute (TWI). A wear resistant rotating tool is used to join sheet and plate materials such as aluminium, copper and lead. The welds are made below the melting point in the solid phase. The excellent mechanical properties and low distortion are attributed to the low heat input. Three Scandinavian companies now use the process for production of large aluminium panels made from aluminium extrusions. Research and commercial FSW machines are now available and included complete installations to weld up to 16 m lengths. This technique is already being applied in the construction of fast ferries and heli-decks.

5.8.3 Mechanised or semi-automated welding

In welding, the term *semi-automatic* is often used to design *manual* welding with wire feeders (MAG or FCAW), today representing more than half of the welding in most yards. MAG or FCAW with high performance procedures ends with a heavy gun carrying the power supply, the wire, the gas supply and, today, the fume extraction hose. When working in a wide space, the lengths of the 3 or 4 connecting hoses makes the welding gun a heavy tool to work with. Support to the welder may be from mobile suspending holders to gantries where the welding system is suspended and moved through the working area.

In shipbuilding there is also a frequent use of self propelled and guided tractors typical on SAW on horizontal surfaces, and light mechanization devices (basically a motorised device running in all positions on a track that is attached to the plate by magnets).

5.9 Laser technologies for cutting and welding

The big attraction of laser technology to the manufacturing industry, specially where thin plate products are extensively used, is due to the limited heat deposition / dispersion during both laser-cutting and welding. Heat deposition causes thermal distortion, which is an important source of re-working and low quality.

Although a big effort has been undertaken by equipment manufacturers, research centres (specially The Welding Institute, UK), gas companies, steel suppliers and, in shipbuilding, the classification societies and some pioneer yards, the introduction of laser technologies in shipbuilding has been rather slow. This in spite of the consid-

erable progress that has been made in other fields such as the precision, electronics and on automotive industries.

The reasons for that lay mainly in the extensive overhauling of the whole steel production chain which the use of laser technologies imply as well as in the very tight tolerances and the consequent manufacturing, handling and positioning issues.

Some selected references on laser technologies cutting and welding in shipbuilding are listed from [37] to [43].

5.9.1 Actions promoting laser relevant to cutting and welding in EU

Laser cutting and welding is promoted through national programmes in UK and Germany. In Germany the Federal Ministry of Science and Technology, has funded the Laser 2000 programme with an annual budget of 35 M€ including education and technology transfer and support SME.

Laser manufacturers, gas suppliers and steel makers have developed new products to make laser equipment more competitive and improve the limits of the current equipment.

First applications of laser on shipyards are found in Germany (Meyer Werft), UK (Vosper), Italy (Fincantieri) and Denmark (Odense). The most interested yards are the passenger and ferry builders, using thin plate with high planarity / quality requirements.

There is a number of EU projects on laser-technologies, including some shipbuilding applications (see [29]), as well as a relevant thematic network (TRANSLAS).

5.9.2 Main types of lasers used for cutting and welding

CO₂ lasers were first developed in USA in 1964. It can handle large power but cannot be transmitted through fibre optics. Delivering and focusing the laser beam to the required require the use of delicate precision mirroring systems as well as the motion of either the work-piece or the whole laser head (or both).

It can be used for cutting ferritic steels (with oxygen at low pressure), stainless steels (with high pressure nitrogen), titanium and magnesium (with argon). It is used with helium or argon as protective gases during welding.

Thermal efficiency is up to 10% and maximum output is about 45 kW. Applications are around 85% on cutting, 14% on welding and 1% heat treatment.

Today, CO₂ lasers can easily cut up to 20 mm of steel and weld up to 7 mm in a single pass (applications up to 25 mm claimed).

Nd YAG (neodymium-yttrium aluminium garnet) were first developed in USA in 1964 at the same time as CO₂ lasers. They are less energy efficient, and have progressed rather slowly. The optical energy produced by Nd YAG lasers, has a significant advantage when compared CO₂ lasers in that it can passed through a fibre optic cable thus allowing far greater flexibility. The auxiliary protection gases, oxygen nitrogen, helium or argon same as for CO₂ lasers.

Thermal efficiency is up to 2.5% and maximum output, to date, is about 5 kW (3 kW practically on industry).

Nd YAG lasers are used up to 70% in precision welding, 25% on cutting and drilling and 5% in marking.

The fibre optic transmission facility makes this laser flexibility ideal for 3D operations. It is used quite extensively on the automotive industry (tailored blank welding) and aerospace.

Hybrid laser / plasma systems for cutting and combined laser / arc welding are in research application phase. Those pioneer shipyards that have already started using laser installations are strongly interested in further R&D.

5.9.3 The advantages and constraints of laser technology in shipbuilding

The main advantages derived from using of laser technology for cutting and/or welding are:

- The same equipment can be used for cutting and for welding, (changing optics and gas protection)
- Energy can be tightly focused (a 3 kW laser focused to within a 0.2 mm diameter spot generates a power density of 95 kW/mm²)
- Low noise and fumes
- High quality square edge cuts
- Chamfer/bevel cutting dross free, low heat affected zone
- Minimum distortion after cutting or welding
- Flexible CNC environment, potential for 3D automation

The main constraints that the use of laser technologies imposes are:

- Investment recovery/ intensive use
- Restrictions on low C, S, and Ph steels needed for welding. New or modified cracking tests used.
- Special planarity and thickness tolerances are needed. Mill stresses released when cutting may produce deformations on the plates, over the laser focus length tolerance.
- Acceptance by classification societies; concern on solidification cracking after welding, and on potential of local corrosion in some joints.
- Redesign of the weld configurations for laser welding (specially T welds)
- Cuts must be often conditioned due to excessive sharpness.
- Single pass butt-welding is limited (to 15 mm). Not competitive with the one-side welding tandem or arc-series submerged-arc in butt-welding of plates.

Extensive testing on material properties welding 6 and 12 mm thickness with participation of the Welding Institute UK and classification societies has been performed in the last ten years. The laser welding database extent is considered not sufficient, while data on fatigue on service of laser welds is practically non-existent. Butt-welding with laser with more than a 0.5 mm gap requires filler metal (or tandem laser), this introduces another variable. Progress on laser hybrid welding processes will be slow and may be promoted only for other specific applications and procedures where sufficient testing and guarantees can be provided. Applications on non-critical / structural parts of passenger ships, i.e. superstructures, can progress more quickly.

5.9.4 Automation issues

A laser facility, in contrast to other means of welding, has to be completely automated. It cannot be manual, semi-automated or mechanically assisted. The automation requirements, in particular of the laser welding processes, are one of the most important bottlenecks in the practical application of laser technologies in shipbuilding. The main issues are:

- Manufacturing accuracy (tolerances, planarity etc)
- Precise delivery (position, speed and focus) of the CO₂ beam; it implies either the precise positioning of the pieces to be welded or the precise positioning of the whole CO₂ laser equipment
- Avoidance or compensation of the thermal distortions during the laser welding process
- Reliable operation; avoidance of expensive, off-line calibrations

5.10 Automating one-of-a-kind processes

The main reason for which the largest part of shipbuilding processes are not yet automated lies in the very nature of the shipbuilding operations coupled with the fact that the robotic market has been almost entirely dominated and tailored to the large volume automotive and commodities industry. In fact:

1. Almost none of the shipbuilding operations are exactly repeatable; at best they are similar. Many operations are performed only once or at most a very limited number of times.
2. Many of them, especially the assembly operations, involve very important payloads, in terms of mass, volume and cost.

As what robotics is concerned, these two facts are of fundamental importance. They mark a clear cut with the robotics and automation technologies as applied in the large production volume industries like automotive or commodities manufacturing. For example, let us consider the automotive industry:

- Most of the operations are repeatable over many thousands of identical cycles involving, most of the times, limited payloads;
- Planning and optimisation of even the most complex processes can be achieved not only through simulation but also through trial and error;
- Operations can be “taught” and the concept of repeatability (precision in repeating a path under given conditions) is more important than accuracy as such.
- Accuracy is usually assured through very rigid mechanical parts and low payload to own weight ratios.
- There are no particular safety and reliability issues.

In the context of a typical shipyard (or, in fact, in many heavy industries or construction sites) none of the above conditions is true. On the contrary:

- Operations are generally one-of-a-kind, that is almost no operation is identical to another; at best they can be *similar* to each other.
- Planning and optimisation can usually be achieved only through simulation,
- Payloads can be very important;
- Teaching is impossible;
- Usually, there exist important safety and reliability issues due to the important masses and dimensions involved and to the very big capital cost of the equipment and the payload involved.

In such conditions (i.e. one-of-a-kind operations), the most important performance criteria of a manipulating robotic system are the ease of path planning and/or the operational flexibility. Autonomy in the execution of certain tasks is a must for ensuring the above stated characteristics.

Although some elements of low-level task autonomy are built in some widespread applications (i.e. the control of the electrode across a weld) heavy industry has made little profit from such technologies, especially in what concerns the field of heavy robotics and handling applications. In fact, many such operations are still performed by “non intelligent” equipment such as heavy-duty transporters or manipulators that are usually under the direct control of the human operator. The fact that in some cases (i.e. inaccessible or hazardous environment) the operator is assisted by a more or less sophisticated sensorial systems (i.e. tele-camera, proximity sensors, force sensing) does not remove him from the control and responsibility for each of the low level tasks (see Figure 5 below). This lack of autonomy in performing low-level tasks is an important source of low quality, errors and delays.

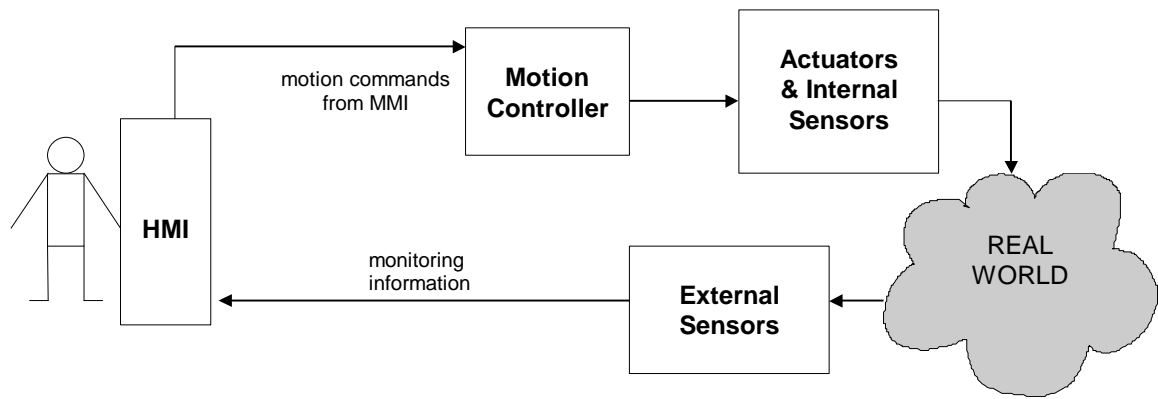


Figure 5: Non-supervised manipulating system; information from external sensors (if they exist) serve for assisting the operator to command the manipulator

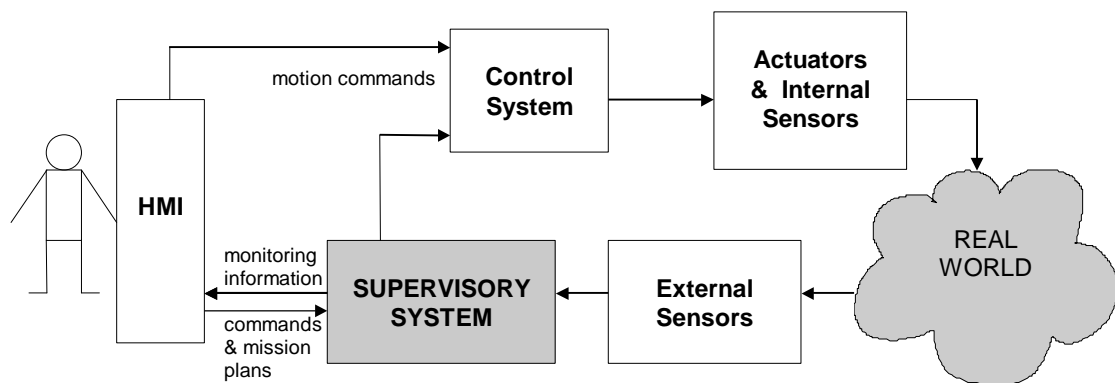


Figure 6: Supervised manipulating system; information from external sensors are fed to the control system rather than assisting the operator to command the manipulator

Integration of the right sensorial information in a supervisory control type scheme (like the one depicted in Figure 6 above) can permit the autonomous execution of many low-level tasks with two important consequences:

- (a) the human operators of robotic manipulators could be concentrated in high level activities (such as planning and supervision) instead of performing low level tasks (such as collision avoidance, precision positioning etc).
- (b) "Small" variations in the work-pieces or in the working environment could be dealt without any need of reprogramming off-line automated or robotised facilities.

Examples of low-level tasks that could be executed autonomously include:

- Obstacle avoidance;
- Adapt to the execution of "similar", not exactly repetitive operations;
- Corrections for work-piece or workspace "inaccuracies" (i.e. due to thermal deformations)

Task autonomy cannot be achieved but through novel "intelligent" control schemes integrating sensorial systems. It implies the use of data fusion, hard real time computing, autonomous mission execution etc., techniques that are far from being established in the environment of manufacturing or engineering industries (see next paragraph) but are used extensively in some military, deep-sea, space and other "high tech" applications. Specially in heavy robotics, when manipulating large and heavy loads, new tracking techniques compensating or bypassing the inevitable mechanical inaccuracies are required for reliable precision positioning and handling.

It is noteworthy that, according to the IFR (International Federation of Robotics) classification [10], no such class of industrial manipulating robots is foreseen. Autonomy is only foreseen in the new category of "service robots". According to a preliminary definition by IFR, service robot is a robot which operates semi or fully autonomously to perform services useful to the well being of humans and equipment, excluding manufacturing operations.

An additional factor to consider is that most heavy robotics/handling installations in shipbuilding and other heavy industries are tailored made, often by the final user himself. This prohibits the amortisation of the cost for the introduction of technologies such as stated above. The already high development cost is further augmented because of the inherent safety and reliability requirements implying extensive testing and validation procedures and the big and expensive experimental facilities needed for the experimental demonstration, testing and validation procedures.

6 Design, planning & logistics

6.1 General considerations

An important part of the information reported in this section on the design tools is based on reference [31], that is on SoA report of the PRODIS thematic network, issued on November 1999. Information on CIM and logistics is based on reference [35], that is on SoA report of CEPS on thematic area 10 on CIM & logistics in shipbuilding.

Another very concise document on modern ship design is *the future of ship design*, by DELTAMARIN Ltd, [44]. Several data, especially on the 3D and 4D product model, have been taken from this document.

By the term *design activities* we mean all these activities that generate the information necessary for the realisation of a shipbuilding project. In a somewhat more restricted interpretation, design is associated just with the product, that is the vessel itself; activities having to do with production scheduling, warehouse control etc are not classified as design activities. In this report the term “design” will be used in its broad interpretation, encompassing production design and planning, scheduling etc.

6.2 The importance of ship design

Recent evolution of the EU shipbuilding (see section 3.1 above), in parallel to the diminishing relative importance of steel working, have caused a significant increase in the volume, value and relative importance of the design activities. In fact, design activities (including management) can easily reach over 10% of the cost of a modern passenger vessel [44]. What is even more important is the fact that design activities have an important impact on many other costs like materials, subcontracting, production etc as well as on delivery time. The importance of design activities has been recognised by the big EU yards, which invest considerable sums on enhancing and integrating their design activities.

In [44], DELTAMARIN Ltd has gathered and analysed more than 50 recently built passenger cruise ships of all sizes. Rather big, sometimes amazing, differences have been found in terms of space utilisation. Even if some of the differences can be explained by different vessel characteristics, there appears to be no plausible explanation other than the differences in design quality and efficiency. Analysing the space-weight relation of recently built cruise ships shows that the most efficient ship has 40% more effective area per lightweight ton compared with the least efficient. A typical difference is about 20%, which can already be considered to be high. The vessel type and standard may have certainly an impact on these numbers, but otherwise it is difficult to find other explanations except efficiency in the design.

Hence, ship design efficiency is of vital importance to shipbuilding industry. In spite of the considerable investments and the developments in the various design tools and methods, there is still considerable room for improvement and substantial economic return potential.

6.3 Ship design activities

We can distinguish, according to its utilisation (i.e. the client for which the design is made), in 3 main types of ship design:

- Pre-design (conceptual and contract design)
- Basic design (including class design)
- Detail design

As far as the approach and tools employed we can distinguish:

- CFD for the hydrodynamic calculations, usually aimed at the verification or optimisation of the hull form and the propulsion

- Classification rules for the verification of the vessel structure under the specific design loads and conditions
- FEA used for structural analysis, usually aimed at the verification or optimisation of the vessel structure under the specific design loads and conditions
- Surface modelling for fairing detail definition of the main hull surfaces
- Solid modelling for the creation of part models
- 3D ship product model

6.3.1 Pre-design

Under the term “pre-design” we include all the conceptual and the contractual design activities. Pre-design is essentially based on the owner’s specific requirements as well as on the applicable rules and regulations. It is of paramount importance for the success and the profitability of the shipbuilding project, it makes extensive use of a wide range of tools and requires very experienced, high-level personnel. It involves the following activities:

- (a) Selection of the general ship configuration, main dimensions and coefficients: This activity is usually based on the judgement, experience and creativity of the designer. Some artificial intelligence (AI) tools have been proposed recently but, for the time being, they have been of limited use. No particular breakthrough is to be expected in this field.
- (b) Preliminary design of the hull form: Although it makes extensive use of specialised CAD packages, it is mainly based on the experience of the designer. Some tools have appear recently, which generate directly the hull form out of the principal dimensions and coefficients.
- (c) Still water hydrostatic calculations: This field is well known; it has been among the first computer based applications in shipbuilding.
- (d) Still water hydrodynamic calculations: Although significant advances have been made in the field of CFD, mainly in what concern the numerical model preparation (pre-processing) and the visualisation of the results (post-processing), CFD hydrodynamic calculations are reliable only in conjunction with basin model tests or when extensive tests and measurements exist for similar ships.
- (e) Ship structural configuration: It involves the definition of the decks and bulkheads as well as weight, volume and centre of gravity calculations. It is a rather well addressed field with a number of PC-based software packages (mainly from classification societies), which assist the designer to rapidly try and evaluate various alternatives.
- (f) Loading conditions and sea keeping analysis: Loading and sea keeping conditions are selected according to the rules and regulations for each particular vessel type. There exist a number of commercially available packages for the investigation and analysis of the results.
- (g) Main equipment data sheets and requirements: Most of the work involved here is straight forward, based on experience as well as on applicable rules and regulations.

Although adequate computer tools are available for almost each of the above-mentioned activities, a lot is remains to be done regarding their utilisation in an integrated environment. The pressure exercised on the shipyards for shorter delivery times in conjunction with the increasing engineering work in an increasingly complex, concurrent environment, puts in first priority the integration of all these pre-design activities.

6.3.2 Basic design (contractual / class)

Basic design is based on pre-design activities, focused on the specific class approval requirements and producing other necessary schemes and arrangements for detail design. Part of the documentation has to be approved by the ship owner. It involves the following activities:

- Hull structure scantlings necessary for class approval: PC based software is usually provided by the class
- FEA structural model(s) for class approval.

- Hull structure class drawings: Only a subset of detailed drawings is required. Necessary data can usually be obtained from the first steps of 3D ship product modelling.
- Equipment data sheets: In most cases it involves just the use of spreadsheets
- Piping, instrumentation and electrical diagrams: Relatively simple graphic editors (with some accounting capability) can handle the job. Recently, 3D ship product model is used so that the data entered to be consistent and available for the later detail design phase. The same holds true for the general arrangement drawings.
- Eventual updates and/or modifications necessary for class approval

In general, most tools used in basic design activities are well established and used throughout the range of the involved organisations. Communications and integration / interfacing between pre, class and detail design activities are items in which there is room for significant improvement.

Class design is an important part of basic design, focused on the specific class approval requirements. Indeed, many classification societies offer, often for free, very comprehensive software packages covering most needs for basic design. Recently, some of them have begun developing 3D ship product software packages [17] in which they plan to integrate, in a product life cycle approach, all the class related information about a vessel, from pre-design to periodic inspections, eventual modifications and maintenance down to its decommissioning and scrapping.

6.3.3 Detail design

The main scope of the detailed design activities is production itself. In general, the amount of work involved (in terms of man-hours) is considerably higher than either pre or class design; it is generally performed by personnel of lower qualification. Detail design associated with the traditional *steel part* of shipbuilding is well covered by a range of software products.

Detail design usually started only when pre-design had been completed and class design had been quite advanced. Shorter delivery times and increasing amount of engineering work have created significant overlaps, which are only recently started being managed by the introduction of concurrent engineering and other collaborative tools. The boundaries between the pre, class and detail design are fading as the lead time from contract to production and delivery become shorter and shorter.

Powerful, integrated CAD packages promising integrated concurrent engineering and collaborative product commerce and resource planning solutions are still in development by the major CAD vendors.

6.4 Ship design software tools

6.4.1 Hydrodynamics

Computational fluid dynamics (CFD) has entered commercial shipbuilding from military and aerospace applications through academia, relevant RTD institutions and towing tanks, which will continue to be the main producers and users of CFD codes.

The ultimate purpose of any CFD code is to provide the solution of the Navier-Stokes equations for time-dependant, 3D, laminar or turbulent flow around bodies of arbitrary shape. This objective is far from reached, principally because of insufficient understanding of basic physical phenomena involved. In particular, the complex vortex flow near the stern of the ship cannot be adequately modelled.

Although CFD tools alone cannot predict the still water behaviour of a given hull with sufficient accuracy, they constitute valuable design tools, used in conjunction with towing tank tests or for comparative analysis of various alternative forms.

Because of the great economic impact of the fuel consumption and the high impact of propeller induced vibration and noise on comfort, the area of resistance and propulsion is the best-developed hydrodynamic area. Nevertheless, CFD tools alone

are not capable of predicting the sea-keeping or manoeuvring characteristics of a vessel, the local loads or the ship's behaviour on extreme conditions.

Further development efforts are driven by the need for an increasingly fast and accurate early design rather than the need of more accurate and elaborate solutions.

6.4.2 Structural

The primary tool for the definition of the structure and scantlings is the Classification Codes. Otherwise, more or less standard FEA packages such as NASTRAN, ANSYS, ABAQUS and other, are used for the hull structural analysis. FEA techniques and methods are fairly standard and rather well developed. On the contrary, an important domain where significant progress has been made lately is that of pre and post-processing. This is due to the significant increase of the graphics capabilities of both UNIX and PC based systems as well as to the new OOP techniques that allow for the building of dedicated, user-friendly interfaces.

As in the hydrodynamic codes described in the previous section, further development efforts are driven by the need for an increasingly fast and accurate early design and are likely to be focused in the following areas:

- Quick definition of an early FEA hull model based on a skeleton configuration of the main structure.
- Mesh parameterisation and re-use.
- Integration of meshing with other phases of the basic and detail design.

Finally, due to the complexity of the FEA calculations and the consequent high level of qualification required by the personnel, medium and small yards are not likely to be using them but on exceptional occasions.

6.4.3 Thermal shrinkage prediction

Heat shrinkage is considered in the detail design process on almost all of the yards. Half of them define shrinkage values for all assembly stages separately and are thus able to attribute shrinkage to the actual cause and location. The others have to distribute shrinkage over the complete part. In addition to some ongoing development activities there is a strong interest in developing methods that allow attributing shrinkage values to the area where it occurs.

Calculation of shrinkage values is done either manually or automatically (in 1 out of 3 yards). They are mostly based on empirical databases. There exist a definite interest for increased use of automatic calculations. The shrinkage calculation programmes are either stand-alone solutions or integrated into the CAD packages. There is a very big interest for highly integrated solutions.

Numerical (FEA) methods for shrinkage calculation are not in widespread use.

6.4.4 Decision Support Systems

Intelligent constraint based programmes are in use at about 20-30% of the shipyards and primarily in Europe. Applications include both assembly planning (product breakdown), scheduling and capacity planning. Ongoing development is being evaluated particularly in the USA and in Europe in connection with ESPRIT and EUREKA projects.

Simulation tools are used at about one third of the responding shipyards throughout the world. Applications relate to assembly planning, schedule and capacity planning as well as facility evaluations. In addition simulation of robot processes and applications is increasingly practised. Further developments are in hand related to capacity planning (bottle-necks) and robot simulation.

Virtual reality tools are currently not so widespread in Europe; more so elsewhere, particularly in USA, in the areas of internal design development and production evaluation. They are more widespread (about 47%) in a wide spectrum of yards particularly for the discussions with owners. Development is particularly seen in relation to complex ship types such as passenger ships and especially naval vessels.

As what further development is concerned, operational applications must increase in order to optimise decision making with regard to engineering and production for ship projects ensuring quick responses compatible with the new CAE potential. More in particular:

At short term:

- Constraint based programming for assembly planning and production planning
- Further development of steel production simulation

At long term:

- Extended use of virtual reality for internal applications such as design development and design for production
- Use of multi media in training

6.4.5 Process data & workshop control

DNC systems are in use universally for steel cutting facilities and 75% of yards have DNC operated pipe bending. Outside of these areas, 50% of yards have other applications including robots and more specialist machine applications. Development of PDM (Process Data Management) applications is particularly focused on robotics. However, this area has not been fully developed yet. Further R&D is required to gather and apply better process data and thereby ensure optimal process, automation and quality solutions.

Development of workshop control systems is driven by automation but has not achieved the same level as PDM with only 60 % applied in steel cutting and 50 % in pipe fabrication. Decentralised control of robot cells exists and also coordination between cells for detail scheduling etc is practised to some extent (< 40 %). The systems are not fully deployed yet, further integration and decentralisation is required, including the human aspects, is under development. Particularly applications outside the automated areas of shipbuilding i.e. main assembly, erection and outfitting are very limited and require further development. The extension of CIM in production beyond the basic requirements of current robot and automation applications is required. The solutions should seek optimal production utilisation, flexibility and user interfaces.

The following R&D needs have been identified:

At short term:

- Development of planning data and tools linked to design systems with a view to reduction of lead time for production preparation and planning.
- Development of prototype fabrication cells using human oriented principles for operation and work organisation.
- Development of daily workshop planning tools for steel and outfitting for shipbuilding based on intranet and focused on human centred interfaces and operational organisation.

At long term:

- Real time process control
- Productivity control methods

6.4.6 3D computer modelling

3D computer models are still mainly prepared to compensate the actual plastic design models. Most of the models, modelling techniques, are specific for structural or piping design.

Models of complete vessels with all disciplines included are still rare. 3D computer modelling technique is generally not used at the project design stage.

Ideally, 3D computer modelling technique should be applied in accordance with the actual design procedure, i.e. starting from the project design phase before the shipbuilding contract is even signed. The same model should then be extended into a

real product when design and engineering are proceeding. There exist a number of companies and shipyards that, together with major CAD vendors, are moving towards providing more or less complete *product model based* shipbuilding solutions. Nevertheless, this target is a very ambitious one and, no matter what the various vendors advertise, it is still very far from being achieved.

6.4.7 Material Flow Management

Bar Coding systems are increasingly used internationally both for steel material (over 40%) and for outfitting (33%). However, on-line material monitoring is, as yet not so widely implemented. Automated warehouses are operational at a third of the yards primarily at the large yards building ship types with high outfit content.

Development of advanced logistics systems is limited to certain key areas and is, in part, related to other automation solutions. Further development of innovative logistics concepts and solutions is necessary. The following R&D needs have been identified:

At short term:

- Increased application of automated material handling systems in shipyard environment
- Material flow / information management with ship data model

At long term:

- Production Logistics Systems
- Transport Management Systems

6.4.8 Shipbuilding related software

A good overview of the use of the CAD / CAE tools in shipbuilding is found in [25]. A list of the major commercial CAD / CAE packages for shipbuilding, available in the market today is listed in Table 11 below. Hydrodynamics and ship theory software is listed in Table 12 while class / rules related software is listed in Table 13.

Apart from the specific SW packages listed here there is a number of general purpose CAD / CAE packages are used in shipbuilding. They mostly include FEA packages (i.e. ANSYS, NASTRAN, ABAQUS) but also specialised robotic and CAM packages (i.e. ENVISION, ROBCAD).

In addition, a number of shipyards have developed and use their own SW, which is not commercially available. It mostly has to do with logistics and production planning SW but in some cases custom-made CAD / CAM packages have been reported.

Nowadays however, there is a clear tendency to separate such SW development activities from the core business of the shipyards. This is done, generally, by forming separate companies, which provide IT services to the mother shipyard and, possibly, to other clients. Such solutions, apart from the functional implications to the shipyard, offer an additional flexibility in terms of wider market integration through mergers, acquisitions by big SW vendors etc.

Table 11: List of major ship design and ERP software used in Europe

Program name	Company	Category
TRIBON	TRIBON Solutions AB, St.Varvsgatan 1, P.O.box 50555, S-20215 Malmoe, Sweden, tel: +46-40-10-3455, fax: +46-40-978415 e-mail: market@tribon.com http://www.tribon.com	Design and production system for shipyards
CATIA / CADAM Shipbuilding	Dassault Systems / IBM France http://www.catia.ibm.com/	CAD/CAM/CIM for shipbuilding

Integrated Ship Design & Production	INTERGRAPH Marine Products Division tel: +1-256-730-7762, +1-800-345-4856, fax: +1-256-730-6708 http://www.intergraph.com	Design of ship model details, compartments, structure and equipment
FORAN v.40	SENER, Ingenieria y Sistemas, S.A. Severo Ochoa, 4-P.T.M. 28760 Tres Cantos, Madrid, Spain tel: +34-91-807-7185, fax: +34-91-807-7203 http://www.foransystem.com/ e-mail: foran@sener.es	CAD/CAM/CIM for ship-building
DEFCAR CAD/CAM modules	DEFCAR Engineering, Spain	CAD/CAM/CIM for ship-building
NUPAS –CADMATIC	CADMATIC OY, Vahaheikkilantie 37, 20810 Turku, Finland, tel: +358-2-412-411, fax: +358-2-412-4444 http://www.cadmatic.com/ e-mail: sales@cadmatic.com Numeriek Centrum Groningen B.V., Osloweg 110, 9723 BX Groningen, The Netherlands, tel: +31-50-5412-632, fax: +31-50-5423-717 http://www.ncg.nl e-mail: sales@ncg.nl	Ship design software
Master Ship	Yachting Consult Nieuwe Emmasingel 17 5611 AM Eindhoven, the Netherlands tel 31 (0) 40 24 32 395 fax 31 (0) 40 24 46 137 www.yachtingconsult.com	Integrated work preparation hull interior and piping Integration of EDM/PDM/ERP
Fairway PIAS	SARC Scheepsbouwkundig Advies en RekenCentrum BV Eikenlaan 3, 1406 PK, Bussum, the Netherlands tel: +31 (0) 35 69 15 024 fax: ++31 (0) 35 69 18 303 http://www.sarc.nl e-mail: sarc@sarc.nl	Hull design, structure
MARS	Logimatics AS Sofiendalsvej 9 DK-9200 Aalborg SV, Danmark, tel: +45-98186511, fax: +45-98184599 http://www.logimatic.dk e-mail: lmc@logimatic.dk In Poland: e-mail: cw@key.net.pl	Material and production control system for shipyards
Perception	SPAR Associates, Inc., 927 West Street, Annapolis, Maryland MD 21401 USA tel: +1-410-2638593, fax: +1-410-2670503 e-mail: info@sparusa.com http://www.sparusa.com	Enterprise resource management software, project management
PipeFAB, IsoFAB, HullFAB, Material, Scopelink, UniDAT, RoboFIX	Caretronic Ingenieurbuero GmbH Niels-Bohr-Ring 3a D-23568 Luebeck, Germany tel: +49-451/389 72-0, fax: +49-451/344 63 http://www.caretronic.de e-mail: info@caretronic.de	Pipe design and production software
Project Engineering System, Design Manager, Plant Design Management System, Plant Visualisation, etc	CADCENTRE Limited High Cross, Madingley Road Cambridge, CB3 0HB, UK tel: +44 (0)1223 556655, fax: +44 (0)1223 556666, http://www.cadcentre.co.uk , e-mail: sales_office@cadcentre.co.uk	Process plant design solutions: design and integration of data

MaxSurf CAD/CAM & HydroMax	Formations Design Systems Pty. Ltd. Australia tel: +61-8-9335-1522 fax: +61-8-9335-1526 e-mail: info@formsys.com http://www.formsys.com	CAD/CAM/CIM for ship-building: design, analysis, construction
AutoShip, Auto-Power, AutoHydro, AutoBuild, Auto-Plate, AutoNC,	Autoship Systems Corp. Head Office: 312-611 Alexander St. Vancouver BC, Canada V6A 1E1 tel: +1-604-254-4171, fax: +1-604-254-5171 e-mail: sales@autoship.com http://www.autoship.com	Design system with export direct to NC cutting systems
GODDESS	UK Royal Navy Agent: Graphic Research Corporation Portsmouth, PO1 3DN, UK tel: +44-(0)1705 291666 fax: +44-(0)1705 291888 e-mail: grc@grc-dea.demon.co.uk	Navy shipbuilding: design, analysis, construction for ships and submarines
DELTAMARIN	DELTAMARIN Ltd. Purokatu 1, FIN-21200 Raisio, Finland tel: +358 (2)437 7311, fax: +358 (2)438 0378, e-mail: deltamarin@deltamarin.com	Virtual reality model for ship design.
<u>International Marine Software Associates (IMSA)</u>	DESIGN SYSTEMS EUROPE Design Systems & Technologies, 150 Rue de Goa, F-06600 Antibes, France tel: +33-492-911324 fax: +33-492-911338 100622.3072@compuserve.com	Design software: hull, propellers, classification rules verification, shipyard management and production
MultiSurf	AeroHydro Inc., PO Box 684, 54 Herrick Road, Southwest Harbor, ME 04679-0684, USA tel: +1-207-244-4100, fax: +1-207-244-4171 e-mail: info@aerohydro.com http://www.aerohydro.com.com European Representative: Reinhard Siegel, P.O.Box 4027, D-24039 Kiel, Germany tel: +49-431-352-36, fax: +49-431-352-37, e-mail: 100411.2124@compuserve.com	3D boats modelling, fairing and CAD software
FlagShip	Proteus Engineering, 301 Pier One Road, Suite 200, Stevensville, MD-21666 USA tel: +1-410-6437496, fax: +1-410-6437535, e-mail: flagship@atinc.com http://www.access.digex.net/~proteus	Naval Architecture Software
Electronic Product Definition (EPD), Shipbuilding Solutions	COMPUTERVISION Corporation, 100 Crosby Drive, Bedford, MA, 01730-1480 USA, tel: +01-617-275-1800, http://www.cv.com	Hybrid modelling, multi-user assembly architecture, product and process enterprise data management
SYSTLA Projector V8	WM-data Oy, Ilmarisentie 20, FIN-15200 Lahti, Finland tel: +385-3-2538511, fax: +385-3-2538520, henim@wmdata.com	Software for calculating of projects quotations
ARAC Arithmetic Robot Application Control	Kranendonk Holland	Robot programming
NauSHIP	NautiCAD SRL, Via Arezzo 9, 54036 Marina di Carrara, Italy tel: +39-585-859280 fax: +39-585-859295 nauship@mbox.vol.it	Design and production software for shipyards

Table 12: Software packages on ship theory and hydrodynamics

Program name	Company	Category
Naval Architecture Package	Napa Oy (Ltd), PO box 322, Munkkisaarekatu 2 FIN-00151 Helsinki, Finland tel: +358 0 228131, fax: +358 0 22813800 http://www.napa.fi	Design systems for ship-yards, including damage stability
General Hydrostatics	Marine Software Creative Systems Inc. P.O.box 1910, Port Townsend, Wash. 93368, USA, tel: +1-360-385-6212, fax: +1-360-385-6213 e-mail: sales@GHSport.com http://www.GHSport.com/HOME.HTM	Calculation of trim, stability and longitudinal strength
Shipmo PC, Shaftkit 2.0	SML Software (division of Fleet Technology Limited), 311B Legget Dr, Kanata, ON, Canada K2K 1Z8, tel: +1-613-592-2830, fax: +1-613-592-4950, e-mail: sml@fleetech.com http://www.fleetech.com	Shipmo PC - seakeeping predictions, Shaftkit 2.0 - marine shaftline static alignment and vibration analysis
PropCAD, PropExpert	Hydrocomp Inc., 20 Rigley Avenue, Suite 100, Annapolis, MD 21401 USA tel: +1-410-2687810, fax: +1-410-2687812, 75477.3577@compuserve.com	PropCAD - propeller design software, PropExpert- propeller selection software
PIAS Fairway LOCOPIAS	Scheepsbouwkundig Advies en RekenCentrum (SARC) BV Eikenlaan 3, 1406 PK, Bussum, the Netherlands tel: +31 (0) 35 69 15 024 fax: ++31 (0) 35 69 18 303 http://www.sarc.nl e-mail: sarc@sarc.nl	More information

Table 13: Class related software packages, rules and databases

Program name	Company	Category
Nauticus hull	Det Norske Veritas, Veritasveien 1, N-1322 Høvik, Norway, tel: +47-6757-9900, fax: +47-67579911, http://www.dnv.com	Ship design analysis, stresses and deformations
DNV Exchange	Det Norske Veritas, Veritasveien 1, N-1322 Høvik, Norway, tel: + 47-6757-9900, fax: +47-67579911, http://www.dnv.com/dnv-exchange e-mail: dnv.exchange@dnv.com	Class information for ship, ISM management, surveys schedule
Ship 2000	Lloyd's Register and UK P&I Club http://www.ship2000.com	Database of Year 2000 compliant equipment
VeriSTAR	Bureau Veritas 17 bis, Place des Reflets 92400 La Défense 2, Courbevoie, Paris France http://www.veristar.com	Hull structural design and condition monitoring
PrimeShip	Nippon Kaiji Kyokai, 4-7 Kioi-Cho, Chiyoda-Ku, Tokyo 102, Japan, tel: +81-3-3230-1201, fax: +81-3-3230-3524, http://www.infoweb.or.jp/classnk London office: 6th Floor Finsbury Circus, London EC2M 7EB, tel: +44-171-621-0963, fax: +44-171-626-0383	Ship design and management, checks conformity with classification rules of ClassNK, Japan.

Marine Technology Abstract	The Institute of Marine Engineers, The Memorial Building, 76 Mark Lane, London EC3R 7JN, UK. tel: +44-171-481-8493, fax: +44-171-488-1854, http://www.engc.org.uk/IMarE , e-mail:mic@imare.org.uk	Reference to over 54000 maritime publications from 1940 to 1996
Marine Computing Guide, World Shipping Statistics, Ports Guide, World Shipping Encyclopaedia	Fairplay Publications Limited , Book Sales Department, e-mail: sales@fairplay.co.uk , http://www.fairplay-publications.co.uk	Electronic publications on disks CD
Data Catalogue	Lloyd's Maritime Information Services, 69-77 Paul Street, London EC2A 4LQ, United Kingdom tel: +44(0)171 553 1683 fax: +44(0)171 553 1961 e-mail: lmis@llplimited.com ,	Shipping databases: cha- racteristics, history, casualty, basing on Lloyd's List.
INS Data	Shipping Publications A/S, P.O.box 43 Sentrum, N-3521 Larvik, Norway tel: +47-33181113, fax: +47-33183676	Ship information database
Skipsfartens Innkjøpsbok, Norwegian Marine Equipment	IMI A/S P.O.box 1513, Sandefjord, Norway, tel: +47-33466844, fax: +47-33466834, http://www.imi.no , e-mail:imi@imi.no	Norwegian marine trade companies catalogues
IMO books	IMO International Maritime Organization, 4 Albert Embankment, London SE1 7SR, UK, tel: +44-(0)171-463-4137, fax: +44-(0)171-587-3241 publications.sales@imo.org	IMO publications on CD

As it can be seen in the tables above, Europe dominates shipbuilding related CAD tools with 3 major providers and numerous SMEs providing high value software packages and services, and the European based Classification Societies, are well placed with its own software in the centre of the world-wide shipbuilding design process. Europe is also well advanced in automation and systems integrators, and in the use of new materials and processes.

Europe has not limited to adapt the automotive or wide oriented CAD or automation to shipbuilding, but has created most of the European systems from inside the yards, from academia and shipyard spin-off innovators. This has not been the case of USA and most Asia. This has created initially some proliferation of software and systems, but now European mergers, association of firms and facilities to combine different software and data-banks, facilitates the multiple choice or migration for specific applications.

East Asian shipbuilders leading the world shipbuilding market are still customers of European software, classification societies, engine licenses and other key parts. A notable exception comes from the collaboration of the Korean shipbuilder Hyundai Heavy Industries (HHI) and one of the leading American CAD vendors, the Parametric Technology Corporation (PTC), for the realisation of the "Pro/Engineering Shipbuilding Solutions" [28], based on the well-known homonymous general purpose CAD system.

7 Integrating design, production & supply chain

Integration of the shipbuilding processes essentially consists in assuring the flawless operation of the information flow between the various stages of the engineering, design, planning and production processes as shown in Figure 2. Some important issues to be considered in this section are:

- Integration of basic design with detail design
- Integration of detail design with production design & planning
- Integration of detail design with the production activities (such as cutting, forming & welding) and the programming of the automated facilities
- Integration of production planning with the control of supplies & outsourcing (sub-contracted services and equipment purchasing)

In an ideal situation, one could conceive a computer system implementing the complete flow-chart shown in Figure 2. In practice, it implies the integration (or just the interfacing) of various specialised computer programmes (CAD, CAE, logistics, etc.) and, sometimes, manual procedures.

The concept of “assembly” yard is becoming reality with the major European shipyards. In this scheme the shipyard is subcontracting major parts of the outfitting work like total turnkeys of different ship spaces. These can be even engine rooms or large cabin areas or restaurants. In these areas everything, except the steel-work, is done by subcontracting companies. This leaves only the coordination role to the shipyard.

This fact sets new requirements for design systems, material and project management systems. Efficient coordination is the key factor for successful new-building.

Actually, there are no general or specific tools and methods available, which could be used throughout the different design and engineering phases; even within each phase many different systems are used, often without proper links and coordination.

There are generally several computer systems at shipyards and within the industry serving shipping companies and shipyards. They are, however, typically tailor-made systems and they lack integration. Product data is spread out between different systems and companies without common product model; thus the data in each system lives its own life. Coordination takes time and, in most cases, it is effective only during the building and installation phase, sometimes leading to rather costly solutions.

7.1 Integration of basic design with detail design

In the basic design all the major characteristics of the new-building such as room arrangements, system diagrams etc. are accurately defined. Specifications state clearly, what to be included in the detail design. Today the individual designers pick this information from the basic design drawings. The result is therefore depending on carefulness and skills of each person reading the documents.

Today in some 3D design systems it is possible to create intelligent system schemes, where the information on armatures, materials and identification data are stored into a database to be used in the detail phase. This way it is possible to eliminate major part of the human errors.

This all must be also linked to the procurement and handling of materials. It is a complicated formula, because basic design needs equipment information, which is in the other hand needs purchase decisions. Procurement needs technical handling and delivery times of material compared to the building philosophy dictate the schedules of purchases. Considering that the major part of the ship's price consists of materials bills, it is clear that this will be of major importance in the systems development of the future.

7.2 Integration of detail design with the production activities

The integration of the design with the production tools is already today's reality. 3D design gives the possibility to have all kind of geometric or material data to be processed for the production machinery. Typically today the plate cutting information, pipe length cutting and bending information is directly fed by wire to the production units.

7.3 Integration of production planning

The function of production planning is to make sure that all the conditions of successful ship manufacturing are fulfilled. This means, that there will be a building place, sufficient human resources, tools, materials and manufacturing drawings in the right place at the right time. This includes also the subcontractor coordination.

The shipyards have various production management systems in use today, but most of them have deficiencies like subcontracting or project follow-up tools.

Coordination of material flow is one of the major tasks also in production planning. This starts already before the ship contract, when the decisions in the major ship equipment (like main engines) are done. This reflects to the production scheduling and that way to design schedules as well. The turnkey deliveries belong also to this category as well. Especially the follow-up of subcontractors should be integrated very tightly to shipyard's own management systems.

The construction of a ship is a huge network of activities, where the dependencies between different tasks are massive and complicated. However, this is a process, which in spite of the differences in ships remains largely the same from new-building to new-building. With good reason it is reasonable to think, that this can be described accurately enough in order to develop suitable software.

Virtual shipyard (simulation of the building process) can be the tool of the future for the integration and management of the real shipyard. Similar tools are already used in automotive industry. This shipyard model should be integrated together with a ship product model, which contains all the ship-related information in the same database. These two combined should provide powerful tools to coordinate the network of suppliers, sub-contractors and shipyard resources.

7.4 Product model

In today's market situation shipyards as well as shipping companies are concentrating on their core business and outsourcing most of the support functions. This serves reducing the costs and balancing the use of capacity in the fluctuating market. Extensive use of consultants, subcontractors and suppliers is a typical situation in shipbuilding.

The product definition becomes essential for the shipyard, ship-owner, class and the subcontractors. Typical contract documents may initially be enough for the yard but when all the major systems and spaces on the ship are subcontracted proper and adequate definition of the ship at the earliest possible stage becomes of vital importance if not critical.

Coordination between the different parties must be fluent and efficient to keep the schedule and, of course, all parties should understand the final end product in the same way, in accordance with the ship-owner's original plan. This is, however, quite difficult when several different parties are involved and the end product is not exactly as originally ordered.

To be able to serve the ship development process from the first idea up to the commissioning and, why not, to its operation and decommissioning, a *product model* is required including all the necessary information for the complete shipbuilding process. It is self-understanding that time is an essential parameter to be included in the model leading to a *4D product model*.

DELTAMARIN Ltd, in collaboration with a major CAD vendor has worked for more than two years with the idea of introducing a 4D model at the earliest possible design stage [44], making it as generic as possible in order to be suitable for all the different tasks in the shipbuilding process. The virtual reality (VR) became an essential part of the process and today we speak of virtual mock-ups in 4D where the 4th dimension is the project / process time.

The first VR ship models were prepared spring-summer 1998, for a passenger cruise ship outline project. The first test case worked better than expected and the yard requested a full VR model to be prepared including exterior, all public spaces, example cabins and selected service spaces. The main issue was to visualize the design of the exterior and the public spaces. It was easy for everyone in project meetings and presentations to understand the specific and special features of for example unsymmetrical cone type atrium, front bulkhead passenger balcony arrangement and similar. It was also interesting to see how easily and quickly alternative solutions could be prepared and compared during the presentations. Figure 7 below is an illustration of typical early project phase model.



Figure 7: Typical early project phase model, from [44]

Several conclusions can be drawn already today:

- The number of required man-hours in preparing a virtual model is not more than is required for preparing typical arrangement drawings. Drawings can be extracted directly from the 4D model.
- Visual presentation of any new idea, space or arrangement is easy and much more efficient than with drawings, renderings or even with cartoon models.
- Presentations and common meetings with the owner, yard, architect, consultant, subcontractor, etc. are greatly simplified. Fly-around and walk-through of the virtual ship as required in the meetings is possible.
- Different alternatives can be on display at the same time and fly-around or fly-in can be made for both.
- Minor changes can be made on the spot in the meeting concerning colours, lighting, furniture, as well as arrangement, structures, equipment, furniture, etc. Major changes may require working 'overnight'.
- Visualisation of changes and alternatives is immediate; decision-making becomes easier and more reliable.
- Functionality of spaces can be easily checked with performance simulations in the virtual model utilising efficient simulation solutions. These can be ro-ro deck operations, or any kind of cargo operations, passenger flows, and escape simulations, luggage handling, galley, catering operations and similar.

In addition, the model can be connected with a virtual navigation simulator with models of any required harbour together with the mathematical model of the ship's manoeuvring characteristics.

All this can be done already before the shipbuilding contract is signed, with one single product model. Consistency and coordinated update of this unique model can help avoiding a lot of typical misunderstandings and mistakes at the earliest possible stage.

A detailed, well-defined virtual reality product model as contract document (CD-ROM) of the new-building enables a quick start for the coordination, design, procurement and planning phase immediately after the contract is signed.

Ideally, the same model can be used for technical design as basis for architectural design, as inquiry specification (or part of it), and as yard building procedure planning model. This reduces the risk of modifications saving both man-hours and, particularly, lead-time.

The basic structural design could be completed in the same model and information could be shared with the class. System diagrams could also be prepared in the model including both system characteristics and important space reservations for ducting, piping and cable trays. The model, complete with piping, ducting, cable trays, main components, equipment and systems, forms the basis for turnkey contracting, detail production planning and workshop drawings.



Figure 8: Vantage class exterior design, from [44]

DELTAMARIN prepared the first full design coordination model for the Royal Caribbean International “Vantage” class vessel (Figure 8). Later on detail navigation bridge (Figure 9) and engine room (Figure 11) coordination models, both including also virtual reality simulations were added.



Figure 9: Virtual bridge model, from [44]



Figure 10: Virtual kitchen model, from [44]

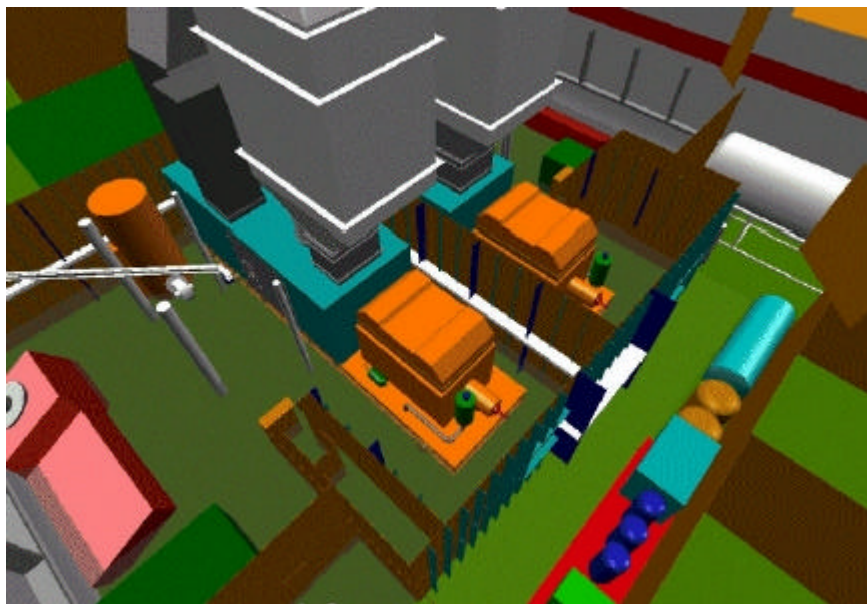


Figure 11: Engine room model for functional checking, from [44]

7.5 Process simulation

The virtual ship models can also as basis for process, safety, ro-ro and any kind of simulations as required essential for a specific project.

For example, a shipyard can be modelled and the building procedures with block assembly, block and grand block outfitting and dry dock building stage can be simulated, checking critical phases, areas, material flows etc. The simulation would require the following steps:

- A complete 4D Virtual Product Model including structure, main piping, ducting, cable trays and main components within the basic design stage is split into hull sections, blocks and main construction phases.
- A virtual shipyard with all the production lines, cranes, outfitting spaces, etc. is modelled.
- The construction process is simulated.

The advantages of the process simulation include:

- Variations can be studied in a transparent mode.
- All parties involved can quickly understand the process and their specific part of it.

- Effect of block outfitting, required outfitting areas, use of modular construction and turnkey supplies can be easily demonstrated.

The main benefit for the turnkey supplier is that he can get adequate technical data and installation process description even before the contract is signed, allowing proper planning and detail design.

Normal planning, scheduling and follow-up tools can be linked with the 4D virtual product model and updating of schedule goes together with the model. An enhanced systematic approach of ship new-building project can be made possible. In Figure 12 below, a first simulation of the block assembly process of a ro-ro passenger ferry by DELTAMARIN Ltd at the Hellenic Shipyards is shown, [44].



Figure 12: Virtual simulation of the Hellenic Shipyards, GR, from [44]

Today for a passenger cruise ship the total number of design man-hours can vary up to 100,000 man-hours (difference) depending on the level and quality of basic design. In dollars this makes \$5-10 million. The effect of using a virtual reality product model properly from the first project stage is leading to even bigger impacts. This represents a huge potential, taking into account that the design activity is easily as much as 10% of the total new-building costs, and the saving effect goes through the complete building process and not just the design.

8 New technologies and R&D activities

8.1 General

Late during the 4th FP, a certain number of maritime related thematic networks have started operating. Some of them, namely ROBMAR, CEPS and PRODIS are directly related with the present study. In particular CEPS has initiated a state-of-the-art report in each of the thematic areas that it encompasses. The first conclusion of this report, for the 'production' thematic areas, was presented at the Odense workshop of Feb.3-4, 1999. These reports, as well as the raw information collected, will be available to AIPS so that we build on top of what has been done and avoid any duplication of work. A first idea is to analyse the CEPS and PRODIS state-of-the-art reports so as to focus the AIPS survey on a limited number of actors who are recognised as having or using the state-of-the-art technology in their respective fields.

JRC – ISIS is the scientific co-ordinator of the ROBMAR and participates to the activities of CEPS network. Other AIPS contributors (DELTAMARIN and IRCN) participate to the PRODIS network. It is therefore intended not only to use the surveys of CEPS and PRODIS but to integrate AIPS as much as possible in the activities of the above networks.

In the recent past, a significant portion of the R&D performed in Europe, related to the automation of shipbuilding processes, has been stimulated, co-ordinated or monitored by various EC services, which are a considerable source of information. As what concerns the up-coming FP5, the recently set-up thematic networks and the European associations (EuroYards, COREDES etc.) are expected to play a major role in this field.

8.2 Study on the maritime RTD activities in the member states

In February 2000, the final report of a study on behalf of the European Commission, DG III (now DG ENTERPRISE) on the current EU member states RTD activities with reference to shipbuilding (including marine equipment, shipping and marine resources) was issued [29]. The aim of the study was to analyse the current state of maritime-related RTD activities and the programmes within the European Union (EU), to help identify possibilities for improved co-operation among the various programmes and establishments, and identify specific actions to create more synergy between the EU and/or national programmes, thereby contributing to the improvement of the competitiveness of the European maritime industry. Its key objectives of this study were:

- to have an overview of the state of play of research in all the maritime industries sectors, namely shipbuilding, including marine equipment, shipping and marine resources;
- to propose synergies, where possible, between EU maritime R&D and national maritime R&D in order to benefit from the context of the 5th Framework Programme on R&D (1998-2002) in view of enhancing the competitiveness of maritime industries.

The results are reported as the overview on the state-of-play of maritime RTD in the areas of shipbuilding, marine equipment, shipping and marine resources. In addition, the overview of the information and communication technologies (ICT) research throughout the whole maritime field is presented. The results of the extensive information gathering exercise have also been assembled in a specially designed database.

The study outlined above was the major source of statistical information on shipbuilding R&D. A statistical review reported a total of 49 programs that include 1488 RTD projects involving 1226 contractors funded from 198 organisations. From the total of 4 RTD areas considered, the one of interest to AIPS study is that for *ship-*

building, the sectors and sub-sectors can be seen in Table 14 below. The other 3 RTD areas are those of *marine equipment*, *shipping*, and *marine resources*.

Table 14: Number of projects by sectors and sub-sectors of Shipbuilding area; from Maritime RTD Study [29]

Sector	Sub-Sector	Projects
Design Tools	Tools for early design	41
	Tools for hydrodynamic basic design	90
	Tools for propulsor design	37
	Tools for structural behaviour	98
Design Methods	Standardisation	26
	Application of new materials	17
	Design for safety	58
	Risk assessment tools	15
Production (generic elements of the production process)	Process integration	21
	QA and QC methods	22
Production/construction technologies	Automation and robotisation	10
	Cutting and joining methods	6
	Production planning	19
Ship Systems and Equipment	General technological development	44
	Modularisation and standardisation	3
	Optimisation of power generation, propulsion systems and other equipment	46
Scrapping of Ships	Life cycle and maintenance assessment	8
	Commercial developments	

Shipbuilding accounted for 3 programmes including 545 RTD projects, the breakdown of which (per sector and sub-sector of the *shipbuilding* area) is also presented in Table 14 above. The following conclusions can be drawn:

- The vast majority (382) of the shipbuilding projects have to do with design tools or methods
- Only 10 projects have been reported on automation / robotisation
- Some 66 of the reported projects are somehow related to integration: 21 on process integration, 26 on standardisation and 19 on production planning

8.3 Recent conferences on shipbuilding IT applications

Papers published or presented in conferences related to the shipbuilding process automation and integration are good indicators of the current trends in shipbuilding R&D. There have been three such conferences recently, one in Japan in 1998, one in US (ICCAS '99) and one in Europe (COMPIT 2000).

8.3.1 Application of IT to Shipbuilding and Shipping Industries

The symposium on "Application of Information Technology to Shipbuilding and Shipping Industries", organised by the Information Technology Committee of the Society of Naval Architects of Japan, was held in Tokyo in December 1998.

Its scope was to exchange information among the shipping industry, shipbuilding industry, marine machinery/equipment industry and classification society, to explore the future direction of development and potential collaboration under the emerging business environment, particularly rapid progress of information technology and telecommunications.

The history of the collaborative development of CIM in Japan was presented. According to the survey on how each shipyard evaluate the current status and effectiveness of their own CIM system, the level so far attained was reported about 70 % relative to the aims. The savings of the man-hour in design was estimated about

20%, and about 30% in construction as compared to 1989. It was pointed out that among many merits brought about by CIM application the greatest merit by CIM application seems to come from easier optimisation of production process, planning, etc. The papers most relevant to AIPS are presented below:

The State of Art of CIM for Shipbuilding in Shipyards in Japan, by Ken Ito (Mitsubishi Heavy Industries, Ltd) and Tomoyoshi Tanabe (Kawasaki Heavy Industries, Ltd);

Major Japanese shipbuilders have made co-operative work of establishing the concept of CIM for Shipbuilding and developing the framework of the CIM for these 10 years. Each shipyard has developed own CIM step by step, applying the results of the projects. Overview of the history of the CIM projects is presented, and the evaluations of the CIM developed by each shipyard are made. Issues for the future of the shipbuilding industries are discussed.

Overview of an Advanced CIM (ACIM) for Shipbuilding by Toshiyuki Amemiya and Masahiro Sonda;

The ACIM project has been launched in 1997 with plan for three years under the auspice of Ship and Ocean Foundation. The aim of ACIM is to enhance the current CIM system through the intensive usage of advancing information technology as well as many assets obtained from previous CIM projects, and put the advanced CIM into practical use. In the ACIM project, we are trying to enable efficient and flexible collaborative engineering for shipbuilding on the basis of the knowledge sharing between multiple disciplines by developing practical product/process model and promoting software integration environment that enables systems and engineers working together on the networks.

IT for Better Collaboration and Cooperation among Shipbuilding and Marine Machinery / Equipment Industries by Norio Hata and Hiroshi Tabuchi;

This paper introduces the outline of three industry wide projects on information exchange among shipping, shipbuilding and marine machinery/ equipment companies as well as a ship classification society. The first project named as "Senpaku (Ship) CALS project" consists a series of experiments for the purpose of establishing core technology for electronic exchange of technical information for realizing "sharing of technical information using computer network" especially among shipbuilders, ship owners and ship classification societies. The second and the third projects, named as "Senpaku EC project" and "Zohaku (Shipyards and Marine parts suppliers) Web project" respectively, extend their scope of information exchange to technical data between shipbuilders and ship machinery/equipment suppliers. It is pointed out in this paper that recent information technology widely popularized as well as rapidly advanced such like as PC and WWW seems to realize better collaboration and co-operation near future among those parties involved in the projects. For real success, however, it is noted that many efforts should also be paid in standardization of various data to be exchanged.

8.3.2 ICCAS '99

The 10th International Conference on Computer Applications in Shipbuilding (ICCAS '99) held in June 1999 by MIT Sea Grant College Program, Cambridge Massachusetts, with the scope to: *review the operational experience with existing computer applications in the building of ships and offshore structures, and look toward emerging advances in information technologies that will become the basis for the next generation of shipyard computer systems.*

Recognising the importance of computers and computerisation in the shipbuilding industry, this conference set out to review operational experience with existing computer applications in the building of ships and offshore structures. It also looked towards emerging advances in information technologies that will become the basis for the next generation of shipyard computer systems. The subject matter of ICCAS '99 covered a wide range of topics in computer applications to shipbuilding. Principal topics included in the subject matter were:

- **Preliminary Design:** Tendering, initial design, general arrangement, cost and work estimation; 19 papers.
- **Detailed and Production Design:** Structure, hull form, hydrodynamic design, machinery, hull and outfitting designs, shell expansion, linkages with suppliers of parts or subassemblies; 3 papers.
- **Assembly and Construction:** Parts manufacture, prefabrication, assembly, erection, scrapping, shipyard robotics and shop automation, parts standardization, accuracy control, and assembly simulation; 13 papers.
- **Inspection and Maintenance:** Inspection standards, liability, surveys, life cycle maintenance, parts and system reliability, documentation and commissioning.
- **CAD/CAM/CIM Systems:** Design, manufacturing, and maintenance systems; shipbuilding CIM, hull form representation, modelling methodology, GUI, intelligent systems, simulation based systems; 9 papers.
- **Product Modelling:** Product model technology, general product modelling system, object-oriented databases, STEP, EDI; 17 papers.
- **Emerging Information Technology:** Virtual reality, automated design and production systems, data and knowledge sharing, communications standards, updated object technologies, computer parallelism; 3 papers.
- **Operation and Management:** Shipyard operation, facilities and human resources, scheduling, production planning and optimisation, work and production flow analysis, stock control, flexible production, organization, project management, concurrent engineering, virtual enterprise, remote production systems, block and building strategy; 15 papers.
- **Information Technology Infrastructure:** System architecture, information flow analysis, inter- and intranet applications; 6 papers.

In all, 86 papers or addresses were given and over half of these had links to AIPS topics. Two important conclusions can be drawn from a first examination of the complete program of the conference:

- The very small number of papers on robotics and automation, themes under the *Assembly and Construction* topic.
- The important number of papers on product modelling, concurrent and collaborative engineering, standards, data exchange etc.

This is yet another indication of the importance of the integration of the various design phases amongst them as well as with production, scheduling and planning activities.

8.3.3 COMPIT 2000

In March 2000 the conference entitled COMPIT2000 was held in Berlin. Many of the contributors to this conference come from academic institutions identified by this study and all relevant papers are also included in the principal papers and authors list in Annex A.3.

With its strong IT orientation, this conference represented a major focus for presenting the topics relevant to the AIPS theme and is seen as a key source of identifying the actors and state-of-the-art of the subject. Around 50 papers were delivered, of which, over one third addressed issues concerning the automation of shipbuilding processes or integration of the building functions.

The principal topics included in the subject matter were:

- CAD / CAM / Robotics
- CIM / CAP
- IT standards/ Electronic data exchange/ Networking technology
- Management Information Systems / Executive Information Systems
- Artificial Intelligence
- Management / Legal / Economical aspects of IT

8.4 Recent R&D projects relevant to AIPS

8.4.1 ROWER II

Welding operations on the edge of blocks and sections of a ship in the dry-dock or in the slipway during the final erection, especially as regards the interior of the ship, are carried out manually. The working conditions for the operators are uncomfortable and the related costs are high.

The development of a mobile robotic welding system to automate this phase of the ship construction would result in the following benefits:

- increase in the productivity by a factor of 3.6 by increasing the welder's arc time in confined spaces and the deposition rate
- reduction by 10% of the assembling lead time in the dry-dock/slipway, which is the bottleneck of the ship production process, thus resulting in an increase of the throughput (and of market share)
- better quality of weld execution thanks to the automated process, with reduction from 20% to 10% of the defective welds to be reworked
- improvement in working conditions of the operators.

A realistic operating target would be to cover all the welds in the central part of large-medium size ships, characterised by a more uniform cell shape. The ROWER II project aims in developing a robotic welding system, at industrial prototype level, consisting of:

- a legged mobile platform, to position the welding equipment inside the cell
- a platform mounted lightweight manipulator to perform fine positioning of the welding torch
- the welding equipment including power source, torch, wire feeder, etc
- a vision system to accurately measure the workspace (weld location and shape), prior to welding
- a control console to program and supervise the system from outside the working cell
- a system to perform Quality Control (QC) of the weld from remote.

The proposed development is the second step of an on-going BRITE-Euram project named ROWER and having scope limited to the welding of a single type of ship cells, those of the double bottom, and making use of a non optimal commercial manipulator manufactured in Japan.

The ROWER II is a 3-year BRITE-EURAM project started at mid 1998. Its consortium includes the following partners:

- Tecnomare (Italy) - coordinator
- Instituto de Automatica Industrial (Spain)
- Lund University (Sweden)
- Fincantieri (Italy)
- Astilleros Españoles (Spain)
- ENVC (Portugal)
- Karlskronavarvet (Sweden).

8.4.2 SNAKE

Multi-Flexible Light Weight Robotic Manipulator (Snake Robot) for One-Of-A Kind and Small Batch Industries of the Future (SNAKE)

IMS (Intelligent Manufacturing Systems) project #99005

Innovative application of various technologies is needed to move shipbuilding and similar heavy industries producing one-of-a-kind or small batch products (discrete manufacturers) into a new era to meet changing national and global demands. This project is one such effort which will accomplish flexible automation of building processes in large and heavy structures such as ship sections, bridge elements etc. An automated, robotic system that can reach into long, narrow chambers with complex

geometry and automatically perform costly and environmentally undesirable welding, cleaning, and painting tasks is proposed.

More details can be found in: <http://www.ims.org/index2.htm>

8.4.3 FANTASTIC

Functional Design and optimisation of ship hull forms, project G3RD-CT-1999-00096.

Today's ship design processes still follow a "trial and error" methodology unsuitable to cope with this market's growing demand. Considering this as a critical limitation to shipyard's competitiveness, major players of the European shipbuilding community contribute their expertise so as to significantly improve their design approach. Focusing on geometric modelling and hydrodynamic analysis as the two decisive components, a new "functional design" process will be introduced allowing the efficient generation, systematic variation, effective flow analysis and rational evaluation of ship hull forms. Aiming at hull form optimisation at both the early and the refined design stage, innovative parametric modelling technique will be developed, established numerical simulation methods will be enhanced and existing optimisation procedures will be supplied. An open and modular system integrating all necessary tools will be implemented and applied at model basins and shipyards.

This is a 36 month long GROWTH project, started early in 2000, coordinated by FINCANTIERI S.p.A. with the participation of CETENA S.p.A., BAZAN yards, NAPA Oy, and other important EU companies and academia.

8.4.4 DOCKWELDER

DOCKWELDER is a recently submitted GROWTH project, coordinated by Odense Steel Shipyard (DK) with the participation of FINCANTIERI (I), AMROSE and MIP (DK), APS (D) and CYBERNETIX (F).

The main objective of the project is to increase competitiveness in European shipbuilding by automating 30% of the welding tasks in the dock area and thus raising the productivity by 10%. In addition, the project aims to improve the working conditions, safety and health of the welders in the ship erection area.

The technical objectives are:

- Establishing an overview of welding automation aspects in the ship erection area,
- Develop a flexible manipulator for welding in closed ship hull structures and demonstrate this in a shipbuilding environment,
- Develop and integrate a motion planning and control system,
- Develop and integrate a process control system being able to manage the significant welding gaps in the ship erection area.

The proposed concept is illustrated in Figure 13 and Figure 14 below.

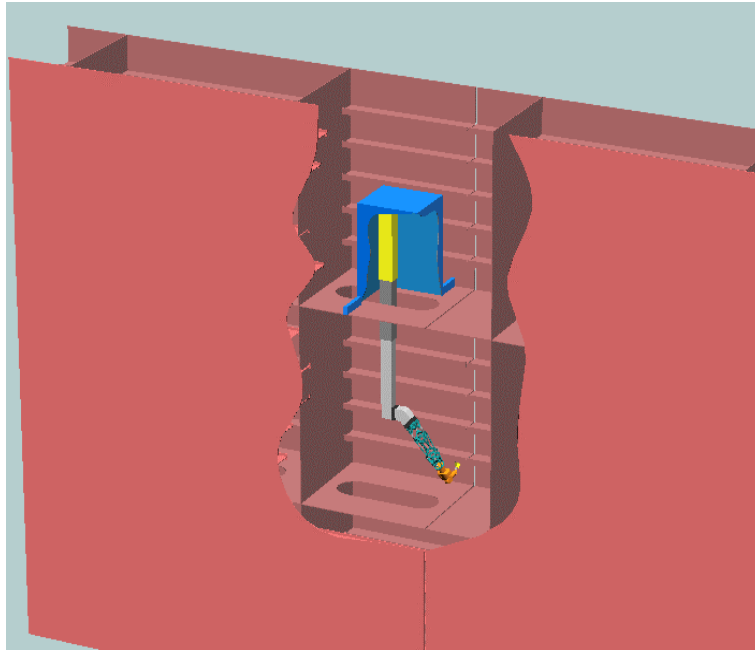


Figure 13: Simulation of the DOCKWELDER concept - source OSS

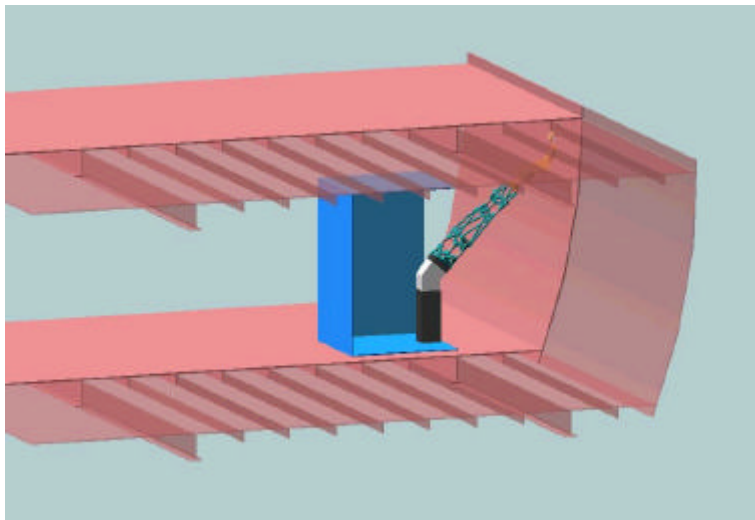


Figure 14: Simulation of the DOCKWELDER concept - source OSS

8.4.5 CEPS

Competitive Engineering and Production in Shipbuilding (CEPS) [7] is a BRITE / GROWTH type 1 thematic network. It deals with the following thematic areas:

Design Process - Modularisation - Standardisation

- Tools for early design procedures
- Tools for hydro-mechanical basic design
- Propulsion design tools
- Tools for structural behaviour
- Standardisation of components
- Standardisation of operational areas

Production Efficiency and I&C Technology

- General production technologies
- QA/QC methods and tools
- New processes & materials
- CIM and logistics

New Materials

New processes & materials

Improvement of Integration

- Concurrent Engineering & Multi-Site Production
- Application of Information & Communication Technologies

Most major EU shipyards and relevant RTD institutes or academia are members of CEPS. It is coordinated by the Chantiers de l'Atlantique (CAT). More information can be found in:

http://www.sts.tu-harburg.de/mareval/Mar_work/marwork.html

8.4.6 ROBMAR

Robotics for the Maritime industries (ROBMAR) [8] is a type 2 thematic network; that is it formed from relevant on-going BRITE / GROWTH projects. It started its activities in Dec. 1998 with the following objectives:

- Avoid duplicating R&D work in the frame of the on-going BRITE projects;
- Investigate on the choice, adaptation or development of common architectures;
- Investigate on the feasibility of modular, open architectures and common core components;
- Exchange information on the robotic & handling technologies in shipbuilding and other maritime applications and generate new synergies and ideas;
- Transfer of technologies from the technology intensive (i.e. offshore, deep-sea etc.) to the labour intensive areas (shipbuilding, vessel inspection etc.) of the maritime industry.

The projects forming the ROBMAR network are well suited for pursuing the above objectives. They are representative of three different maritime applications:

1. Miniature ROV for inspection and gauging (ROTIS);
2. Robot for hull and top-side cleaning (OCTOPUS) and
3. Mobile robot welding system (ROWER-2)

DOCKWELDER as well as AURORA (another GROWTH project on the underwater ship hull cleaning) will join the network as soon as they get started.

ROBMAR cross-links the partners of the participating projects. It intends organising at least two specialised workshops and maintains active links with other thematic networks like CEPS (Competitive Engineering & Production in Shipbuilding – IMT network) and ICIMS NoE (Intelligent Control and Integrated Manufacturing Systems – ESPRIT network). It is open both towards new projects and towards new European or national networks and similar initiatives.

The ROBMAR network is co-ordinated by TECNOMARE, while JRC acts as scientific coordinator.

8.4.7 VRSHIPS-ROPAX 2000

The "Virtual Ship – ROPAX 2000" is a technology platform proposal in the frame of the GROWTH program, KA #3 (marine technologies)

In keeping Europe's competitive edge against world-wide competition, one of the main challenges to be addressed by the European Maritime Industries is to follow-up the successful pattern introduced by other major European industries, particularly the aerospace industry, and to effectively integrate IT into the ship's life cycle process. Consolidation, mutual co-operation and rationalised effort to utilise technologies

to their greatest effect can only strengthen European shipbuilding industry. The VRSHIP-ROPAX 2000 focuses on integrating current effort dispersed throughout Europe to provide a standardised platform upon which a variety of maritime industries can function. It will eventually help European maritime industries to:

- Maintain and improve their position against world-wide competition by improving their knowledge and
- Technological skills;
- Combine competitiveness/profitability with safety and environmental protection;
- Look at technology and innovation as the main way to survive in the global international market.

The resulting platform is expected to provide short and medium term benefit to European ship operators, regulatory bodies and shipbuilders and longer term benefits to the maritime industry as a whole through the embedding of high technology in the very fabric of designing, building and operating the ships of the future. In particular, the project aims to integrate and simulate critical technologies of ship systems to ensure safe and reliable transportation of goods and people. Critical technologies addressing development of areas such as powering and propulsion systems, outfitting, internal arrangement, systems configuration, hull form design, hydrodynamics and structural analyses are already receiving attention from across the spectrum of the maritime industry. This necessitates that due attention is paid and concerted effort expended in the conception and development of an integrated platform to allow for systematic integration, management and testing of the various technologies to ensure overall design optimisation and product performance, while addressing all the life phases of the ship including design, production, operation and disposal.

To achieve its aim VRSHIPS-ROPAX 2000 will employ state of the art methods from various research areas to conduct the work. These include database meddler architecture, knowledge sharing initiatives, collaborative and virtual design environments. This will require development of database systems, coordination and communication mechanisms and applications of standards such as STEP and CORBA to a large-scale engineering project. VRSHIPS-ROPAX 2000 will also address the need to ensure ship safety, starting at an early stage in the design process. It will do this by integrating design and simulation tools, which individually already have a certain predictive power into a much more potent whole, which, in addition, will enable the visualisation of the consequences of design decisions. Though the virtual platform will be generic the focus of the ship platform will be on a ROPAX, as awareness of safety problems in this area is at a high level after the *Estonia* and *Herald of Free Enterprise* tragedies. The VRSHIPS-ROPAX 2000 proposal relates directly to two of the main points reflected in the EU's Council Resolution of 22nd December 1994 on the safety of roll-on/roll-off passenger ferries. It will enable intact and damage stability requirements to be more easily met by simulating a ship in various sea conditions, and it will allow the simultaneous design of optimum evacuation routes and the evacuation procedures which utilise these routes.

Thus the project will deliver:

- An integrated virtual platform prototype system.
- Software simulation tools and virtual models of the ship system.
- An integrative architecture for critical ship technologies.
- A virtual platform for real time and a ship platform for physical performance evaluation.

The consortium consists of 48 partners from 12 countries, including 9 in industries, 19 companies, 9 RTD establishments and 8 academia.

Understanding of the wide-ranging and central role of the project can be readily realised by reference to the thematic network SAFER EURORO Cluster (Appendix A) and the direct links with the Maritime Industry's R&D master plan explained therein. VRSHIPS-ROPAX 2000 is the integrative platform that "pools" together advanced technological tools to assess performance of a ship system from first principles and

thus help amass experiential information and insight. It will provide not only a platform of ship system critical technologies but also a generic virtual platform for any ship type. The project supports the European maritime industries in:

- Maintaining adequate strategic control over technological developments in ship-building and shipping operation.
- Adapting and integrating new technological developments in other advanced branches of the European industry, particularly aerospace and information technology.
- Exploiting European 'know-how' and European maritime industry's worldwide leadership in ship design and ship operation supporting services.
- Further improving the ship design and ship operation process by use of virtual modelling tools, enabling the simulation of ship's 'life cycle' from the initial conception, the design, production and finally operation under normal and extreme (emergency) conditions, with clear impact on ship's economy, efficiency, safety and protection of human lives and of physical environment.

As an example of the potential contribution from the project, the design of a 50 m GRP mine hunter can take 4,000 hours of conceptual design, 40,000 hours during the definition phase and 400,000 hours in the detail design phase. It could be argued that savings of up to 1/3 in the definition phase and 1/4 or 1/5 in the detailed design phase. The final results would be of a better quality in any case, but just considering the above 0.5 M€ could be easily saved in a project of this size.

8.5 Shipbuilding automation related R&D

The fact that only 10 projects reported for the shipyard automation / robotisation by the maritime RTD study reflects essentially two things:

- The shipyards cannot finance nor can they be the driving force for long-term R&D on robotics or automation.
- The fact that, despite some notable (and very expensive) exceptions in some hi-tech applications (like space robotics), the relevant technologies are not yet matures for promising any practical industrial application.

This is consistent also with the analysis of the papers presented at the major international conferences relative to the AIPS study.

A notable exception to the above is OSS (Odense Steel Shipyard); it is the only EU shipyard that invests on long-term RTD concerning robotics for one-of-a-kind operations. In fact, OSS has participated actively in many such projects like the most recent SNAKE and DOCKWELDER.

8.6 Integration related R&D

The number of European or national RTD projects as well as the number of papers presented at the major AIPS relevant conferences, related to integration is quite important. On top of that, there is an important RTD activity done by private companies and major CAD vendors, which, due to the associated commercial interests, is proprietary and not sufficiently well documented.

We note that the areas that are covered better in terms of performed RTD are those of:

- Integrating ship design with production design and planning
- Data exchange
- Concurrent engineering
- Virtual enterprise
- Integrating the various ship design activities - standards

On the contrary, RTD on CIM and automated facilities programming integration is not as well covered. This might reflect the fact that interfacing CAD data with CAM equipment is considered a rather consolidated straightforward procedure not needing any further R&D.

8.7 The impact of novel production technologies

There is a number of novel production technologies, which are either being introduced or are considered for future use by the major EU yards. They include mainly:

- Laser technologies for cutting and welding
- New materials (aluminium, composite or sandwich)
- New bonding techniques

These technologies alone cannot change significantly the shipbuilding industry. Nevertheless, the specialised facilities and know-how required for most of these processes, combined with the introduction of new vessel concepts could, under certain circumstances, act as a catalyst for the transformation of the EU yards to the *virtual shipyard* and the network of technology intensive enterprises / suppliers of tomorrow.

The necessary circumstances quoted above have to do with the development and deployment of the necessary tools, infrastructure and mentality for the integration of the design and production activities around the *product model*, in the context of the *virtual shipyard* concept (see section 7).

8.8 Conclusion and recommendations on AIPS related R&D

The 3 major conferences during the last 3 years (Tokyo 98, ICCAS 99 and COMPIT 2000) as well as the BMT maritime RTD study indicated a scarce RTD effort in robotics & automation. They indicated an important effort on integration issues like: product model, standards, concurrent engineering and data exchange. These facts confirm:

- The importance of integration at short and medium term: Shipyards and other *players* of the sector are conscious of this fact and are already investing in this direction.
- The reluctance of the shipyards and other maritime RTD institutions to finance (or be the driving force) for any long-term RTD activities on automation and robotics for one-of-a-kind processes.

Shipyards cannot invest, nor can they be the driving force in any long-term R&D activities on robotisation of one-of-a-kind processes, for the reasons that have been discussed in the previous sections. Nevertheless, in order for shipbuilding to become a technology intensive, rather than work intensive sector, tedious, unhealthy and dangerous work must inevitably be robotised. Such long-term R&D is therefore necessary if shipbuilding is to become a technology intensive rather than a work-intensive industrial sector.

EC, along with national authorities and shipbuilder's associations must find alternative ways to encourage basic and long-term R&D and stimulate the technology transfer from other *high tech* applications, in order to permit the introduction of all the necessary technologies for the efficient robotisation / automation of the one-of-a-kind operations in shipbuilding, construction and other heavy "one-of-a-kind" industries. Such ways may include:

- Network relevant R&D institutes, academia, shipyards, other one-of-a-kind industries and automation equipment providers.
- Stimulate trans-sector activities regarding the application of autonomous robotic systems (service robots operating in remote, dangerous or unhealthy environments).
- Financing of basic and long-term R&D of industrial relevance, even without evident economic returns.

9 Competitiveness of EU shipbuilding

Even if the effects of integration, process automation and robotisation on the productivity are not questionable, their effects on competitiveness are not as clear. Especially in what concerns the competitiveness vis-à-vis their Far Eastern counterparts the situation is as follows:

9.1 Effects of automation

Given that, as analysed in the above sections:

Further automation of the shipbuilding productive processes cannot have significant economic returns but at medium / long term,

- It involves considerable amount of basic R&D activities, which cannot be performed, financed or owned by individual shipyards
- Basic technologies and solutions from such rather basic R&D activities, are bound to proliferate much faster than the time needed to be implemented and give tangible economic return.
- Even where process automation / mechanisation looks promising at short term (i.e. painting and coating), in the modern global economic and IT context, it cannot guarantee but a very brief competitive edge.

Investing in automation, in whatever form and however necessary it might be, cannot, by itself, improve the competitiveness of the EU shipbuilding industry nor can it secure its present market niche.

It must be pointed out that, as soon as the basic automation technologies become available, Korean (and in the future also the Chinese) shipyards are in a much better position to implement these technologies than their EU counterparts. There are two basic reasons for that:

- The current market niche of the Far Eastern shipyards is much more suitable to automation improvements than the EU market niche.
- Far Eastern shipyards follow quite closely the international R&D activities and already have a lot of agreements with top EU shipyards and technology providers.

Although it was not possible to visit, in the frame of the AIPS study, any Korean shipyard, all the information we have point out that they have modern installations and are keen and capable of applying any new promising technology.

9.2 Effects of integration

Investments on integration are bound to affect the productivity of the shipyards in a much more direct way than investments on automation of any single process. Under some conditions, its effect on competitiveness can be quite significant for the individual yard as well as for the EU shipbuilding as a whole. More in particular:

- The erection of large cruise vessels, fast ferries etc, typical of what are still considered to be EU market niches, are much more apt to profit from an integrated, concurrent engineering and production environment than tankers, bulk carriers etc.
- Although the required investment for introducing such an environment to a particular shipyard is not as heavy (in fact much of the development cost is shared and buffered through the big CAD vendors), its implementation requires radical structural, organisational and mentality changes. These changes cannot be implemented but gradually, they are heavily custom / application driven, they can be quite long to implement and, if wrong decisions are taken at the beginning, they can be quite risky. As a consequence, applied pioneer solutions cannot be copied or transferred as easily and the effects of any successful innovative application are bound to have a longer lasting effect.

Nevertheless, at medium / long term, production integration alone cannot assure any competitive edge over the Far Eastern shipyards nor can it secure the current market niche. On the contrary, there are examples of Korean shipyards¹⁰ that have already established partnerships with leading CAD vendors in order to further enhance their productivity and competitiveness and penetrate some typical EU market niches.

9.3 Considerations on the competitiveness of the EU shipyards

The competitiveness of the EU shipyards, specially vis-à-vis their Far Eastern competitors, is a matter that goes far beyond the scope of the present study. Nevertheless, we allow some considerations that can serve for further thoughts:

European shipbuilding cannot, in general, retain its actual market niches, even more so it cannot gain the market sectors lost recently in favour of its Far-Eastern competitors just by technology or R&D investments, be it on automation or on design and integration.

Instead, following the experience of other sectors, EU shipbuilding must target on its integration in the context of a competitive and sustainable European shipping. The recent developments in information and communication technologies make possible a coherent *product model* type of approach, where a network of shipyards and other related industries and enterprises respond collectively to the need for a producing, maintaining, adapting and decommissioning the fleet of vessels necessary to assure a sustainable European shipping.

Ship owners and ship operators must see these *virtual shipyards* or *better virtual ship-making industries* (i.e. networks of specialised shipyards, equipment manufacturers, repair yards, service providers etc) as a long-standing partners, much like the way the airlines see the big aircraft manufacturing consortia.

¹⁰ Hyundai Heavy Industries (HHI) Ulsan shipyard is in partnership with Parametric Technologies Corporation (PTC) to develop *the complete next generation shipbuilding solution* [28], an integrated shipbuilding environment

10 Conclusions

10.1 Challenging environment

The over-capacity in production, mainly in the sector of merchant vessels, has caused dramatic price reductions (from 15% to 30% over the 1998 prices) in particular for some vessel types (tankers, VLCCs, etc.). The situation of the shipbuilding market has accelerated the trend of EU shipyards towards building vessel types with high technical content and specialised know-how like containerships, LNG and LPG tankers, dredgers, luxury cruise vessels and ferries.

Increasing vessel complexity means significantly less steel work (sometimes lower than 20% of the total cost) and increasingly important design, planning and management (it can represent over 10% of the cost of a modern passenger vessel). The very short delivery times, imposed by the fierce competition and the rapidly evolving market, emphasise even more the need for efficient design, planning and management.

In the past, shipyards have been largely self sufficient in all disciplines of shipbuilding process. Nowadays however, workloads can vary significantly across various disciplines and the complexity of certain work requires a lot of highly skilled personnel for limited periods of time. Due to this reason most of the advanced shipyards use extensively subcontractors and total turnkey deliveries suppliers, moving rapidly towards the concept of "assembly" yard.

Nowadays, successful, in-time, completion of complicated ships (such as modern high-speed ferries or big passenger vessels) in a concurrent engineering and production environment sets new challenges for the standardisation and integration of the processes.

The shipping world is relatively conservative in technology thinking. The investments, be it for ordering a ship or purchasing new production technology, are considerable and everybody tries to minimise the economical risks. However, the major EU shipyards have taken up the challenge imposed by the modern global market economy and the particular shipbuilding market situation and are changing fast.

10.2 Low priority for further automation

Very high level of automation as such is not of the highest priority in the development list of the shipyards. The nature of shipbuilding, which is one-of-a-type production with few series-production features, makes efficient and cost-effective automation difficult.

The first part of the steel production process (marking, cutting, 2D blocks etc) is already quite well automated. The 3D block and grand-block assembly as well as the dockside erection are very difficult to be automated or robotised; robotic technology is not yet mature to offer economically viable solutions.

The diminishing portion of steel construction, which is technically the easiest target for automation, makes investments on further automation of individual production processes even more questionable.

Outfitting work is still at the beginning of the automation process. Here, it is the subcontractors that are likely to develop new production technologies. Automation is likely to be developed for workshop or subcontracted activities.

10.3 High priority for integration

Ship design efficiency is of vital importance to shipbuilding industry. In spite of the considerable investments and the developments in the various design tools and methods, there is still considerable room for improvement and substantial economic return potential. Design activities (including production planning and management) not only constitute an important part of the total cost of the vessel project but also

have a significant impact on the other costs (production, procurement, delivery time etc).

At present, there exist a range of valid CAD, CAE, CAM, CIM and ERP tools already deployed in the major EU yards. The major issue as what concerns the quality and efficiency of both the final product and the production (incl. design) process itself lays in the efficient cooperative engineering and production.

In brief: at short-medium term, the major productivity gains in EU shipbuilding can be achieved through rationalisation of work phases, good planning and integration rather than automation. The final target is a *virtual yard*, operating in a cooperative / concurrent engineering and production context together with a network of specialised contactors, suppliers. The central concept for such a context is that of the *4D product model*.

10.4 Need for technology transfer and long-term R&D

Shipyards cannot invest, nor can they be the driving force in any long-term R&D activities on robotisation of one-of-a-kind processes, for the reasons that have been discussed in the previous sections. Nevertheless, in order for shipbuilding to become a technology intensive, rather than work intensive sector, tedious, unhealthy and dangerous work must inevitably be robotised.

EC, along with national authorities and shipbuilder's associations must find ways to encourage basic and long-term R&D in order to permit the introduction of all the necessary technologies for the efficient robotisation / automation of the one-of-a-kind operations in shipbuilding, construction and other heavy "one-of-a-kind" industries.

Acknowledgement

The authors wish to thank **Lucio Sabbadini** and **Luciano Manzon** of FINCANTIERI S.p.A. as well as **Michael Goldan** of VNSI (Dutch shipbuilders association) for their useful comments.

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Annexes

- A.1 External subcontractors to the AIPS study
- A.2 Shipyards and other organisations contacted
- A.3 COMPIT 2000 – programme
- A.4 The Dutch collaborative experience
- A.5 The CESA working group on cooperation

A.1 External subcontractors to the AIPS study

The following companies (in parenthesis the names of the persons responsible for each contribution) have contributed as subcontractors of JRC to the AIPS study:

- | | | |
|--------------------------------|--------------------|---------|
| 1. IMC Associates | (Graham Clarke) | UK |
| 2. DELTAMARIN Ltd | (Matti Lietepohja) | Finland |
| 3. Renaissance Shipping | (Willy Patzwahl) | Germany |
| 4. MT Consultants | (Marios Tseriotis) | Greece |
| 5. IRCN | (Guy Babaud) | France |

The business briefs and/or CVs of the above experts as well as their expected contributions can be found in [2]. Contracts have been stipulated with JRC following the approval by DG III.D.5 of the AIPS detailed planning.

The responsibility of each subcontractor, as initially planned, in terms of countries, processes, technologies and R&D activities, is given in the tables below:

AIPS project countries	J.R.C.	Deltamarin	I.M.C.	Renaissance	M.T.	I.R.C.N.
	Denmark		x			
Finland		x				
Sweeded		x				
Norway		x				
UK & Ireland			x			
Germany				x		
Poland				x		
France						x
Spain	x					
Portugal	x					
Netherlands	x					
Italy	x					
Greece					x	
Croatia					x	
Romania					x	
Cyprus					x	
Ukraina	x					

AIPS project processes	J.R.C.	Deltamarin	I.M.C.	Renaissance	M.T.	I.R.C.N.
Automation						
Production planning				x		
Fabrication	x					
3D shape sub-blocks						
Assembly	x					
Erection						
Finishing - outfitting					x	
Integration						
Standards & modularity						
Pre-design <-> Basic design						x
Basic <-> detail design		x				x
Design <-> Production						
Plann. & Supplies					x	
Outsourcing						

AIPS project technology	J.R.C.	Deltamarin	I.M.C.	Renaissance	M.T.	I.R.C.N.
Engineering						
CAD / CAE tools		x				
New designs & materials		x				
Production						
Steel flow handling						
Cutting						
Welding						x
Flexible manufacturing	x					
Robotics	x					
Assembling						
Planning				x		
Other						
Warehouse						
Outsourcing management						

AIPS project R&D	J.R.C.	Deltamarin	I.M.C.	Renaissance	M.T.	I.R.C.N.
Thematic networks						
CEPS	x					x
PRODIS		x				x
ROBMAR	x					
EC sponsored programs						
DG III	x		x			
DG VII	x			x		
DG XII	x					
DG XIII	x					
Other						
Shipyards	x	x				x
Universities / Institutes	x		x			x
Other (equip. manuf. etc)		x		x	x	

The above planning has been, in general, respected. The contribution of each of the above subcontractors is given integrally as separate reports. The contribution of JRC includes the contributions of JRC-ISIS (F.Andritsos) and JRC-IAM (J. Perez-Prat).

A.2 Shipyards and other organisations contacted

The following shipyards, industries, academia or other institutions have been visited, interviewed or contacted in the frame of the AIPS study (ASS: assosiation, SHY: shipyard, RTD: research institute or academia, SU: suppliers, GOV: ministry or governmental organisation):

Company	Type	Place	Country
ACLUNAGA (Cluster)	ASS		Spain
ADIMDE – Shipbuilders & Aux. Industries			Spain
AEDIMAR - Auxiliary Equipment	SU		Spain
AESA Astano	SHY	Ferol	Spain
AESA Sestao	SHY	Bilbao	Spain
AESA Sevilla	SHY	Sevilla	Spain
AKER FINNYARDS	SHY	Rauma	Finland
Astilleros de Huelva	SH	Huelva	Spain
Astilleros de Pasaia	SH	Pasaia	Spain
Barreras	SHY	Vigo	Spain
BMEC – British Marine Equipment Council	ASS		UK
BMT - British Maritime Technology	RTD		UK
Central Consulting Group	SU	Groningen	Netherland
Central Industry Group	SU	Groningen	Netherland
Central Staal	SU	Groningen	Netherland
Chantiers de l'Atlantique (CAT)	SHY	St. Nazaire	France
COAPROA - Purchasing Association	ASS		Spain
Damen	SHY	Gorinchem	Netherland
EC – DG ENTERPRISE	GOV	Brussels	Belgium
EC – DG RTD	GOV	Brussels	Belgium
EC – DG TREN	GOV	Brussels	Belgium
FINCANTIERI S.p.A.	SHY	Marghera	Italy
FINCANTIERI S.p.A.	SHY	Monfalcone	Italy
Foro Maritimo Vasco - Maritime Cluster	ASS		Spain
Freire	SHY	Vigo	Spain
Gerencia del Sector Naval - Ministry of Industry	GOV		Spain
Hovaldswerke Deutsche Werft	SHY	Kiel	Germany
IHC Holland Beaver Dredgers	SHY	Sliedrecht	Netherland
IHC Holland Dredgers	SHY	Kinderdijk	Netherland
IHC Holland NUBE & Staal	SU	Kinderdijk	Netherland
Kockums AB Karlskronavarvet	SHY	Karlskrona	Sweden
Kranendonk	SU	Tiel	Netherland

Kvaerner Masa Yards Inc.	SHY	Turku	Finland
MARSYS - supplier	SU	Madrid	Spain
Merwede	SHY	Hardinxveld	Netherlands
Mr Cliff Funnell – contributor to BMT EC study			UK
Mr George Bruce – Newcastle University dept for marine Technology	RTD		UK
Mr John Craggs – First Marine Intl. Authors of UK Government study			UK
Mr Tom McNamara – Southampton Institute, research contributor to IMC	RTD		UK
Naval Architecture	RTD	Delft	Netherlands
Odense Steel Shipyard (OSS)	SHY	Lindo	Denmark
PYMAR - S&M Yards Association	ASS		Spain
SARC b.v.	SU	Bussum	Netherlands
Schelde Scheepsnieubouw	SHY	Schiedam	Netherlands
SSA - Shipbuilders and Ship repairers Association	ASS		UK
UNINAVE - Shipbuilder Association	ASS		Spain
Universidad de a Coruna	RTD	Ferrol	Spain
Universidad de Madrid	RTD	Madrid	Spain
Van der Giessen de Noord	SHY	Krimpen	Netherlands
VSNI – Dutch Shipbuilders	ASS	Zoetermeer	Netherlands
YACHTING CONSULT	SU	Eindhoven	Netherlands

A.3 COMPIT 2000 – programme

Thursday, 30. 3. 2000		
09:00	Volker Bertram, (TUHH, Germany)	Knowledge-based Systems for Ship Design and Ship Operation
09:30	Guus van der Bles (NCG, Netherlands), C. Dirkse (TU Delft, Netherlands)	Integrated Shipbuilding by Concurrent Engineering
10:00	Rainer Müller, Claudia Nederee, Joachim Schmidt (TUHH, Germany)	MARINFO: The Maritime Industry Information Infrastructure
10:30	Bruce Bongiorno (Univ of Michigan, USA)	The Role of Directory and Trusted Third Party Services in Shipbuilding Industrial Electronic Commerce
11:00	coffee break	
11:30	Uwe Langbecker, Uwe Rabien (Germanischer Lloyd, Germany)	EMSA Business Cases as Draft Industry Standards for Product Modelling
12:00	Manuel VENTURA, J. Vitoria, Carlos Guedes Soares (TU Lisbon, Portugal)	Implementation of STEP Translators Using the Ship Hull Product Model
12:30	Marcus Bentin, Karsten Stenzel (TUHH, Germany)	STEP Interface between TRIBON and POSEIDON
13:00	lunch	
14:00	Robert Bronsart, Steffen GAU (Univ Rostock, Germany)	A Platform for Co-operative Inter-Organisational Work in Design and Production
14:30	Clemens Odendahl (Univ. Saarland, Germany), Peter Wieland (DnV, Norway), E. Weitzenboeck (Univ. Oslo, Norway), D. Jaramillo (GL, Germany), S. Makris (Univ. Patras, Greece), A. Cacho, C. Guedes Soares (TU Lisbon, Portugal)	MARVIN, a Virtual Enterprise Network for the Maritime Domain
15:00	Pekka Koskinen (Oy EDI Management, Finland)	Level of IT in European Sea and Inland Waterway Ports
15:30	coffee break	
16:00	Berend Bohlmann (Flensburger Schiffbau-Gesellschaft, Germany)	IT Integration in Modern Design of Ships
16:30	David ROBINSON (American Bureau of Shipping, USA)	The Role of Information Management in Ship Safety
17:00	Morten Lovstad, Simon Holby Behrens-Nielsen (Det Norske Veritas, Norway)	NAUTICUS - Knowledge Management and Decision Support throughout the Ship's Life Cycle

Friday, 31. 3. 2000		
08:30	Bart Lamiroy, Radu Horaud (INRIA, France), Tom Drummond (Univ. Cambridge, UK), Ole Knudsen (Odense Steel Shipyard, Denmark)	Visually Guided Robots for Ship Building
09:00	Markus Vincze, M. Ayromlou, M. Zillich (TU Wien, Austria), S. Galt, N. Hewer, O. Neckelmann, R. Waterman (PTC Ltd, UK), A. Gasteratos, R. Martinotti, G. Sandini (Univ Genova, Italy), C. Gramkow (Odense Steel Shipyard, Denmark), S. Hoffgaard, O. Madsen (Aalborg Univ, Denmark)	RobVision - Visually Guiding a Walking Robot through a Ship Structure
09:30	Sjoerd Hengst, R.J.J.F. Takken (TU Delft, Netherlands)	Robotising in the Dutch Shipbuilding Industry
10:00	Fivos Andritsos (JRC, Italy)	Integration and Robot Autonomy: Key Technologies for Competitive Shipbuilding
10:30	coffee break	
11:00	Thomas Stidsen, Jens Clausen (Danish Technical University, Denmark)	Large Steel Plate Storage Optimization
11:30	Marco Cremon (Fincantieri, Italy)	From Hull Design to Production: Production Planning, Hierarchical Bill of Materials and Workshop Documents
12:00	Jong Gye Shin, C.H.Ryu, S.J.Sohn, J.H.Lee, W.D.Kim (Seoul National Univ. Korea)	Simulation-Based Productivity Analysis for a Multi-layered Design of an Integrated Automated Line Heating System
12:30	Henrik Clausen (Danish Technical Univ., Denmark)	Numerical Method for Plate Forming by Line Heating
13:00	lunch	
14:00	Jens-Herman Jorde (Bergen College, Norway)	The Synthetic Lines Plan - An Aid in the Preliminary Design Phase
14:30	Antonio Rodriguez, M.Vivo, A. Vinacua (PT Cataluna, Spain)	New Tools for Hull Surface Modeling
15:00	Miroslav Gerigk (TU Gdansk, Poland)	Artificial Intelligence in Guiding Ship Subdivision for Safety
15:30	coffee break	
16:00	Andreas Friis-Hansen (Danish Technical University, Denmark)	Influence Diagrams for Optimal Maintenance Planning
16:30	Hugo Grimmelius (TU Delft, Netherlands)	The Use of First Principle Modelling for Faulty Behaviour Prediction in the Design

		Stage
17:00	Pietrzykowski, T. Dziedzic, Janusz Uriasz (Marit. Univ Szczecin, Poland)	Knowledge-Based System for Evaluation of Ship's Navigational Safety

Saturday, 1. 4. 2000		
9:00	Stefan Krüger (Flensburger Schiffbau-Gesellschaft, Germany)	Design Loads for Rudders from First Principle Investigations
9:30	Daniele Peri, Michele Rosetti, Emilio Campana (INSEAN, Italy)	An Example of Ship Hull Optimization via Numerical Techniques
10:00	Stefan Harries (VWS Berlin, Germany), Lothar Birk (TU Berlin, Germany)	Automated Optimization: A Complementing Technique for the Hydrodynamic Design
10:30	Aleksander Kniat (TU Gdansk, Poland)	Optimisation of Pipe Routing in 3D Space
11:00	coffee break	
11:30	Ivan Oestvik (LMG Marin, Norway), Dimitris Konovessis (Univ of Strathclyde, UK)	Application of Black Board Systems to Ship Design
12:00	Michael G. Parsons, David J. Singer (Univ. of Michigan, USA)	A Fuzzy Logic Agent for Design Team Communications and Negotiation
12:30	Nickolas Sapidis, Gabriel Theodosiou, Panagiotis Kaklis (NTUA, Greece)	Free-Volume Modeling in Engine-Room Layout using Virtual Solids
13:00	Lunch	
14:00	Tomasz Cepoeski (Marit. Univ. Szczecin, Poland), Tomasz Abramowski (TU Szczecin, Poland)	Optimisation of Water Ballast Discharging Operation
14:30	Ludwig Furstenberg (ITE, South Africa)	Combining Artificial Intelligence with VTS for a Traffic Management Information System
15:00	Ludwig Furstenberg (ITE, South Africa)	Expert System Techniques Applied to Virtual Prototyping and Design
15:30	coffee break	
16:00	Frutuoso M. Silva, Carlos Guedes Soares (TU Lisbon, Portugal)	3D Virtual Environments for Ship Manoeuvring Simulation
16:30	Markus Aarnio (Deltamarin, Finland)	New 3-D Tools Allow Early Project Stage Virtual Models and Simulations
17:00	Aldo Zini, Attilio Rocca (CETENA, Italy), Marco Raffa,	The Integration of Virtual Prototyping in Ship Design

	Roberto Costa (Fincantieri, Italy)	
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Sunday, 2. 4. 2000		
9:00	Peter Beier (Univ Michigan, USA)	Web-Based Virtual Reality in Design and Manufacturing Applications
10:00	Marco Barcellona (INSEAN, Italy), Volker Bertram (HSVA, Germany)	Virtual Reality Applications for CFD Post-processing
10:30	Ehsan Mesbahi (Univ Newcastle, UK), Volker Bertram (HSVA, Germany)	Empirical Design Formulae using Artificial Neural Nets
11:00	coffee break	
11:30	Kourosh Koushan (Marintek, Norway)	Prediction of Propeller Induced Pressure Pulses Using Artificial Neural Networks
12:00	Ehsan Mesbahi, Mehmet Atlar (Univ Newcastle, UK)	Artificial Neural Net Applications in Ship Design
13:00	lunch	

A.4 The Dutch collaborative experience

The Dutch Maritime Cluster

Dutch yards are in a strong maritime cluster, supported by a very active shipyard association (VNSI) promoting initiatives such as research on organization, logistics, and EDI platforms and IT applications.

The Dutch cluster has been described in a economic impact study published by the Delft University Press in separate volumes dedicated to shipbuilding industry, marine equipment industry, The Royal Netherlands Navy, the Dutch seaport sector, the shipping sector and the offshore sector, fishing, services, maritime construction and dredging works, inland navigation, offshore, aquatic sports, suppliers, and all shipbuilding and auxiliary industries. Shipbuilding and auxiliary industries exported 46% of the production and representing less than 9% of the total turnover of the maritime cluster, but is understood as its cornerstone.

The maritime labour market was calculated in 1996 on more than 106,000 jobs, and total employment generated was estimated on 193,000. The number of seafarers was expected to increase from 13,750 in 1996 to 18,600 in 2004 showing good prospects extended to the rest of the cluster (i.e. shipbuilding)

Indirect value generated by the shipbuilding sector is estimated no less than 1.3 times the size of the direct value added many in small companies. Offshore only, accounts 343 Dutch offshore companies all sizes from the multinationals to the small ones.

The NML (Nederland Maritiem Land) foundation represents the maritime cluster.

The VNSI association of Dutch yards has about 100 members:

- 20 on sea-going shipbuilding,
- 15 in ship repair
- The rest being builders & repairers of coastal, work and inland ships

Around 40 yard sites appears regularly on the order-book and deliveries published by the Dutch magazine HSB International. Many yards sites are today in groups or holdings (IHC, DAMEN- see list)

General overview of the Dutch shipbuilding

Dutch yards are innovative in strategy, logistics and on the commercial and financial approach. The yacht industry is considered at a close level to shipbuilding (mega-yachts up to 90 m and more may have more added value than 100 m cargo vessels).

Commercial shipbuilding self-limits to 140 m maximum length (the competitively is favoured under this size) although some yards may built ships up to 250 m of length.

Series are rare in the bigger sizes but some yards may combine one of a kind high value ships with standard low cost small standard dredgers or work-boats built in two or three modules (hull, propulsion machinery, and deck equipment) in own account, ready for quick delivery.

The steel work moves between the heavy-duty equipment and structures of dredgers and the lighter inland or less than 140 m sea-going ships. Dredgers of all types are the speciality of the Nederland shipbuilding

Nederland shipyards synergy with research centres (TNO and MARIN), the University (Delft, side by side to TNO) and specialised industries and engineering (hydraulics, CAD and ERP suppliers) is worth to be taken as an example.

Priorities

Dutch yards' priorities were reported as:

Logistics: the ship type and the shipyard characteristics define the optimal construction strategy. The construction strategy is the main cost reduction option

Technology specialisation: the ships built have a higher added value on top of the "pure steel" and the yards competitively main enabler is to maintain the "number one" on its specialty.

Research priority is on new types of ships and on increasing ship and equipment (dredging) performances.

Integration: Dutch yards give importance to integration they consider as part of the logistics and what they translate as "engineering" (production strategy)

Software providers

CAD

There are three major firms of CAD software in the Netherlands

- The CIG (Central Industry Group) NUPAS, associated with CADMATIC (Finland)
- Yachting Consult
- SARC

Automation integration

Kranendonk ARAC software

ERP

Baan, a Dutch firm makes one of the best-known worldwide ERP software, but only two yards in the Nederland uses it. Baan IV that is a general purpose software and needs to be adapted to shipbuilding. One yard uses MARS, a ERP software for shipbuilding made by a smaller Danish provider.

As a consequence of the interest of the Dutch maritime industry, in EUROPORT 2000 a special section for software with a special room for scheduled presentations was included. See copy of the program of presentations attached.

Automation

Plate and profile cutting and marking is highly automated through two main contractors.

Welding automation is cautiously approached and does not appear to be a priority. The interviews with Kranendonk and TU Delft describe the automation approach of the Dutch automation integrator and of the Dutch yards (see separate report by Perez-Prat).

Nederland is accepted in the European shipbuilding as an example for clustering and logistics on medium and small construction (up to 140 m)

A.5 The CESA working group on cooperation

The CESA working group on cooperation consisted of representatives from:

- Fincantieri S.p.A. (Italy)
- Aker Finnyards Oy (Finland)
- Astilleros Españoles S.A. (Spain)
- Chantiers de l'Atlantique - ALSTOM (France)
- Estaleiros Navais de Viana do Castelo (Portugal)
- Flensburger Schiffbau-Gesellschaft GmbH (Germany)
- Howaldtswerke-Deutsche Werft AG (Germany)
- Schelde Maritiem BV (The Netherlands)
- Van der Giessen de Noord (The Netherlands)

These 9 shipyards decided to exchange visits, collect and compile information in a standardised way on the technological processes the layout and the equipment of their respective yards.

The work of the workgroup is an example of openness and collaboration between 'competing' EU industries with the common of sharing knowledge and know-how on shipbuilding production technologies.

During each visit, usually of one full day, the participants were shown the complete yard, were given the opportunity to ask any question and take, through an official photographer, any picture desired.

The work of the workgroup has been documented in the "Production Technologies Catalogue", in HTML format, on a CD, made available to every participant at the workgroup.