

SHIP PRODUCTION COMMITTEE  
FACILITIES AND ENVIRONMENTAL EFFECTS  
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WELDING  
INDUSTRIAL ENGINEERING  
EDUCATION AND TRAINING

April 1997  
NSRP 0532

# **THE NATIONAL SHIPBUILDING RESEARCH PROGRAM**

## **1997 Ship Production Symposium**

### **Paper No. 12: An Integrated Steel Workshop for Shipbuilding: A Real Application of Automation**

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

## Report Documentation Page

*Form Approved*  
*OMB No. 0704-0188*

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

1. REPORT DATE <b>APR 1997</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>The National Shipbuilding Research Program 1997 Ship Production Symposium, Paper No. 12: Paper No. 12: An Integrated Steel Workshop for Shipbuilding: A Real Application of Automation</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Naval Surface Warfare Center CD Code 2230-Design Integration Tower Bldg 192, Room 128 9500 MacArthur Blvd Bethesda, MD 20817-5700</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>The original document contains color images.</b>					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>SAR</b>	18. NUMBER OF PAGES <b>15</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

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**THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS**  
**1997 Ship Production Symposium**  
**April 21-23, 1997**  
**New Orleans Hilton Hotel**  
**New Orleans, Louisiana**



# An Integrated Steel Workshop For Shipbuilding: A Real Application Of Automation

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## ABSTRACT

*The paper describes the layout of an innovative automated steel workshop for the manufacturing of ship blocks, recently set up at Fincantieri's Monfalcone shipyard. The system implements the results of a European EUREKA! Research program called FASP - Flexible Automation in Ship Prefabrication.*

*The various working areas of the shop are described; for each of the new technologies being applied, the level of automation and integration with the other areas is discussed; the advantages obtained are compared with the best typical standards of a traditional production workshop.*

*Inside a fully automated workshop, the information support must have a high integration and flexibility level.*

*The two main issues relevant to information technology are described, i.e.:*

- *the modular and integrated systems for the design, part program generation and transmission; and*
- *the production programming, management and control system.*

## GENERALITY

The prefabrication workshop is the area of the yard that generally offers the greatest opportunities to achieve efficiency increases through the introduction of automation and the application of innovative technologies in search of improved competitiveness, cutting costs and shorter manufacturing lead time.

Such an approach is based on the following issues.

- Most of the production process has traditionally been based on methods contemplating manual activities. The exploitation of just low-to-medium levels of automation reduce time-consuming and labor intensive exercises, especially considering the necessary minute adjustments and remakes.
- Improved accuracy in the process can be achieved at different stages of prefabrication by resorting to automated systems of a higher sophistication while limiting or eliminating manual operations. The accuracy of blocks obtained with such solutions, results in substantial savings in terms of labor and time needed in the downstream assembly and outfitting operations.
- A smoother running management of lines and areas can thus be achieved allowing for a steady, unbroken production flow, substantially easier planning routines and reduced intermediate storage periods.

Bearing in mind these considerations; with the aim of obtaining a man-hour cut of 50% during prefabrication; and a reduction of 1 to 2 months in building lead time, Fincantieri set up the FASP research project in 1989 - the acronym stands for "Flexible Automation in Ship Prefabrication" -.

The target was to study, develop and set up a

demonstration model of a prefabrication workshop at Fincantieri Monfalcone shipyard, the Company's largest. The model features automated robotized lines/areas, fully integrated with the CAD-CAM system and the Production Control System. This concept, as translated into reality on the production floor, is able to handle the production of different structural members of different type and size, making it possible to build ships of very different structural characteristics, at the same level of efficiency and quality. The research covered not only hull construction but also hull design, production planning, monitoring and management.

The technologies and methodologies, whose application within the prefabrication activities were considered in the program, are:

- robot application,
- laser cutting and welding,
- off-line programming,
- production simulation,
- automatic bending systems,
- parts marking and automatic tracking,
- parts handling with manipulators,
- on line quality control,
- telemetry for the verification of the manufactured products,
- advanced sensors application,
- visual and image processing systems, and
- control techniques of deformation due to thermal stress.

The main techniques for the implementation of a Computer Integrated Manufacturing system have also been analyzed within the research program.

## THE RESEARCH ORGANIZATION

The schedule called for a 6-year term, ending 1995.

Partners of FINCANTIERI, FASP project leader, were:

- ANSALDO, an Italian electro-mechanical group;
- ASTILLEROS ESPAÑOLES, a Spanish shipbuilder;
- ENEA, (Ente per le Nuove tecnologie, l'Energia e l'Ambiente), an Italian research committee;
- IGM Robotersysteme AG, an Austrian robot welding company; and
- SOLVING, a Finnish air cushion transportation group.

The research project period was organized in three phases.

Phase 1: Study, planning and design of the reference model.

Phase 2: Design and on-site testing of the critical processes and relevant technologies.

Phase 3: Construction of the prototype prefabrication workshop to measure up with the original target of the project.

## THE AREAS OF INTERVENTION

Within the frame of the studies, at phase 1, a thorough analysis of the current situation in the various areas of the prefabrication workshop was carried out. The situation is outlined in a scheme (see Figure 1), that shows the until-then typical division of the workshop in a cutting-bending area and an area where welding operations are performed. Each area contains its own buffers for intermediate storage of semi-manufactured elements and a stockyard/selection area is the connection between the two shops. The development of these studies led to a modification of this general configuration into an integrated one as shown in Figure 2. This scheme also identifies the critical areas that have been targeted from studies of specific technological work packages (i.e. specific, targeted application fields and related

studies). The research project was then broken down to address the critical areas accordingly:

- The profile line,
- The subassemblies area,
- The panel line,
- The flat blocks line,
- The plate bending area, and
- The curved blocks line.

Other work packages that, together with those mentioned above, cover the other issues of the project as listed below.

- The "Measurement Technologies and Quality Control" work package, that has originated most of the studies, concerns the application of new technologies, with particular emphasis to:
  - measurement techniques with advanced sensors like laser and ultrasonic telemeters;
  - vision and image processing systems;
  - tracking system; and
  - robotics systems for workpieces recognition and selection.
- The "Production Management System" deals with the studies of an innovative model for workshop activities, scheduling and management.
- The "Technical Information System" deals with the integration of the existing Information System with the new production technologies defined by the other work packages.

A study of the type and number of pieces to be processed by each area has been made, taking into account the production mix foreseen for the entire workshop. The production mix considers various ship types. As an example, a general comparison between the number and type of elements to be processed relevant to the construction of about 1.5 cruise ships per year or of about 4.5 container ships per year is shown in Table I.

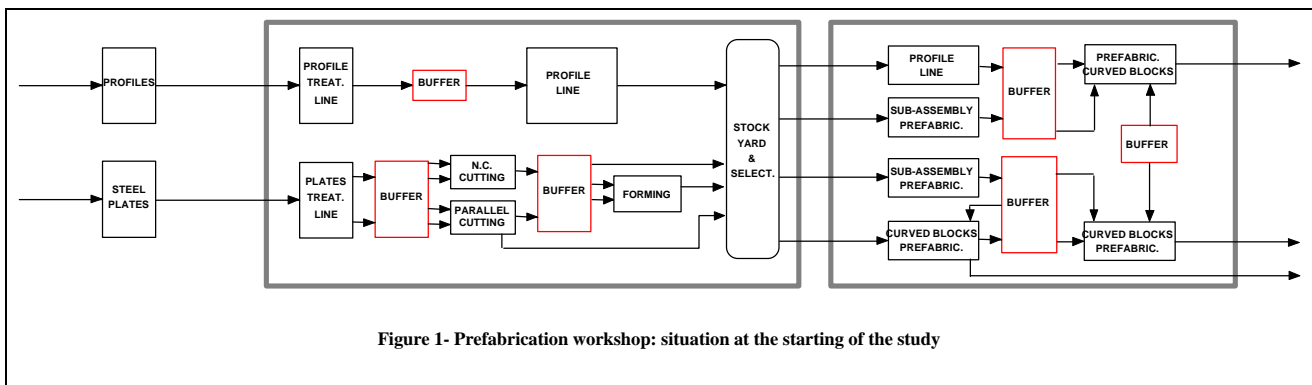


Figure 1- Prefabrication workshop: situation at the starting of the study

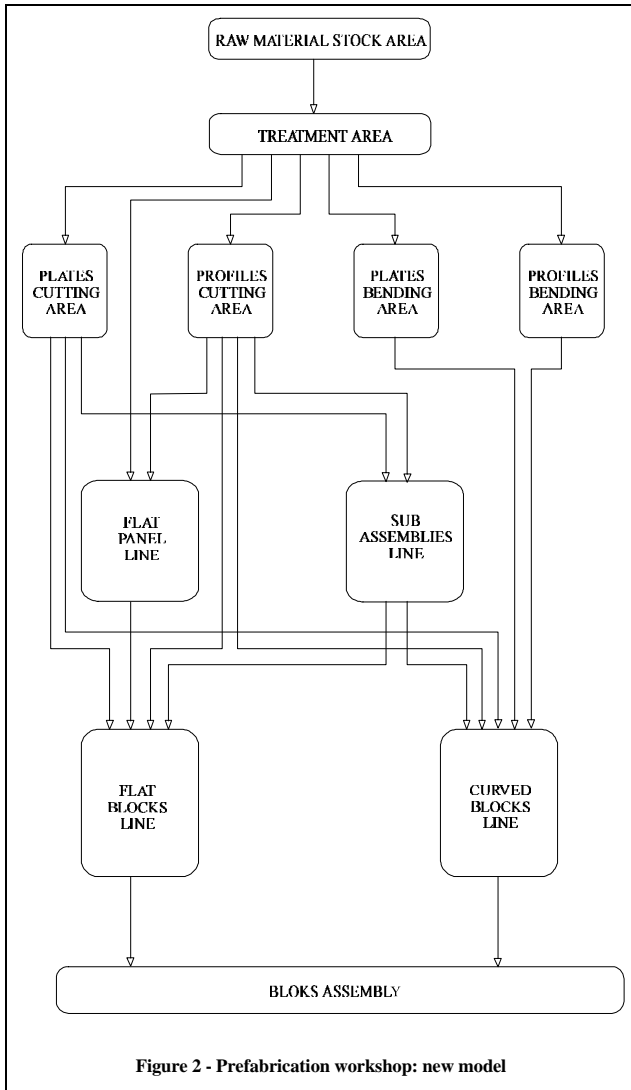


Figure 2 - Prefabrication workshop: new model

For each of the process areas a deep analysis of the current production model has been carried out, taking into account productivity, technologies used, quality of the product, stocking time, minor adjustments, remakes and the resources.

Various new production models have been conceived for each of the areas, taking into account application of the new technologies mentioned and the general targets of the FASP project.

The promising solutions for each area have been tested by production simulation software packages, taking into account the number and type of elements to be processed. That procedure, together with considerations about cost-effectiveness, level of integration between areas, quality requirements for the products and others, have all contributed to outline the final configuration of

each area.

**THE NEW LAYOUT**

As a result of these studies, a new layout for Monfalcone shipyard was developed. A general description follows.

As a result of these studies, a new layout for Monfalcone shipyard was developed. A general description follows.

**The Profile Line.**

It is foreseen to process about 35,000 raw bars per year, with a production of 110,000 - 120,000 finished pieces per year in the new profile line.

The line is provided with a loading buffer, a feeding roller conveyor, a marking/tracing machine and a cutting robot.

WORPIECES PRODUCED PER YEAR SUBDIVIDED ACCORDING TO SHIP TYPE			
WORKING AREA	WORKPIECE TYPE	QUANTITY PER YEAR AND SHIP TYPE	
		CRUISE n.1,5	CONTAINER n. 4,5
Treatment line	Plates	9170	12980
	Sections bars	30400	24020
Plates cutting area	Cut pieces	149800	132860
Sections cutting line	Cut pieces	107510	105350
Plates bending area	Curved plates	1830	3450
Sub-assemblies area	S.S.A	3570	10400
	S.A.	10800	13710
Flat panel line	Flat panels	870	1030
Flat blocks area	Sub-blocks	500	1200
	"Open" blocks	450	220
	"Closed"blocks	60	320
Curved blocks area	Sub-blocks	150	300
	"Open" blocks	70	110
	"Closed"blocks	20	110
	Special blocks	40	210

Table I

Considering that in the traditional profile processing areas the costs for marshalling cut pieces is higher than the one for the cutting itself, particular attention has been paid to the “logistic” issue. An innovative system, able to automatically palletize the finished pieces, has been designed. Two different and separate pallets’ areas have been conceived, with:

- pallets to service the panel line (pieces of about 16 m length); and
- pallets to service the subassembly area (pieces of 0.5 to 5.5 m length).

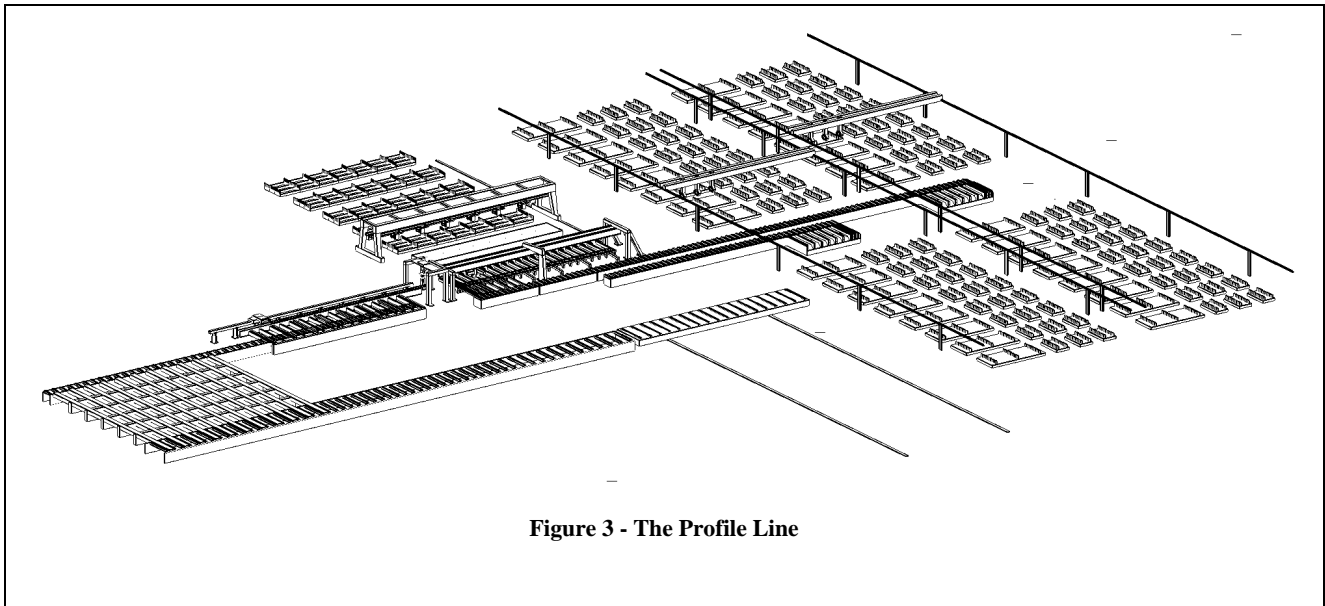
Sorting is carried out according to specific principles which refer to the Production Management System, where pieces laying on pallets or racks are laid down in the same sequence as clamping in the downstream working areas. This requires maintaining strict

tracking and continuous control on pieces at the inlet and outlet of the sorting area. Figure 3 shows the general arrangement of the profile processing area.

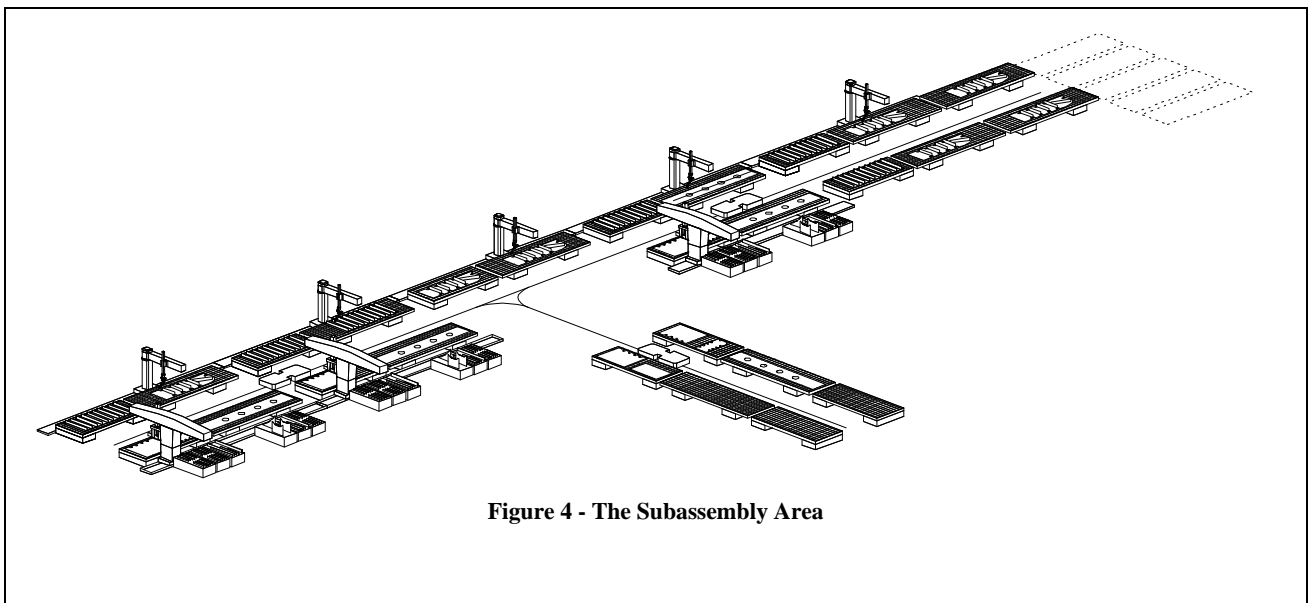
**The Subassembly Area.**

The subassembly area is designed to process 180,000 elementary pieces per year, with an output of about 20,000 subassemblies per year. It consists essentially of a series of dedicated production stations and a transfer system for repositioning pieces being processed from one station to another. The production stations are of three types: assembly and tack welding, welding, finishing.

The assembly stations consist of robotized systems which, in a



**Figure 3 - The Profile Line**



**Figure 4 - The Subassembly Area**

completely automated way, are able

- to pick up the stiffeners from a pallet/rack (one of those prepared in the profile process area),
- to position them on the plate bases that constitute the subassemblies,
- to push them with the necessary pressure in order to obtain good contact, and
- to perform the spot welding.

The plant is equipped with a vision system in order to identify the precise position and fit of the stiffeners on the bases.

The welding station consists of advanced robotized plants for fully automated finish welding of the subassemblies which are already assembled.

The finishing stations consist of plants equipped for controls and several finishing operations, mainly of manual mode, to be carried out in some of the corners and other minor areas not

accessible by the robots.

The various subassembly bases to be processed are arranged over mobile platforms and moved, from one station to the following, by means of a shuttle, based on an air cushion system. The shuttle is capable, in a completely automatic way, of taking a platform, transferring and placing it in the proper work station.

The introduction of an automated shuttle, up to now considered to be an innovative solution applicable only in mechanical systems, resulted in a significant improvement in a completely automated carpentry production plant.

A general view of the subassemblies area is shown by Figure 4.

#### **The Panel Line.**

The panel line is designed to process about 1,100 panels per year (weight from 5 to 80 tons - thickness from 5 to 40 mm).

The panel line consists of the following major components:

- milling machine for plate edge preparation,

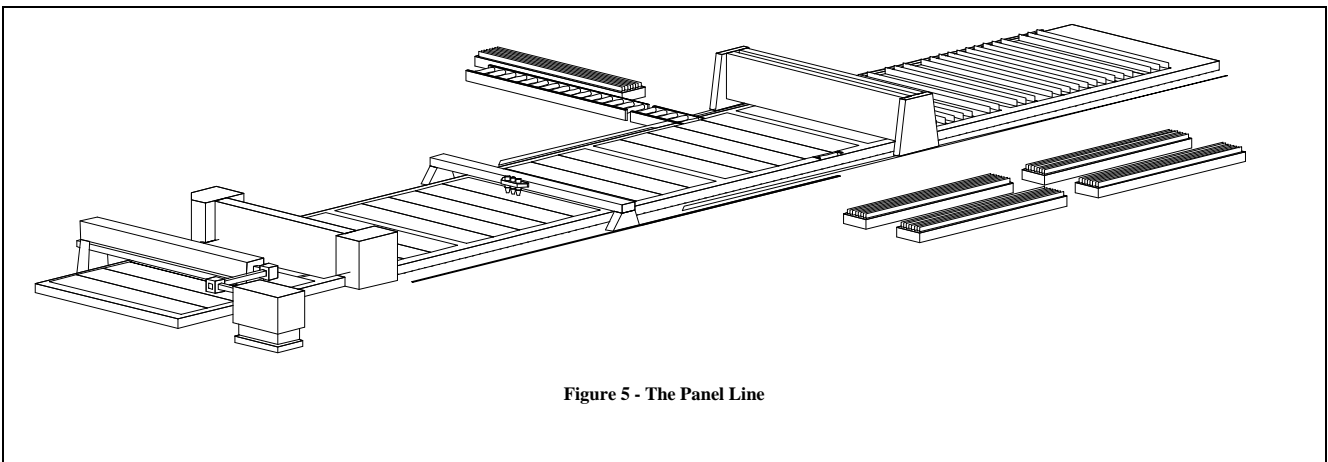


Figure 5 - The Panel Line

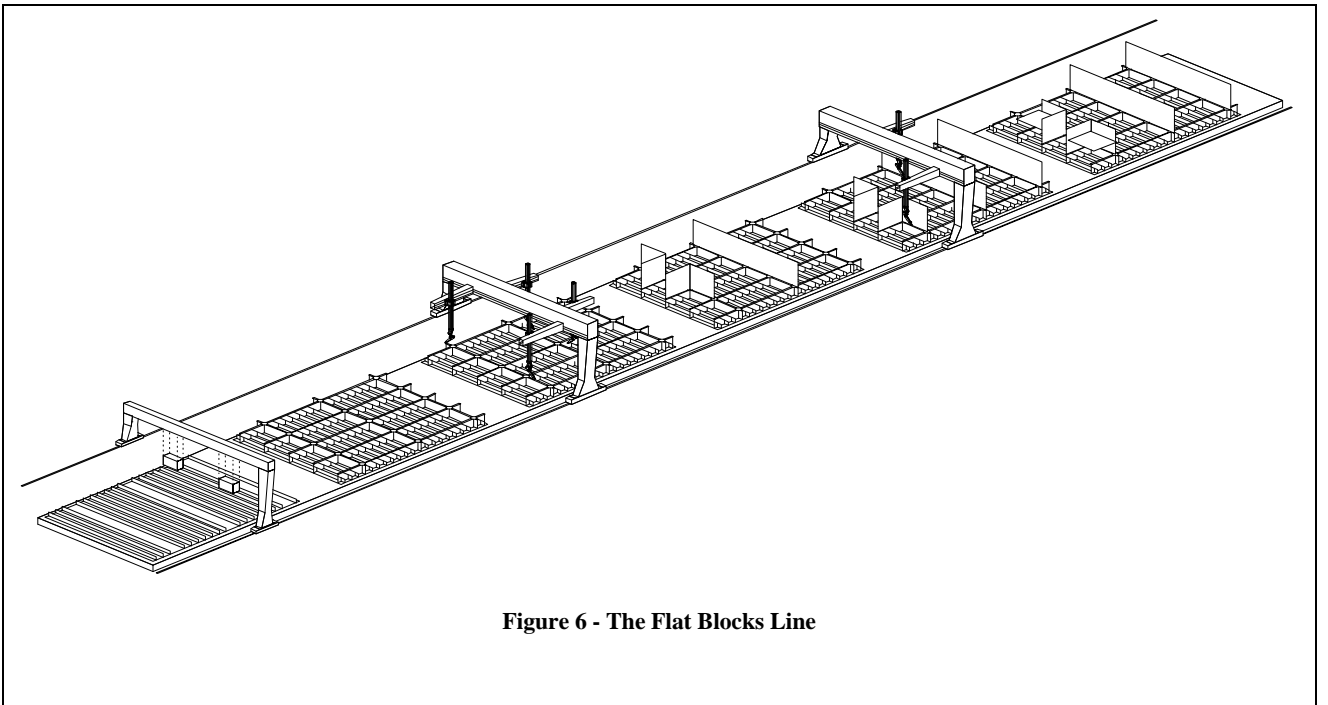


Figure 6 - The Flat Blocks Line

- one-side butt-welding station,
- trimming station for trimming panel edges, and
- stiffeners mounting and welding station.

The one-side butt-welding station is based on the submerged arc welding process, but studies are in progress - following a feasibility study carried out within the FASP program - for a future installation of a laser plant prototype for 16 m long panel butt-welding. The prototype will be completed in the first months of 1997. Compared with traditional submerged arc welding, laser technology offers a measurable advantage in terms of higher welding speed and very limited plate distortion, due to low heat application.

The studies for this new technology application are supported by practical experimentation on 3.5 m long joint welding and are relevant to:

- metallurgic requirements for the steel to be welded;
- definition of the parameters and tests for the welding acceptance by the Classification Societies;
- edge preparation accuracy, in conjunction with the welding plant controller system requirements and the filler wire to be used; and
- particular requirements relevant especially to a relatively long high-power laser beam transmission (due to a 16 m long joint).

A general arrangement of the panel line is shown in Figure 5.

#### **The Flat Blocks Line.**

The number of flat blocks to be produced is about 1000 per year. The flat block area includes two quite distinct lines, one for the open flat blocks (i.e. missing one or more sides), the other for the closed flat blocks.

The open block line includes three working areas : assembly, welding and finishing. The assembly areas are equipped with mechanical systems, able to facilitate rational, safe, and ergonomically optimized work, without physical strains on the part of the operators. The area is optimized for production of quality elements, with suitable dimensional tolerances and deformations.

The welding areas are operated by integrated robotized plants. Two gantries, one equipped with four and the other with

two welding robots, are arranged for the welding of all the parts of the open blocks.

The closed flat block line is also equipped with three working areas, with a lower level of automation. The transfer of the blocks down the line is by air cushion.

A view of the flat block line is shown by Figure 6.

#### **The Plate Bending Area.**

The methods currently used worldwide for both bending the plates and checking the relevant shape, are manual and based on the availability of highly skilled and experienced operators working on non-automated large machines. The human element traditionally plays substantial role in the process.

The steel plates to be processed in the new system are about 2,000 per year, with thickness from 5 to 30 mm.

The technology innovation efforts with FASP have been particularly intensive with respect to this working area. They have focused on the development of a thoroughly innovative approach, based on the exploitation of a computer controlled machine, in order to:

- curve plates with a high degree of precision,
- obtain a drastic reduction of work,
- eliminate remaking at the curved block assembly stage, and
- manage the line in full integration with the other lines and the Information System.

Various possibilities have been investigated for the technology to be applied for plate bending, and for the curvature vision and checking system. The choice made depended on :

- engineering a machine capable of processing plates as large as 16 m x 4 m and
- developing a software capable of receiving information on the actual curvature, comparing it with the final expected values (received from the CAD system) and, according to the relevant comparison results, sending the order to the machine hardware for a next "bending pass".

The line heating methodology is the system chosen for the plate bending machine. Figure 7 shows the configuration of the innovative prototype plant.

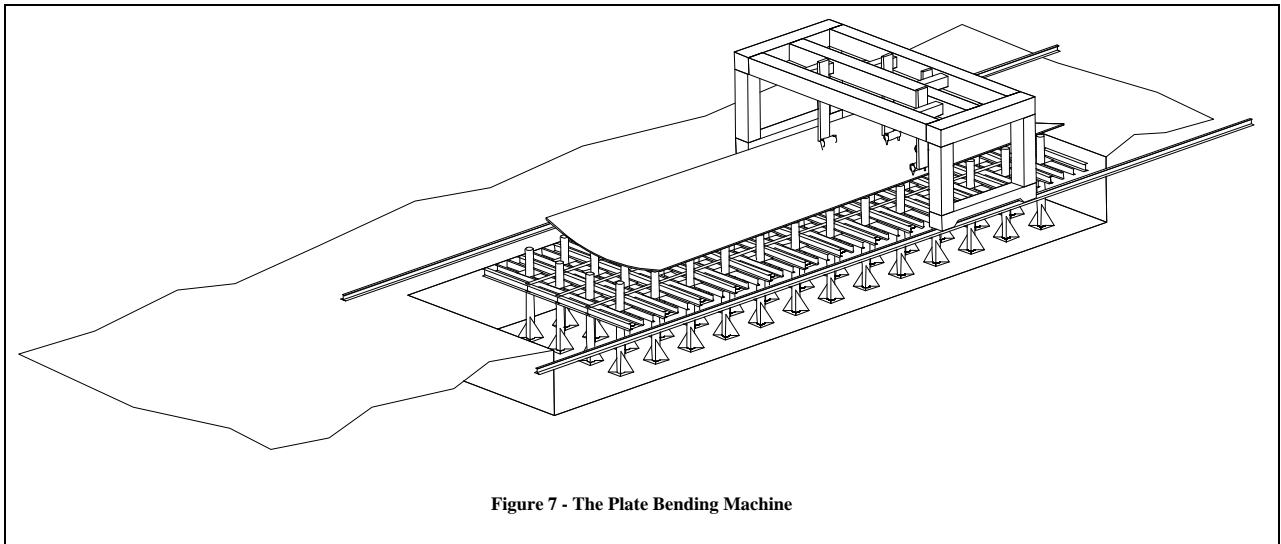


Figure 7 - The Plate Bending Machine

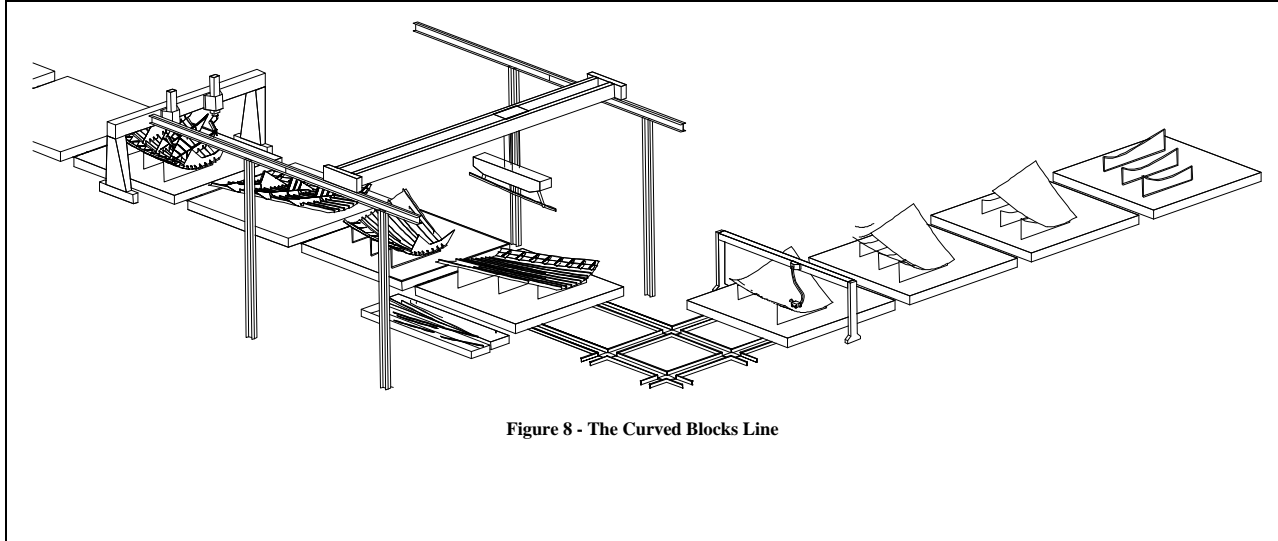


Figure 8 - The Curved Blocks Line

### **The Curved Blocks Line**

The FASP research has identified the families of curved blocks and their quantity, related to different ship types, the planning and the technological problems inherent to the various processes.

The inputs to the line are curved plates, curved profiles and subassemblies, processed in the relevant working areas. In one year about 350 curved blocks are manufactured.

The results of the study are represented both by a considerable reduction of manning and crossing time, and by a high degree of dimensional accuracy.

The curved block line consists of the following major components:

- a number of platforms, moved by an air cushion system;
- robotized arms, arranged on small trolleys, able to butt weld the curved plates in order to obtain the curved panel;
- a manipulator for stiffener mounting and tack-welding, and
- welding stations for stiffeners, with a gantry equipped by two welding robots.

As was the case with the welding robots for the flat blocks, a remarkable effort has been devoted to cut to a minimum, through computer simulation, the time necessary for the preparation of the part programs. This issue is discussed in the following pages.

A general configuration of the curved block line is shown in Figure 8.

### **THE NEW INFORMATION SYSTEM.**

The introduction of large numbers of robots and NC machines in the new prefabrication workshop requires numerous modifications in the construction of hull blocks. Such modifications re-echo directly on new requirements for Fincantieri information system, in fact it is necessary:

- generate control and process structured data for a remarkable number of different machines;
- describe the productive operations with greater detail, both for production planning and controlling needs and for correct use of the machines; and

- manage a greater volume of data, in a consistent and controlled way (integration among the various departments, information exchange, variation notification, etc.).

The definition of an implemented information system, able to coordinate and control the shop activities; and to generate, store and manage the necessary new data, was a goal of FASP project.

As mentioned before, the whole of this system is subdivided into two work packages of the project:

- Prefabrication Control System - that covers planning and production controlling topics, and
- Technical Information System - that covers technical data definition and part program generation.

### **The Prefabrication Control System.**

The prefabrication control system deals with two data-management levels, the shipyard information system (level 4) and the workshop information system (level 3). This scale architecture allows the information flows to be clearly defined and facilitates the identification of specific responsibilities.

The shipyard information system provides all the structures required to level 3 to control production activities, such as:

- general planning of all production orders at the shipyard;
- management of materials available from the warehouse; and co-ordination with the technical system, which provides technical documentation for production.

The workshop information system, which receives data from level 4, must synchronize the production activities allocated to individual areas, optimizing the production resources.

Hereinafter the content of the main software components, called subsystems, are described. A data flow diagram (see figure 9) and a brief report of functions supported is given.

### **Resource Work-Load Check (level 4) - PPR.**

The PPR subsystem provides a support for the general planning activity of the shipyard. The processing performed provides:

- scheduling support during milestone verification with a check

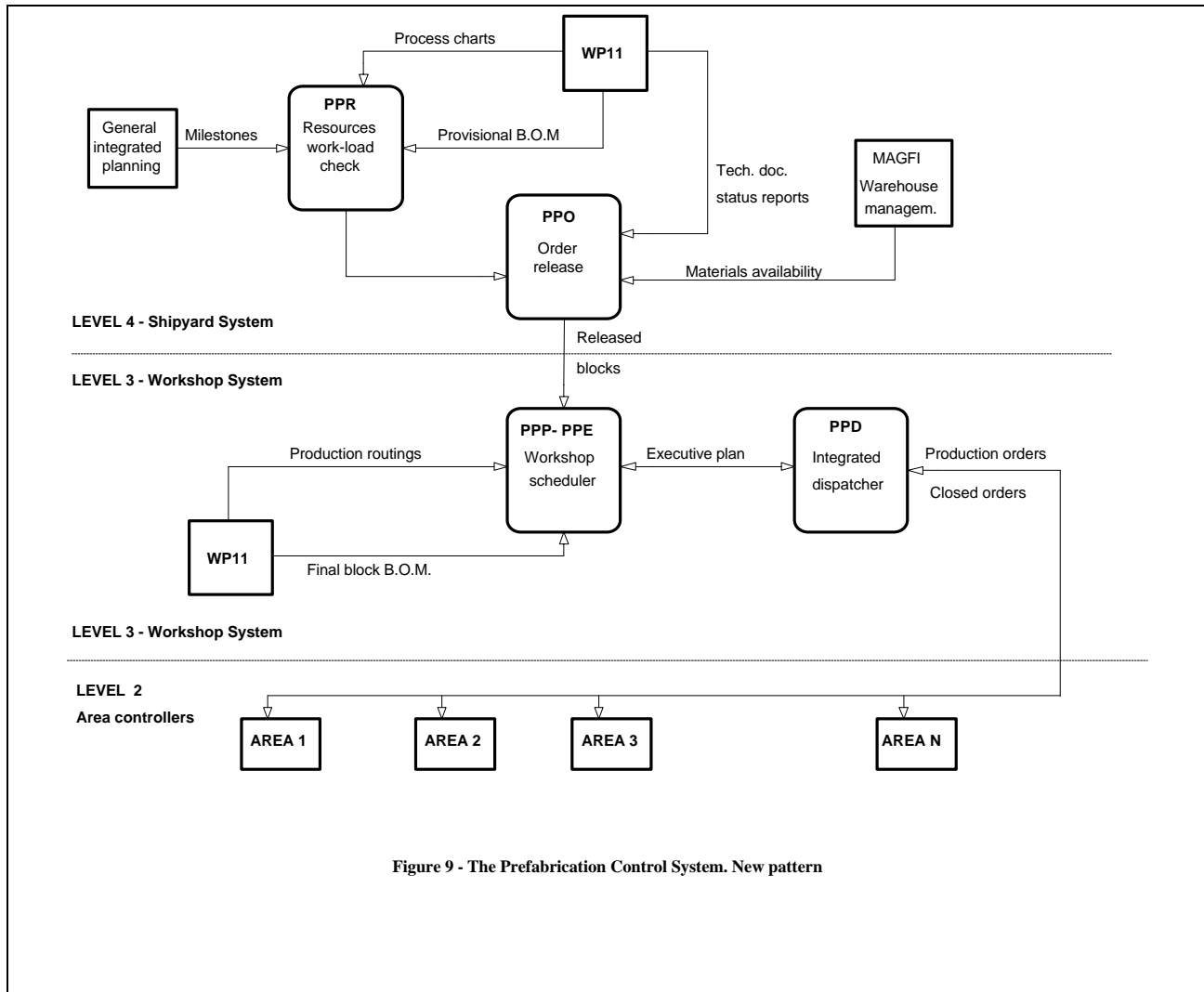


Figure 9 - The Prefabrication Control System. New pattern

on effective capacities of the workshop; and

- a profile of load varying with time, for each resource used in the areas.

**Order Release (level 4) - PPO.**

The PPO subsystem provides the shipyard production control department with the tools necessary to keep the workshop supplied with feasible production orders. The processing performed provides:

- verification of the feasibility of the orders in terms of primary resources,
- assignment of the materials stored in the warehouse, and
- gathering of all data before sending to the workshop system.

**Operative Planning (level 3) - PPP.**

The PPP subsystem generates a weekly workshop plan for the orders released by level 4. This planning takes account of the information sent by level 4, of operations introduced or generated locally, and of actual progress of activities already released to areas. The program is also capable of tracking availability of production resources and using the production

resource requests specified by production routings.

**Executive Planning (level 3) - PPE.**

The PPE subsystem performs detailed scheduling daily. The output is the short-term executive plan, which is then taken over by the real-time function of release to the areas.

**Integrated Dispatcher - PPD.**

The PPD subsystem consists of a set of modules that generate and transmit production tasks to the various areas and receive production progress and other information needed to update the status of the workshop. The system also support the management of communications with areas (level 2), executing driving and monitoring functions.

**The Technical Information System.**

The main goals of the technical system are the following:

- describing the form and the structure of the hull and getting its

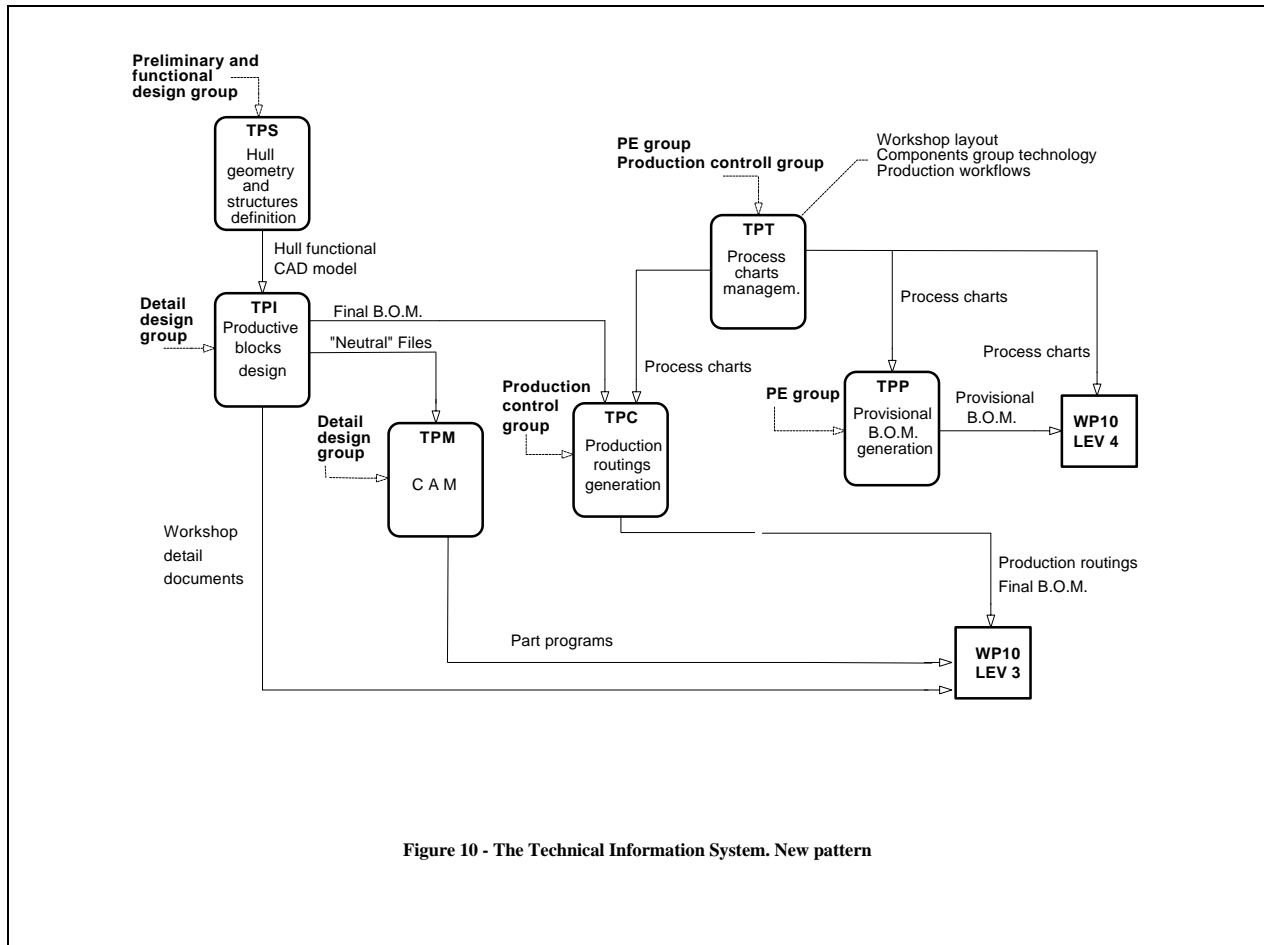


Figure 10 - The Technical Information System. New pattern

drawings;

- storing and managing the technical data needed for detailing the hull construction operations and for getting the part programs necessary for automatic machines;
- supporting group technology concepts to allow the partial reuse of data from previous projects;
- formalizing workshop layout in terms of material flow and resources, and typical workshop products in terms of standard cycle times;
- guiding the complete definition of the product structure (engineering bill of material); and
- managing technical documentation like constructive drawings, technological process, production routings, and part-programs for each component.

A brief report of the main software components functions supported follow (see figure 10 for the data technical system data flow diagram); within the TPM subsystem a particular module is presented as a key example.

**Hull Geometry and Structures Definition - TPS.**

This subsystem, that is the first one to be utilized in the design cycle, supports the hull basic design and allows the definition and the verification of the geometric model of the main surfaces, and structures.

**Productive Blocks Design - TPI.**

The TPI subsystem supports the activities connected to block engineering concerning:

- the transformation of the hull functional model into the productive model or block model,
- the creation of the engineering bill of material, and
- the preparation of the detailed technical documentation.

**Production Routing Generation - TPC.**

The TPC subsystem supports the activities connected to the generation of production routings. These are data structures introduced by the FASP project as representations of the action sequences necessary to produce the various components located by the bill of materials. The routings include data regarding labor and machines to utilize, times necessary to the activities execution, tools, workshop surfaces, equipment and technical documentation.

**Provisional Bill of Materials Generation - TPP.**

The TPP subsystem create and manage a provisional version of the engineering bill of materials to be used for rough cut planning in the early phase of a ship life cycle, when the engineering is not yet completed and the final bill of materials is not available.

**Process Charts Management - TPT.**

The TPT subsystem provides the definition and maintenance activities for the logistic model of the prefabrication workshop. The logistic model is a set of data structures representing the productive and logistic flow of the families of components (materials categories) which the workshop can treat, i.e. made inside or purchased outside. The data structures are subdivided into two groups:

- workshop layout, and
- flow of families of components (process charts).

**Computer Aided Manufacturing (part program generation) - TPM.**

The TPM subsystem implements and verifies the part programs for operation of the numeric control machines and robots. TPM mainly supports work preparation for the following automated production lines and areas:

- Robotized profile sections cutting and palletizing,
- NC sub-assemblies mounting and robotized welding,
- NC panel line,
- Robotized flat blocks structures welding, and
- Robotized curved block structures welding.

**An Example: TPM.B - Arc-Welding Robot Off-Line Programming System.**

Historically, ships have been manufactured as one of a kind products with great variation in design, construction and build. Traditional welding methods typically required about 70

hours of programming per 1 hour of robot welding. Programming was done on-line. This means that the robot was taken out of production the entire time needed to create programs.

In shipbuilding, nearly every single ship is a prototype: two ships can be very similar but not identical. This means that every single ship component (i.e. ship section, ship block, ...) requires programs that are unique.

By using off-line programming, shipyards can reduce the programming time to only a fraction in comparison with traditional on-line programming.

Fincantieri chose simulation software to achieve curved and flat block off-line programming. Simulation products offer built-in libraries of most common industrial robots (geometry and kinematics model), standard torches, positioners, gantries, and related equipment. Workcells are easily developed using these built-in libraries. Nonstandard components of the workcell, like the workpiece (in our case curved blocks), are imported via IGES from the CAD model.

Starting from a standard commercial product, a layer of software has been developed to allow a rapid and efficient programming of robots.

The development that has been performed is based on the following concept.

The majority of welds used for ship construction can be categorized into families. Each family can be programmed as a "primitive" or template, then parametrically mapped to each weld seam. In this way, programming curved blocks - with highly individual and curved seams - for example, is as easy as programming flat blocks having mainly flat and similar sections. The primitive capture years of welding experience and form a

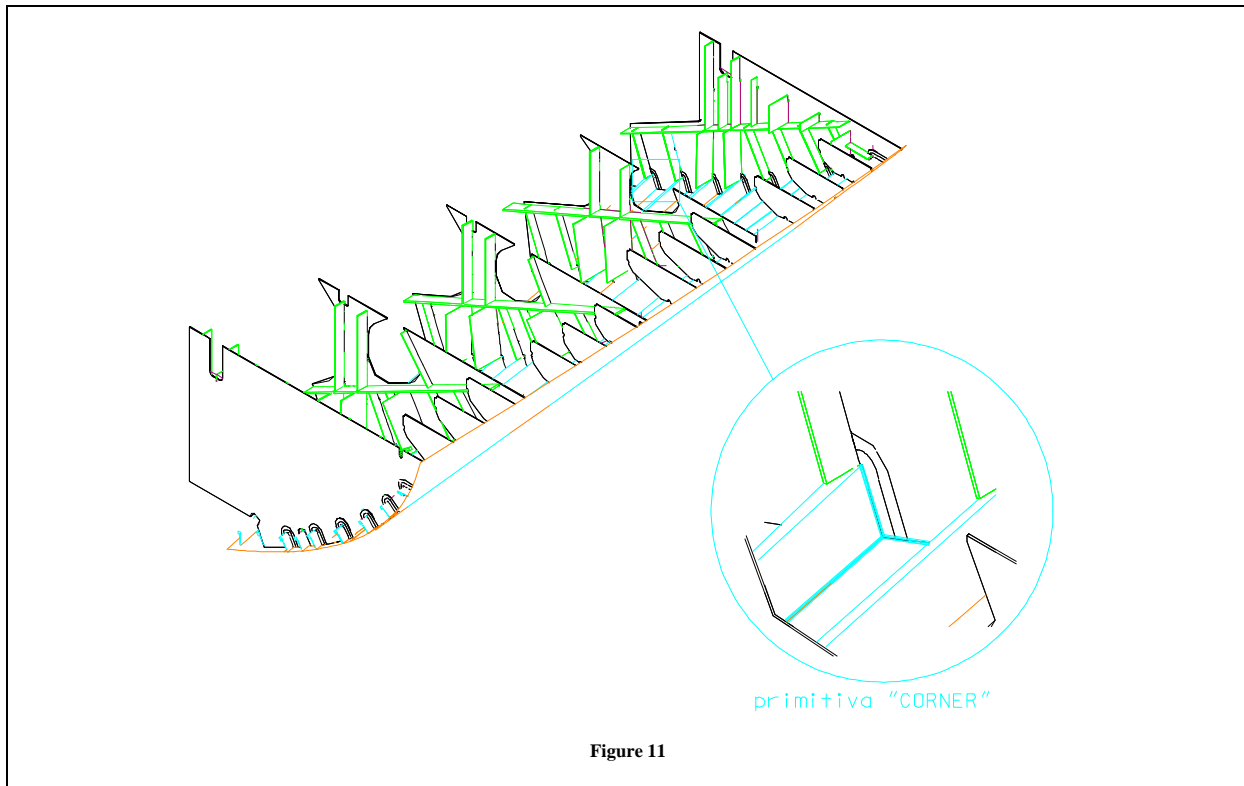


Figure 11

knowledge base for preserving vital information.

Thus an off-line robot program can be created in nearly the same amount of time as the robot work cycle itself.

#### *Primitive.*

User defined parameter values are used to define tag locations, orientations and auxiliary data. This allows one to dramatically limit the number of interactions by the user. Rapid selection of weld zones that have similar, but not identical, geometry as is commonly found in ship structures (see figure 11 ).

A parameter popup is used to define the location and orientation, with respect to part geometry, of individual tag points. It is also used to define starting and ending conditions (i.e. distance, surface, vertex, etc.).

This popup is generated by what are referred to as primitive files. Primitive files consist of system variables and keywords that define how and where to generate weld paths.

Primitive files contain variables used to define the location and orientation of tag points (tag points are used for indicating destination positions for robot motion) in and around a joint or combination of joints.

Libraries of primitive files have been created to define standard, or unique, joint configurations. Keywords are available that can actually restrict the simulation system operator from modifying primitive system variable values. This helps ensure that important system variable values, that are defined by a weld engineer, cannot be modified during primitive execution.

A primitive file can be invoked using standard buttons of the simulation environment.

Once invoked, user-defined prompts contained in the primitive file can be used to indicate the type of geometry selections required to define the weld joint(s).

#### *Primitive and Weld Process Data*

A set of functions and variables are available to define robot specific weld process parameters including those parameters that allow the control of sensors like camera and arc seam sensing.

It is also possible to reference external weld process data files. This process data file must exist in the process library and must be loaded into the robot welding device. Table references will be automatically placed in the appropriate tag points. When the appropriate function is invoked, a robot program is automatically generated with the appropriate weld data references.

#### *Primitive and Off-Line Programmers*

The majority of robot programming is done by users that are not computer or robot experts. Therefore, it is essential that the system is easy to use and smart enough to maintain important weld procedural information defined by weld engineers.

This is why primitive libraries are created before the programming is done. In this way robot and weld engineers can identify typical weld zones and structures and study appropriate primitives. One of these primitives is able to place weld paths with more than 50 points in just few mouse clicks.

The end user of the off-line system does not have to take care of these single points. The end user have to consider just the seam, and decide which seam configuration is better for a given geometry. Via points to ensure collision-free motion between weld joints are automatically generated. To minimize robot cycle times, weld paths are logically ordered and sequenced. Complex camera

sensors and robot master slave configurations are also inserted by the primitive without any input required from the end user.

#### *Primitive and Interactions*

Using the primitive system the number of user interactions is dramatically reduced. To program a certain typical area of a block, the user only needs to execute the correct primitive and select the weld zone with few mouse click on the "most meaningful" surfaces.

Reduction of the user interactions means that the system is automatically executing most of the operations and therefore errors due to wrong user inputs decrease.

For this reason primitive make robot programs generated off-line more reliable.

#### *Primitive and Methods*

In addition to automatic path generation, a mechanism able to detect errors and correct them is available to the weld and robot engineer that is developing primitives.

During primitive execution, "methods" detect collisions, near misses and joint limits. Specific "rules" inserted into the primitive file tell the system how to behave and how to modify tag points in order to correct the error situation.

In this way test and modification become activities that are executed automatically by the system. Users do not have to take care of these tests and modification any more.

Methods help making off-line programming system more rapid and efficient.

Robot programs became less sensitive to the user skill for what concern quality.

## **CONCLUSIONS**

The first application to actual production of the new system herein described was for the construction of a 77,000 gross tons cruise ship with a passenger capacity of 2,400 in 1,050 cabins. The results of this application have confirmed the effectiveness of the solutions adopted and the real possibility to meet the targets as originally foreseen.

The particularly high percentage ( more than 50% ) of labor for passenger ships outfitting in respect to the workforce devoted to the hull, suggests undertaking a project similar to the one described above covering the various outfitting activities. This field is considered at the moment to be among the most rewarding issues for the research in the near future.

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