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 the 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 trough 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 subcontractors 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.