Minimization of Production Cost by use of an Automatic Cost Assessment Method and Simulation[1]

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Abstract

This paper will present different ways to minimize cost in shipbuilding industry. Amongst them we have the production simulation methods, the cost assessment methods and the optimization methods.
Nowadays, cost assessment is a key task of an integrated ship design. The various methods to estimate the production cost differ with the known information (input data). The less information is detailed, the earlier a method can be used in the design process. The more information is used, the better we can assess the differences between design alternatives.
The methods presented here and the "design for production" concept promise to increase the productivity trough the following points: a more accurate cost estimation, an improvement in the deadlines planning and the production schedule, a progress in distribution of the workload between the various production workshops, a better knowledge of the individual costs that will permit to reduce the global cost.
In order to illustrate our work, we present in this paper three methods to decrease the global cost of a ship.

Introduction

The shipbuilding activity requires a lot of labour. Indeed, for a passenger ship, the ship hull (steel part) represents approximately 20% of the cost of the ship and the cost of labour represents about 60% of the cost of the ship hull. For our western countries, this fact induces relocation of ship manufacturers towards regions having lower labour costs. Indeed, we can observe in the history that the leadership in shipbuilding moved from UK to Japan and latter to Korea, whereas today China is getting a bigger and bigger part of the market.

To avoid this delocalization and to remain profitable, Europeans decided to devote themselves only to the ships with high added value, like passenger ships, or with high technology, like the LNG carriers.
To keep and increase their shipbuilding world market share, opposite to Asian competitors, the European shipyards are always obliged to increase their competitiveness significantly. Moreover, the nature of the European shipbuilding market prevents large production series; each ship is unique, and the installation of full automatic processes remains complex.

Even if significant efforts have already been achieved by the shipbuilding industry to reduce the costs of each individual stage of ship construction, the European objectives in this domain must still be achieved: reduction of the design and manufacturing cost (25 to 30%) as well as times of production cost (20 to 30%). Another important research field concerns the development of the best product by using multi-purpose optimization integrated design, quality, safety, environment and efficiency.

Since the main part of the construction cost relates to the production and since the producibility of a ship is basically defined at the design stage, the main promising track of cost savings is to assess the production cost as soon as the options of construction are fixed ("Design for production/Design to cost").

The ability to assess ship construction costs is necessary for the commercial success of a shipyard;

- overestimate the cost will place the shipyard out of the competitive range, and

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- underestimate the cost will result in a financial loss and possible bankruptcy.

To answer at this request we studied several levers such as the cost estimate assessment methods, the simulation or the optimization which are here exposed.

Simulation tools into the shipbuilding design process

Today the design method used in the shipbuilding plays a primary function at the first stages of the project. According to a traditional approach, during these phases, the majority of the decisions are taken based on experiment and opinion of the designers. However, these decisions have a strong influence on the ship and also on its entire life cycle, production, maintenance, etc.

In order to compensate cost increases or quality decreases due to flexibility lost for modification of scantling (see Fig. 1) during the ship design, the shipbuilding tries to apply the concurrent engineering concept rather than a sequential engineering. The decisions of each stage are made by considering the constraints imposed by the other stages of the ship life cycle. Now, the problems that were only checked at the end of the project are now included in the design stage to reach a better solution. Each department does not wait any more until the precedent had finished but has to consider that a decision can occur in the course of project. [1]

As illustrated on Fig. 1, one of the effects of concurrent engineering is to move the information curve upstream because the effectiveness and the quality of the information on the ship are improved from the first stage of the project. This aspect is particularly strategic as the design process has a cost which varies from 5% to 15% of the total cost and moreover decisions taken during this initial stage determine about 60 to 95 % of the total cost. [2]

Methodology developed within the present research framework will increase and accurate the knowledge relating to the ship by the prediction the useful data to assess the cost before the full CAD/CAM model has been completed. Thus, the designer will know earlier more information and will be able to make the best decision from the design stage. The first errors of the project, the most expensive ones, could thus be avoided.

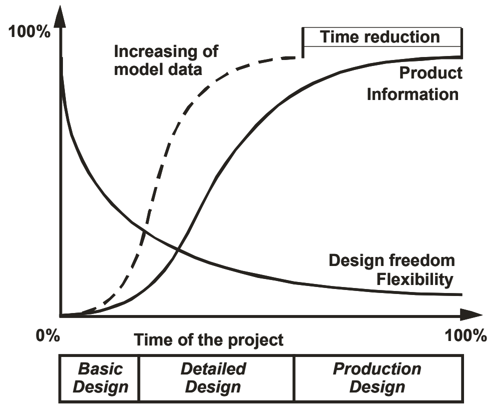

Fig. 1: Evolution of the design information relating to the ship

The challenge consists to create different tools in order to increase the design information of the project as soon as possible. In this paper we present 3 methods applied at different stage of the project to perform this objective:

1. *An analytical cost assessment module for the detailed design stage.* This tool is designed to assess the cost one month before the production (see flag 1 in table 1). In the further, it will be possible, while being based on the results of the analytical model, to build for the "basic de-sign stage" a cost model based on default values possibly statistically based (see flag 1 in table 1). Indeed, at this stage, the databases do not contain enough information. Then, for the later stages, when all the data are available, it is planned to reach a 100% rational cost assessment tool. It is thus planned to have a progressive and continuous feeding of the rational model.

2. *Simulation and optimization of a pre-manufacturing workshop.* This tool is designed to elaborate the best production ordering of a pre-manufacturing workshop some weeks before the production (see flag 2 in table 1). His aim is to decrease the lean time and smooth the workload of the workshop.

3. *Simulation of a panel line workshop by using of a statistical data generator*. This tool is dedicated to the simulation for different time horizons. For a long term approach (see flag 3 in table 1), the data are rough and

the objectives remain general bit for a short term approach, the information are more accurate and it permits to simulate in detail the workshop behavior. An interesting advantage of the tool is the opportunity to use accurate data for a long term approach when the production concerns a sister ship. Indeed, in the case of the construction of two identical ships, the production of the second one benefits the data of the first one.

Strategically decision	Tactical decision	Operational decision
• Business strategically planning • Stable resources	• To produce at lower cost to satisfy the request • Schedules	• To regulate daily problems • Stock management, labour, equipment
Basic Design	*Detailed Design*	*Production Design*
>18 months	*8 – 12 months*	*1-2 months*

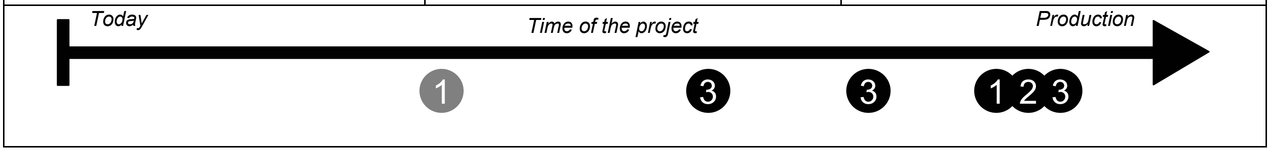

Table 1: Decision into the shipbuilding design process

An analytical cost assessment module for the detailed design stage [8]

The basic idea of the project is to implement a real time and automatic cost assessment method of the ship hull production that integrates all the design criteria and the production parameters. This tool assists the designer from the earliest conceptual design stage up to the latest detailed design stage and permits him to reach the least expensive option considering simultaneously the design criteria and the production parameters (See [3]).
Today, the first prototype is in test stage to the AKERYARDS shipbuilding within the framework of the European project Intership which has financed the study.

The methods for estimating production cost are classified into [4]:

- *Top-Down (macro, cost-down or historical) approaches (empirical, statistical and close-form equations, ...), [5][6][9]*
- *Bottom-Up (micro, cost-up or engineering analysis) approaches (direct rational assessment) [10]*

Despite its popularity and frequent references in the literature, top-down approaches have serious disadvantages. We therefore choose a “bottom-up approach”. Indeed, the goal is to control the short-term cost and then to identify the main key factors of the cost. Subsequently, we generate the missing data to assess these factors starting from the matured elements available in basic design stage up to the final detailed engineering stage.
Our idea is, to build a methodology allowing the analytical cost assessment in the "detailed design" stage. The use of a cost module based on an analytical method is essential because the statistical analysis of the data is questionable.

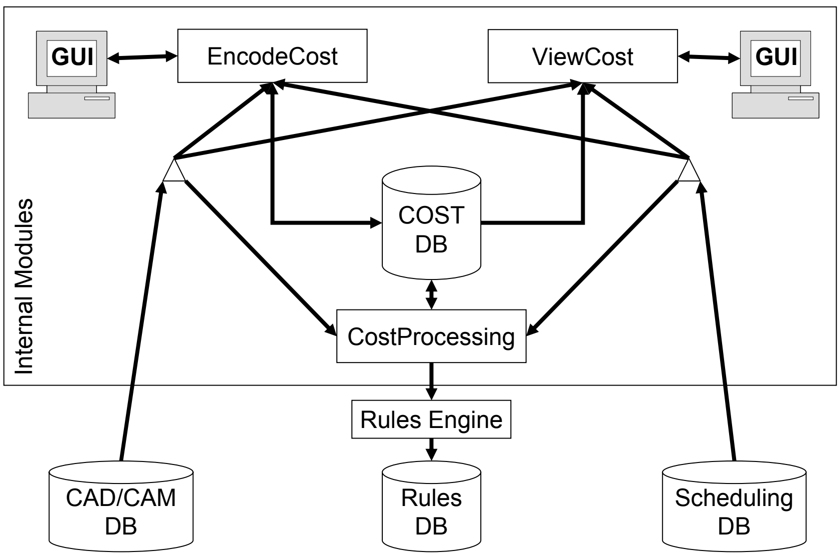

Fig. 2: Data flow for software’s

The goal of this work is to establish a methodology and a tool to solve a very common problem in all shipyards: the cost assessment problem. A first prototype tool has been developed in order to solve that problem. Fig. 2 represents the flows diagram of the developed software. The application will be articulated around three secondary sub-modules. It contains a graphical encoding module (*EncodeCost*), a processing module (*CostProcessing*) and a graphical visualization module (*ViewCost*). Moreover, the data are stored in an Oracle Data Base (*Cost DB*).

The majority of the data which are necessary to the cost calculation are recorded in the relational CostDB data base. The Graphic User Interface EncodeCost, developed in java, is designed to introduce the data in a user friendly way. From there, we can reduce risks of encoding mistakes. On the one hand, the GUI proposes to the user to visualize the data stored in COSTDB data base and on the other hand it proposes to see a complete management tool. The GUI is reusable insofar as the graphic elements are built according to data's present in the tables of COSTDB. This method gives a great flexibility since a modification of the data base requires a small effort to update the software.

The cost calculating unit CostProcessing is an independent module which consults the CAD/CAM DB and the scheduling DB. The CAD/CAM DB contains dimensional data (plate thickness, profile length, profile scantling, weld length, weld throat, etc), quantitative data (number of profile, number of holes, etc.) and finally the qualitative data (steel quality, surface quality, weld position, etc.). The scheduling DB contains various general data related to block splitting, dates, etc. And finally, the Rules DB contains some production rules peculiar to the shipyard. It carries out the requested calculation (according to the tree structure of the ship) and records this calculated cost in COST DB. This module will calculate the labour cost of the hull structure.
The display unit entitled ViewCost collect the data inserted in COST DB by the calculating unit. The sums of the elementary costs and the merging according to the user choices will be recomputed in real time during the interrogation of the data base.

The cost visualization application (ViewCost – see Fig. 3) is splitting in two great hierarchical structures. We will proceed to the display of the cost via a double tree diagram, the first one represents the ship hierarchy (1 – Fig. 3), the second one the cost structure (2 – Fig. 3). These two parts interact to show the data and the calculation results in a user friendly way. We note that Fig. 3 shows also the item list of given assembly (3).

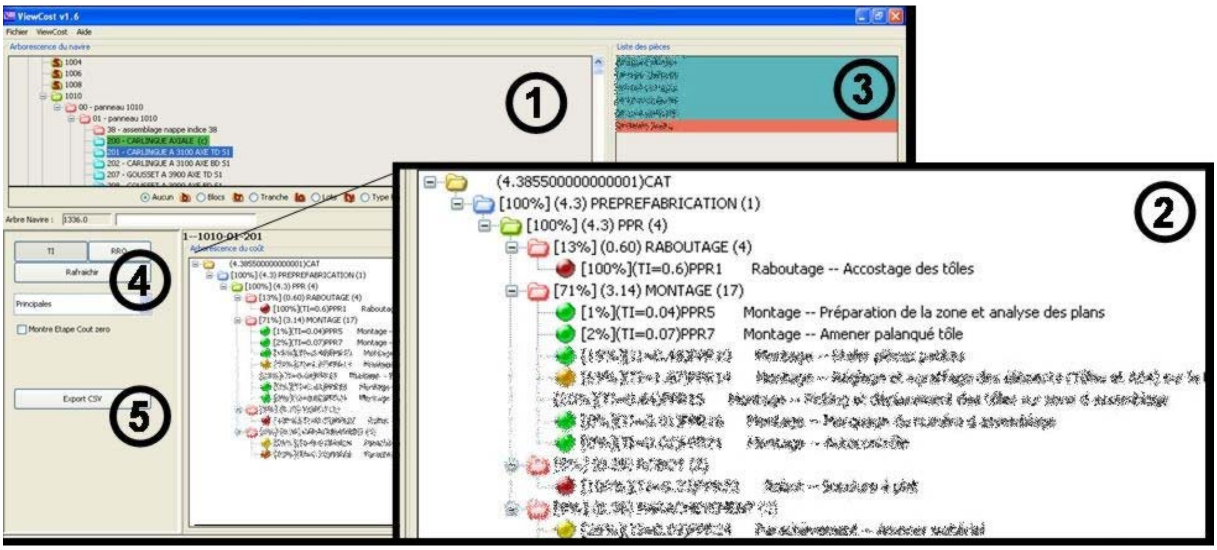

Fig. 3: Main frame of the ViewCost software (debug data)

Nevertheless, the user will be able to choose some calculation options (4). Consequently our work focuses on the costs analysis and the productivity of the production system. In practice, after selection of a subset in the hierarchical ship structure (1 - Highlighted selection on Fig. 3), the user presses the button "refresh" and the cost structure calls the sums requests which show the cost according to the selected options.
The cost tree structure (2 – Fig. 3) is shown with a percentage and a colour gradation so that it is very easy for the user to distinguish where the bigger costs are. We also show the absolute cost production in hour. Thus, we can drive out the expensive designs and the lack of productivity. Thanks to the ship tree and with the additional data which can be consulted (quantities, items outlines, etc.) the user can more easily and more quickly identify which are the causes of an abnormal cost.

A major innovation concerns the cost that can be calculated for any subassemblies of the ship, from the smallest up to the largest. We can thus compare the cost of the various assemblies' of the ship. We can find new innovative designs which will reduce the cost production (design for production).

Simulation and optimization of a pre-manufacturing workshop [7]

These simulation models will be presented in the paper; they correspond to workshops situated in the French shipyard AKERYARDS FRANCE.

The software used to model the workshop is Plant Simulation (previously called eM-Plant) and the major advantage is that this object-oriented software allows a precise visualization of the workshop behaviour (movement of the elements, etc.) and permits to consult the characteristics and statistics of any object when the simulation is running. Results can be recorded and be compared with other ones from previous simulation runs.

The first workshop shown in Fig. 4 is divided in several manufacturing cells and produces sub-assemblies having a maximum dimension of 10 m by 4 m.
The main characteristic of this workshop is its symmetry: left side is identical to the right side. Each side has its own tools and its own arrival of pieces and exit of finished assemblies. However, there is one tool which is shared between the two sides: the automatic welding robot. This is the only link between the two sides.

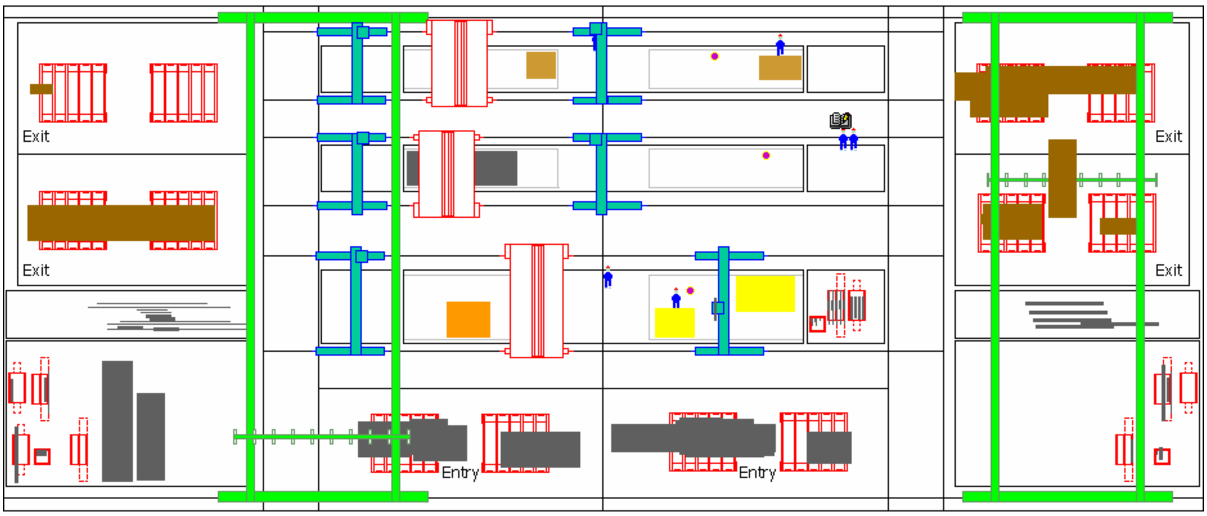

Fig. 4: Model of the welding workshop

Of three different production lines, two are identical and the third allows treating bigger pieces. Each line (or "cell") contains two symmetric parts (or "half-cells") which produces their own assemblies. Each half-cell has one area to store containers (area that will be called STK area) and one area to produce the assembly by realizing the sequence taking-welding-finishing. Pieces will not arrive in the workshop by the same way: long plates arrive by container in the entry area, long girders come by the side and are stored just before the exit containers, and smallest pieces arrive in small containers put in front of each work area (in the STK area).

Two crane bridges, one on each side, bring input pieces from the entry zone located in the bottom of the workshop (see Fig. 4) to the work area of the corresponding cell.
The crane bridge is also used to evacuate finished assemblies and to evacuate them on one container of the exit (two containers are used for the evacuation for each side). Assemblies can be classified in different groups depending on the largest assembly to which they belong (called "panel"). So at the exit, we will pile only same assemblies on the exit containers. We have two different exit containers, so we can have two different groups of assemblies at the same time in the workshop. Unfortunately, it will not be always the case so when we have an assembly to evacuate and if there is no free container, we store it in a temporary area (just before exit containers).
For each half side, we have one mechanized gripper. It is used to bring pieces from the containers of the STK area to the work area and to tack them. For very small pieces, the mechanized gripper is not used but manufacturing and tacking is done manually by workers.

The welding robot is the only tool which is shared between the two sides of the workshop. It is a completely automatic tool, which is used to weld pieces that have been tacked before either manually or by the mechanized gripper.
In inputs we have a list of assemblies that have to be realized. In fact, we have two different lists, one for each side. These assemblies are grouped and constitute what we call a kit. A kit can contain only one assembly, but may also contain four or five small assemblies. All assemblies of one kit will be done on the same half-cell at the same time. *Our goal is to find the best sequence of all these kits to minimize the total time of production*. These kits have to be defined before by the user, and cannot be changed for the moment, but it could be interesting in a further research to try to obtain directly these kits by an optimization tool.
For the simulation the sequences of these kits are inputs but by using optimization it is possible to find the best sequences which gives – in mean – the shortest production time.
At the start we fix two sequences of kits (one for each side) which is the order of production of the kits. As soon as a half-cell is free, we allocate the next kit in the list to this free half-cell. Thus we don't know at the start of the simulation where kits will be done. Plates are stacked at the entry on containers (PM) according to the orders of this sequence. The advantage of this way of functioning is thus to avoid using unnecessarily the crane bridge to stack up plates from PM to a temporary area because plates we need will always be on the top of the stack. Unfortunately the major problem is to equilibrate each side of a cell in order to saturate the welding robot. Indeed this operation is the longest so it is really important to avoid down time of this tool. With this method it is very difficult to satisfy that balance.
The model developed is very detailed, parameters introduced in the simulation are (list non exhaustive): supply and evacuation times (different for each container), set-up time, speed, acceleration of the crane bridge and of the mechanized gripper, tacking time by meter (different if done manually or with the mechanized gripper), take down and up time (for crane bridge and mechanized gripper), maximum capacity of each container, …
Each time introduced in the model is a mean (with a distribution, variance and bounds associated) and can be changed easily.
Simulation can provide us interesting results as occupation of crane bridges, of mechanized grippers or also of workers. It directly tells us which tool in the workshop is a bottleneck. Another interesting result is the time of each operation for each kit. But the aim of this study is to link this model to an optimization module in order to obtain a better solution by avoiding the tests and errors process.
The *genetic algorithms* are the most appropriate tools to solve this problem because the model is complex. Another raison is that we optimise sequence of assemblies.

The optimization goal is to find the best kits sequence which minimizes production time (objective function – called fitness). As explained before, there are some constraints on this sequence because assemblies which belong to the same panel must be realized successively (because at the exit of the workshop we book each container for one type of panel and thus we cannot evacuate assemblies if they belong to more than two different panels). Thus some kits will be grouped together and we will do the hypothesis that the fabrication's order of these groups cannot be changed.
Results showed further are our first results and some developments must still be done to improve the optimization. The formulation for the genetic algorithm is not very easy. We have 14 chromosomes to make one individuals.

Fig. 5 below shows the evolution of the fitness (best, mean and worst).

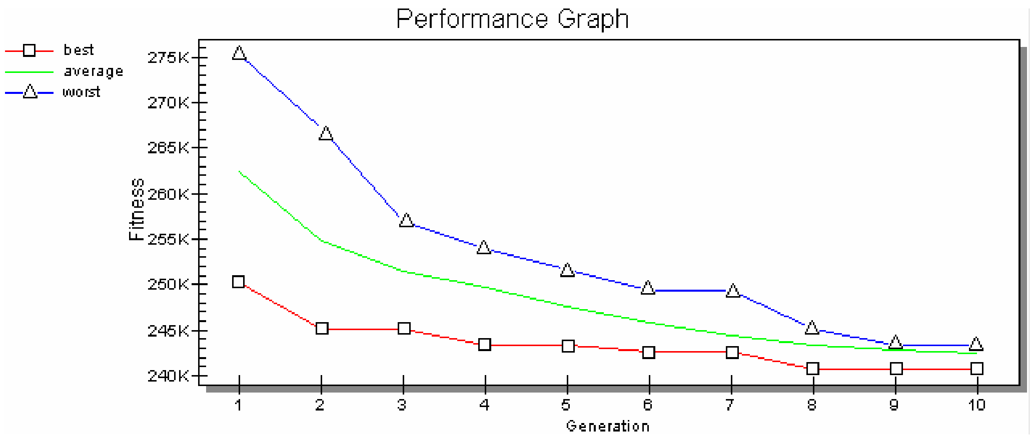

Fig. 5: Evolution of the fitness – Half-cell sequence

We have to be careful when we analyze the results: the convergence of the mean and of the worst curve are due to a homogenization of the population. The gain between the best fitness and the mean of the first generation is 8.4% (and 3.6% between the best fitness at the first and the last generation). When we run a great number of different random

sequences without any optimization, the best result obtained is 249K which is not as good as the result after one optimization.
In conclusion, even if the optimization capability has not yet been fully validated (keep in mind that these results are the first results, different parameters have still to be done to improve the process), it is very interesting to choose the results of the optimization as a first sequence (gain of more than 8% on a random distribution), which could be modified manually after a more precise analysis of all the results.

Simulation of a panel line workshop by using of a statistical data generator

This project aims to model the panel line workshop that responds to flow logic. This workshop shown in the Fig. 6 includes two parallel lines and is separated in two parts. The mechanical part manufactures panels by using automated machines and the mechanical part produces sections by thanks to manual workers and welding robots. The issue encountered in panel line is the following; all the products are not similar and are thus characterized by different processing times. The mission of the planer is thus to find the best production sequence that firstly allows the fabrication of the higher number of entities and secondly smoothes the total workload so that the number of workers to engage is constant.

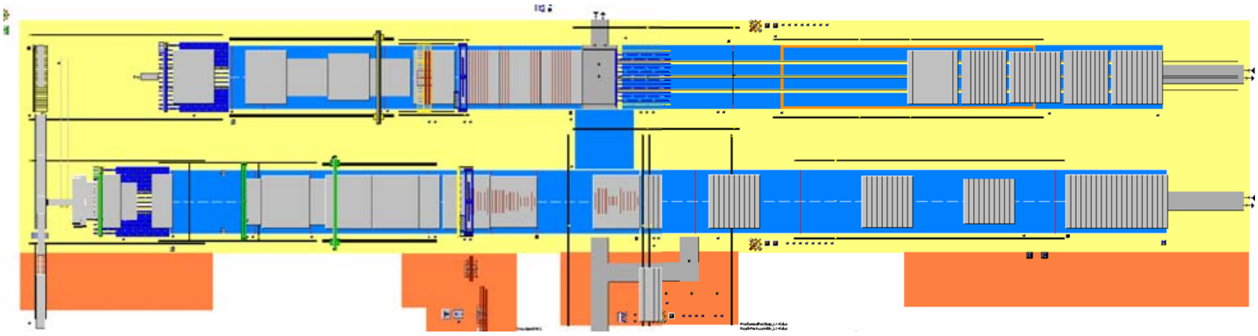

Fig. 6: Simulation Model of the Panel line workshop

The objective of this project is to offer a tool that permits the production management of the workshop for different time horizons. For the long term horizon, the tool will help its user to find the best production sequence and to fix the general decisions about laborers. For mid term and short term horizons, the tool can be exploited firstly to estimate the beginning and end dates of the elements assembly and secondly to manage more precisely the production: adapt the sequence when there is a problem, dispatch individually the workers on the working posts, manage the storage and the logistic, etc.

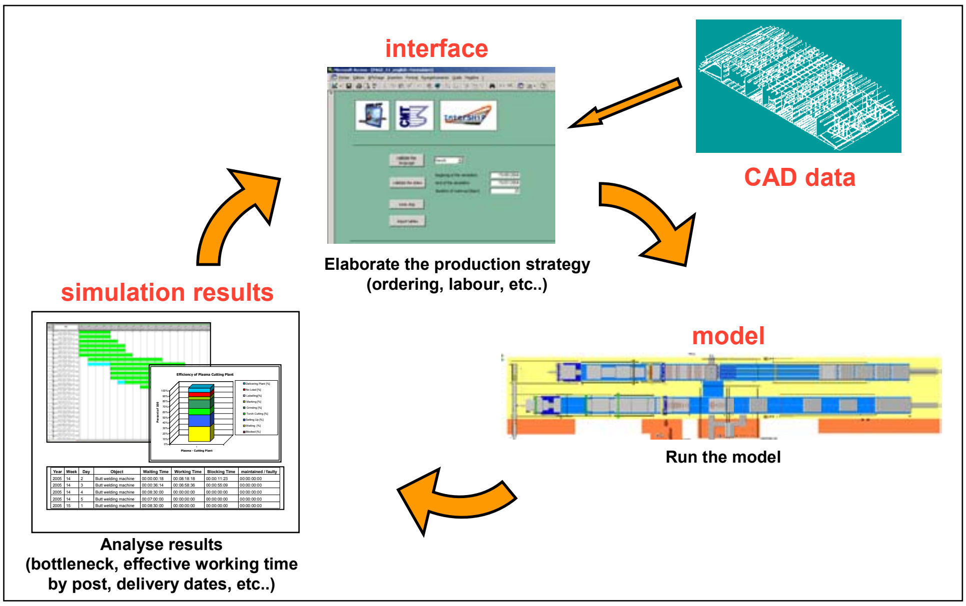

Fig. 7 : Utilization methodology of the simulation tool

The simulation tool helps pertinently the planer in his job, indeed the simulation tool allows to increase the efficiency of the workshop by utilising the resources at their optimal level. The utilization methodology of the tool is shown on the Fig. 7; trough the interface, the planer can establish a production methodology, launch the simulation and analyze the corresponding results. Then, he can modify some production choices and progressively elaborate the best production strategy so that all the work is well distributed between the working posts (eliminate the waiting times) and the labour capacity corresponds to the workload without fluctuating too much in the time (avoid to engage to much labour).
Here are the principal factors that can lead to a smoothing of the workload, a better use of the labour, an improvement in the container management:

- number of workers
- work in 1-2-3 shifts
- production sequence of panels
- production sequence of sections
- assembly of panels in 1 or 2 parts
- storage parameters (number of containers and parking, staking or not on a container, etc..)

A optimization tool could also be used for the panel line issue but the advantage of our method is that the simulation provides much better possibilities for shipyard personnel to interact with the tool in a planning process and to understand the solutions proposed by the tool (optimization method mostly act as a "black box" where data are put in and results are put out). They will be able to predict and face more easily problems such as machine breakdown, workers absence, delivery delay, etc. The simulation tool would also allows them to tackle the storage issue because by now, the storage is often used to adapt more easily the workload and face delivery problem, but it implies a long handling time.

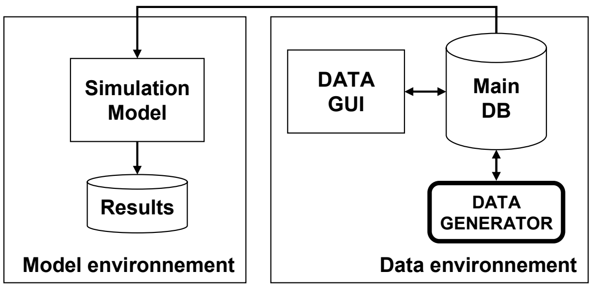

Fig. 8 : Pattern of data transfer

Data generator

The approach we chose for the simulation tool was to utilise, for all the time horizons, the same level of details. It was thus necessary to generate some data when they were not available (see Fig. 8). The idea was thus to establish mathematical relations linking the precise elements data to the rough information (knew in long term horizon). In practical terms, we have gathered the precise data of already build ships and we have manipulated and analysed them to find mathematical rules linking elements (panels and sections) characteristics to the characteristics of their constituents. We have used a data mining tool that has permitted, trough different methods, to analyse the correlation existing between attributes and to the establish relations (based on hyperbolic tangent formulation) by the neuronal network method.

For the panels, the relations to establish are quite simple because there are only two constituents: the plates and the stiffeners. The data known long time before production are the panels' characteristics (approximate values of length, width and weight) and the data to generate are the number and the dimensions of plates and stiffeners. On table 2 are, for example, the simple formulas relating to the plates.

plates thickness	$= ax^3+bx^2+cx$ (x = panel weight [tons] / surface [m²] / 7,5 [tons/m³])
plates length	= panel length
plates width	= 2 m if plates thickness < X mm = 3 m if plates thickness > X mm

plates quantity	= round (panel width / plate width)

Table 2 : Relations estimating the plates characteristics

For the sections, it is a little more complicated because there are different types of constituents (girders, bulkheads, pillars, brackets, etc.) and each element type is not necessarily present in all sections. So, there are two scopes for the analysis: firstly, point out the sections that generally have not the constituent in question and secondly, establish rules to determine the number and the dimensions of the constituents.
The long term data relating to a section are: the dimensions (length, width and weight), the workload (working time in man hours for welders and shipbuilders) and the specific attribute *family* that refers the localisation of the section in the ship. To point out the sections that do not incorporate the constituent, we use visualisation graphics such as histograms and decision trees (see Fig. 9), the finality of this analysis being thus to extract rules to characterise the pointed sections (ex : the sections from family 2 and 3 having a surface inferior to 120 m² have no pillars).
Once we have elaborated this filter, we can exploit the sections having the constituent in concern and launch a *data mining* analysis to estimate the constituents' characteristics. The idea, here, is to work on cumulative dimension of constituents in place of the constituent quantity. Indeed, since the dimensions of a particular constituent type fluctuate a lot inside a same section, the relations would be based on a non homogenous data group and thus would not estimate correctly the constituent number. The solution is to cumulate the determinant dimension of constituents and deduce the quantity after. For example, in the case of the bulkheads, the relation given by neuronal network method permits to estimate the surface of all the bulkheads of a section; the number of walls is simply this global surface divided by the average dimension of a bulkhead.

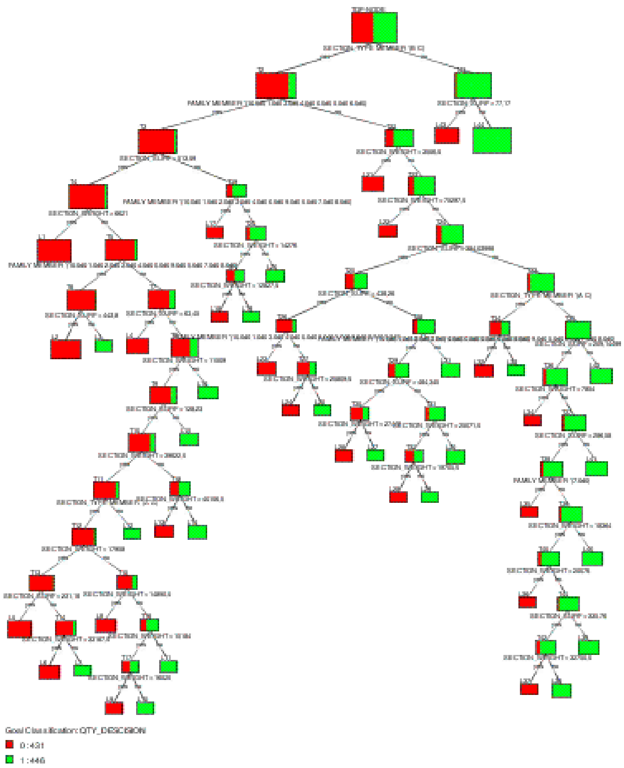

Fig. 9 : Decision tree

Conclusion

The high complexity of the production of a ship, due to the interaction of a great number of different disciplines (hull construction, electricity, fluids, interior fitting, propulsion, etc.) requires firstly an intensive design and secondly a detailed production planning where most of the tasks are carried out in parallel. In order to obtain the best quality, the lowest price and the shortest manufacturing lead time, it is necessary to increase the number of simultaneous tasks. So the management of the information flow becomes necessarily more and more complex, [3].

The current challenge for the European shipbuilding is to use these large and various information flows through the different stages: negotiation, design, production and maintenance, so that construction can be carried out with more effectiveness. In addition, it is expected that the design may be fully optimized for the production (design for production).

Each example presented here has an unusual lever in order to reduce the total cost of shipbuilding process:

- The analytical cost assessment modules for the detailed design stage are designed to influence the work of the designer by real time follow-up of the cost, in a design-to-cost process.
- The simulation and optimization of a pre-manufacturing workshop are coupled to an optimization module in order to drive out the potential lean time and lack of productivity.
- Simulation of a panel line workshop uses a statistical data generator in order to simulate the production as earlier as possible.

The results of these simulations and cost assessment presented methods are the increasing of the productivity by:

- *The use of the design data and the cost model that will lead to a more accurate approach compared to the existing cost model;*
- *The improvement of the planning of the deadlines and the establishment of a better production schedule - at the detailed design stage;*
- *The improvement of the distribution of the workload between the various production workshops and better assessment of the productivity - at the stage of design for production;*
- *The use of the "design for production" concept by integrating the information about the cost production at each design stage;*
- *The simulation of updated production scenarios few weeks before the production;*
- *Before investment, simulation and impact study of various improvements of the production facilities;*

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