Space Allocation Optimization Applied to Lower Hulls' Production of Semi-Submersible Platforms

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Abstract

This paper presents a part of new developments included inside a holistic optimisation strategy during the design cycle of ships. The first part of the paper describes an algorithm to maximize the number of ship blocks and ship sections to produce in workshops during a certain time window. A tool was developed in order to support planners to improve the space utilization and workshop productivity. Thanks to this software, the scheduling is now done more efficiently and above all it takes less time. The second part of the paper describes a recent development of an algorithm able to generate a feasible blocks erection sequence starting from the blocks splitting definition. The idea is to integrate this module as a new functionality inside simulation software in order to take into account blocks sequence during the elaboration of the optimised production strategy. The two developments were validated on the lower hull of a semi-submersible platform coming from a new Brazilian shipyard.

1 Introduction

1.1 Production simulation coupled with optimisation

Nowadays, more and more applications of simulations and optimisations are used in production planning to increase production performance and competitiveness of shipyards, *Steinhauer et al. (2005), Kim et al. (2007), Souza et al (2008)* and *Bentin et al. (2008)*.

In the context of production planning, the performances achieved with an overall production strategy can be assessed according to different criteria, such as *lead time* and *manufacturing costs*. The typical issues arise during the production are the balancing of working load and working force, the detection of bottlenecks and the maximization of resources utilization.

The production scheduling consists in establishing the best fabrication strategy (that can be represented by a production parameters system) in order to minimize both lead time and manufacturing costs. Those parameters can be quantitative, such as human resources or production facilities features, or qualitative, such as manufacturing sequence, workload dispatching on different working areas or priority strategies.

If the consequences of the variation of only one quantitative parameter on the production performances are relatively easy to foresee without the help of simulation, it becomes quickly much more complicated if several parameters are simultaneously modified. Optimisation based on production simulation models can be used to find one of the best set of values to minimize both lead time and manufacturing costs.

Production simulation coupled with optimisation tools used during the design stages can enhance the productivity of shipbuilding industry. Advantages are among others:

- New policies, production procedures, decision rules, production flows, organizational procedures, transportation systems, and so on, can be assessed without committing resources for their acquisition
- Hypotheses about how or why certain phenomena occur can be tested for feasibility before the production

- Insight of the interactions between production variables can be obtained
- Insight of the variables importance on the production performance can be obtained
- A production simulation study can help in understanding how the system operates rather than how individuals think the system operates
- The "What's happen if" questions can be answered. This is particularly useful in the design of new production systems.
- We can do the evaluation of very complex systems where analytic solutions are not known and for which production simulation is the only possible approach
- Production simulation models often have a visual interface, sometimes with graphic animations and this fact makes them more reliable to the eyes of managers

1.2 Production simulation and concurrent engineering

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 during the ship design (see Fig.1), the shipbuilding industry 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, *Bocquet (1998)*.

As illustrated on Fig.1, one of the effects of *concurrent engineering* and *simulation and optimisation tools* 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, *Syan et al. (1994)*.

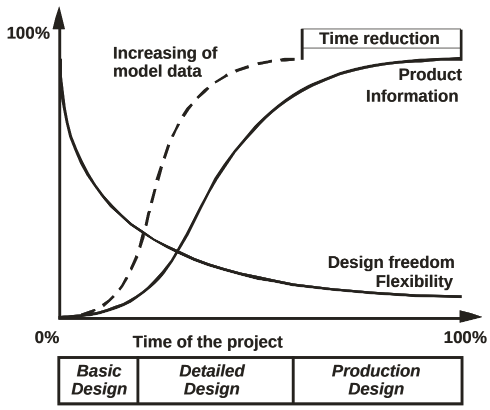


Fig.1: Evolution of the design information relating to the ship

The methodology developed within the present research framework will increase and clarify the knowledge relating to the ship by the prediction of useful data before the full design model has been completed. Thus, the more information is known earlier by the designer, the better the decisions are made in the design process. The first errors of the project, the most expensive ones, could thus be avoided.

1.3 Continuous optimisation during design and production stages

As presented in the previous section, 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 a part of some developments included inside a holistic optimisation strategy during the design cycle of ships. Some of these developments are already finished; others are just being developed by our research team.

The holistic optimisation strategy takes into account the following method and tools, Fig.2:

1. **LBR5** – LBR5 is software able to optimise the scantling of amidships section by considering concurrently the minimization of production cost, the minimization of steel weight and the maximization of the moment of inertia. Recent papers presented the latest software development such as the development of a detailed production cost assessment module, *Toderan et al. (2007),* the development of a multi criteria optimisation module, *Richir et al. (2007),* the implementation of fatigue module and finally the implementation of a vibration module, *Constantinescu et al. (2009)*.
2. **Block Splitting Optimisation** – The block splitting of the ship before manufacturing is one of the most strategically decision during the ship design. Indeed, this choice is like a spinal column for all production stages. Moreover the resolution of this problem requires taking into account many technical constraints such as required transitions in plate thickness, standard plate size, block assembly bay dimensions, block weight, block dimensions, panel line workshop dimensions, etc. Some developments are currently underway in our research team to optimise the block splitting by considering the production costs.
3. **Block Sequencing Optimisation** – This issue is intimately linked to the block splitting and must respect technical restrictions. The resolution of this problem requires taking into account various constraint like physical constraints, planning and production control constraints, block assembly constraints, etc. The sequence of blocks fabrication is predominant in the global production problematic of the shipyard since it has strong impact on the downstream and upstream production flow. Indeed, the block sequence imposes the delivery dates of all subassemblies and material and is directly linked to the lead time of the ship. In this paper (see section 3), we present a first development in order to find the block erection sequence minimizing the lead time of the process.
4. **OptiView** – OptiView is software able to optimise the space utilization inside shipyard workshops. The dynamic allocation of blocks in shipyards is a huge, difficult and time-consuming effort. This optimisation software help the planner to minimize the surface lost on the ground. Recent papers presented the latest software development, *Caprace et al. (2008).*We present in this paper (see section 3) some results obtained when using this software for optimising the construction of the lower hull of a semi-submersible platform.
5. **Detailed Production Simulation with Discrete Event Simulation** – The idea of the discrete event simulation is to model the real behaviour of the workshop in order to evaluate different production strategies and select the best one. The modelling step aims to characterize the performance of the workshop, integrate modules representing the machines, the material and the resources and implement the rules existing between those entities. The model allows thus to traduce the complex interactions that can occurs between all actors of a real production environment. The analysis step aims to assess the impact of different production parameters on results such as resources utilization rates, lead time, etc.

In this paper, we validate some parts of our developments on the scheduling of a lower hull of a semi-submersible platform coming from a new Brazilian shipyard. We investigate deeper the space allocation in section 3 and block erection sequencing stage in section 4.

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*

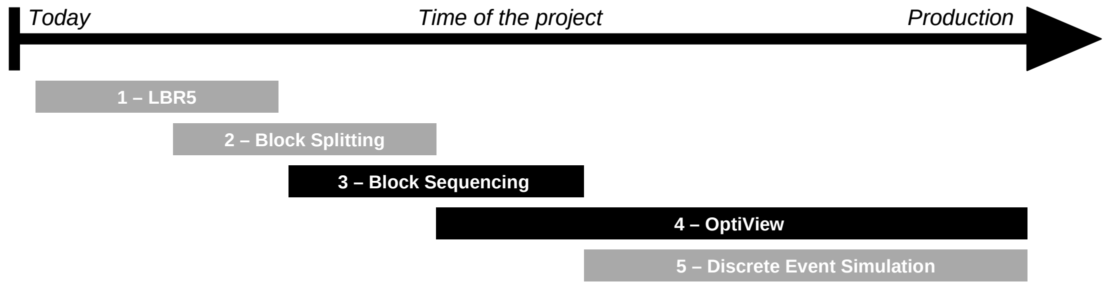


Fig.2: Optimisation during the shipbuilding design process

2 Case Study – the lower hull of the semi-submersible platform

A case study was carried out in order to validate parts of the full methodology presented in this paper. The case study was developed using information coming from Atlantico Sul Shipyard (EAS) related to one of its projects: the construction of Lower Hull of P-55 platform.

P-55 Platform will be installed around 125km away from Brazilian coastline on Roncador field, located on Campos Basin. It is a semi-submersible platform design to have an oil production rate around 180k bpd. EAS signed up contract to construct P-55 Lower Hull with Petrobras by end of 2007 and began services on early 2008. Fig.3 shows an illustration of P-55 platform.

Fig.3: P-55 lower hull illustration

EAS is a greenfield shipyard under construction in North Eastern Brazil and is being built to become a major player on international shipbuilding industry.

It incorporates the most modern technology available and is developing its processes targeting benchmark productivity levels, *Pires et al (2009).* To reach such productivity levels it is imperative to research and develop tools as the ones object of this work.

Mainly concerned about the efficiency of its planning and utilization of resources for the production of lower hull of a semi-submersible platform, data was made available to perform an analysis using the above mentioned tools.

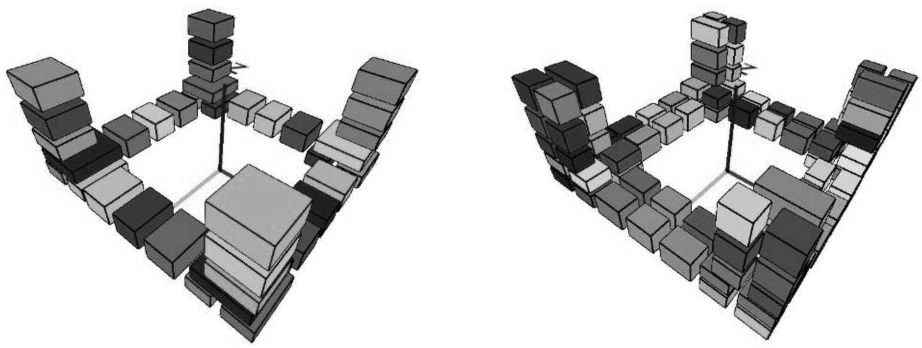
The lower hull of the semi-submersible platform has following characteristics:

- a squared base with 94x94 meters;
- four nodes on each corner of the squared base;
- four pontoons linking each of four nodes;
- four columns emerging from each node up to an elevation of 44 meters.

Roughly main dimensions of the platform structure are 94x94x44 meters.

A build strategy was developed to guide decision regarding detailed design and production phases. The main build strategy adopted is as follows:

- there are 92 sub-blocks weighing between 100~300 tons, see Fig.4 (b);
- sub-blocks are merged together resulting 36 blocks weighing between 300~800 tons, see Fig.4 (a).



(a) 36 Blocks *(b) 92 Sub Blocks*

Fig.4: Lower hull of the semi-submersible platform

3 Part 1 – Space allocation optimisation

3.1 Space allocation issue

The assembly of big elements requires necessarily available space within the fabrication workshop to perform the production. The space allocation problem arises at yard because of space scarcity for arranging the building blocks of ship. Since the blocks become larger and heavier, the production space in the shipyard becomes extremely restrictive. The largest units are limited in zones where they can be produced due to the lifting and handling capacities. The limited space available in shipyards and the increase of blocks and sections size force the planners to optimise the use of the available surface within the workshops and storage areas. In order to solve this problem of blocks allocation on assembly area, researchers developed different optimisation techniques like simulated annealing or CST (Constraints Satisfaction Technique), *Okumoto et al. (2005), Lee et al. (1996, 2005), Finke et al. (2007).*

For a shipyard, it is critical to accurately plan the space in the production areas to ensure that blocks are moved only when and where it is necessary to efficiently use the available space. On the same way the minimization of the unused ground by the maximization of the allocated blocks may lead in unnecessary moves, while minimizing unnecessary moves results in a less efficient use of the space.

The dynamic allocation of blocks in shipyards is a huge, difficult and time-consuming effort. The difficulty in space allocation arises in the fact that:

- The allocation of space to one block significantly affects the availability of floor space for the other blocks, *Finke et al. (2007)*. Scheduling production space to satisfy an erection schedule becomes even more complex when unexpected changes to the schedule occur (e.g., upstream process delays, weather related delays or subcontractor timeliness).
- The allocation of space in a industrial environment is an issue with different complex production constraints:
  - Block height must be taken into account because, sometimes, blocks have to be evacuated by a crane bridge above others blocks.
  - Spacing between blocks might be required for safety and accessibility raison.
  - Spacing bellow blocks might be required for transportation with skid platforms.
  - Preferred location for some blocks might be required to allocate block close to specific tools or equipments

This illustrates the need for a flexible tool that can assist planners in, not only generating optimal spatial layouts, but also modifying day after day these plans accordingly with the variation of the initial schedule (delays, unplanned maintenance, etc.).

The scheduling tool (OptiView®) has been developed to satisfy all these requests. Coupled with a heuristic optimisation solver, the software becomes a very helpful and powerful tool to generate the optimal spatial arrangement. One of the most important features of the software is its user friendly interface and its easy adaptation to any workshops with space allocation problems.

3.2 Approach

An innovative approach has been developed to optimise the use of work area space. It contains a visualization tool and an optimisation tool. The software is coupled with a heuristic optimisation solver which is inspired by an algorithm used for "3D bin-packing problems". More details about the method are available in the following papers *Langer et al. (2005)* and *Caprace et al. (2008)* presented in previous session of COMPIT.

Target workshops are mainly assembly halls where huge blocks and sections of ships and offshore structures are assembled just before being sent in the dry dock. Nevertheless, the tool can be easily adapted to other workshops. In shipyards, space is the most critical factor. Indeed the blocks occupy important surface for a quite long fabrication time. A not adapted planning engender a lost of space during a certain time and leads thus to a reduction of the productivity and an increase of the ship fabrication duration if the concerned workshop is a bottleneck. The planning task of assembly halls faces thus a 3 dimensions problem (position of elements in space and time) that is not easy to solve manually. Moreover difficulties are linked to the fact that, firstly, the fabrication duration of each element depends on the number of workers dedicated to its mounting operation and secondly, the allocation of space to one block significantly affects the availability of floor space to every other block.

The objective of this software is to offer a decision tool to the planner to assist him in utilizing efficiently the surface available in a workshop thanks to:

- The automatic allocation of the activities (blocks, sections, panels, etc.) in the workshops;
- The minimization of the surface lost on the ground;
- Long-term and day-to-day simulations to analyse the impact of a delay on the global planning;
- The generation and processing of a planning data (generation of allocation plans, display of labour graphics, management of the industrial calendar, etc.).

This tool aims to provide planning proposals, i.e. a location and a starting day for each block. Unfortunately, it may happen that the available surface in the assembly hall is not sufficient to produce the entire set of blocks. In this case, the tool can help the user to take the most efficient decision.

3.3 Application case on the lower hull of a semi-submersible platform

This case study focuses on the Sub block assembly workshop of the new Atlantico Sul Shipyard where relatively small stiffened panels are joined to form sub blocks (100~300 tons). This assembly workshop has a rectangle shape with 375x40 meters i.e. 15 000 square meters.

The objective is to build consecutively five identical platforms in the assembly area. Loading the yard with this hypothetical production level would test its capacity to accommodate series production of either platforms or ships. An optimal scheduling must be found to reduce the total production time.

First of all, we need to determine for each block the "earliest start date" and the "latest end date". Our only restriction is the end date of the project: the 5 platforms must be built. Another important point is that the platforms can not been build simultaneously and a delay between the start of each of them is indispensable (Δ). This delay is an important parameter that can change greatly the schedule. In consequence a parametric study will be done to see its effect/impact.

To build a platform, the production sequence is known with simple and logical restrictions – for instance a pillar's sub block can of course be placed only after below blocks are finished.

As input, we have thus:

- The final delivery time;
- Delay between the starting date of each platform (= first parameter to study):
- Sequence restrictions for blocks of a platform (=erection sequence);
- Duration to build/assembly each block

With these parameters we can perform a Microsoft Project analysis that will give us <u>for each block</u> an <u>earliest starting date</u> and <u>a latest starting date</u>. In fact, the real early start dates are wrong because we don't have information's about constituent of sub-blocks. Consequently, the planning of elements of sub block is not available. Normally this is the building of all these sub blocks that can give us information about earliest starting date. Without this knowledge we have to make another choice: we will vary the delay between the earliest and the latest starting date and make a study of the impact of this delay (δ). This time margin is our second parameter.

For each sub block, duration, earliest and latest starting dates are now known. The space allocation tool OptiView can thus be run.

If a feasible solution is found, main results are:

- o The real starting date for each sub block;
- o Position of each sub block.

If no feasible solution is found (at least one block cannot be scheduled), it indicates that one of our parameter is too restrictive: we have to increase the delay between each platform or to increase the starting time margin for each block! The general process is indicated in Fig.5.

A parametric study has been carried out with 25 tests cases with variations of the two aforementioned parameters.

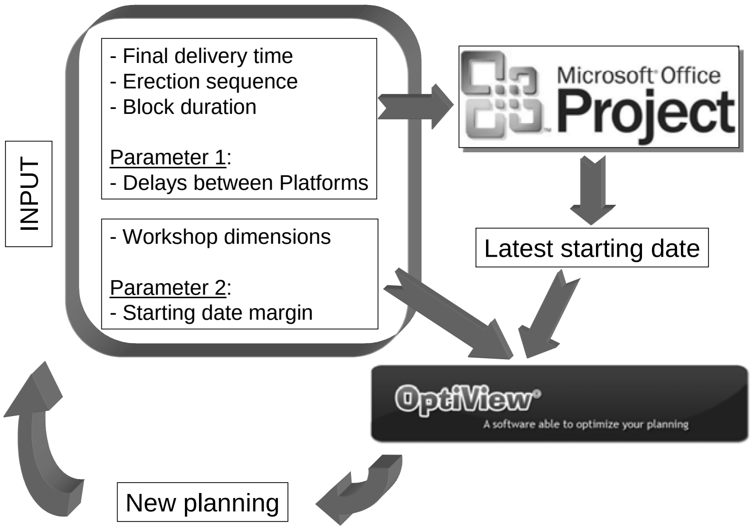


Fig.5: Scheduling optimisation process

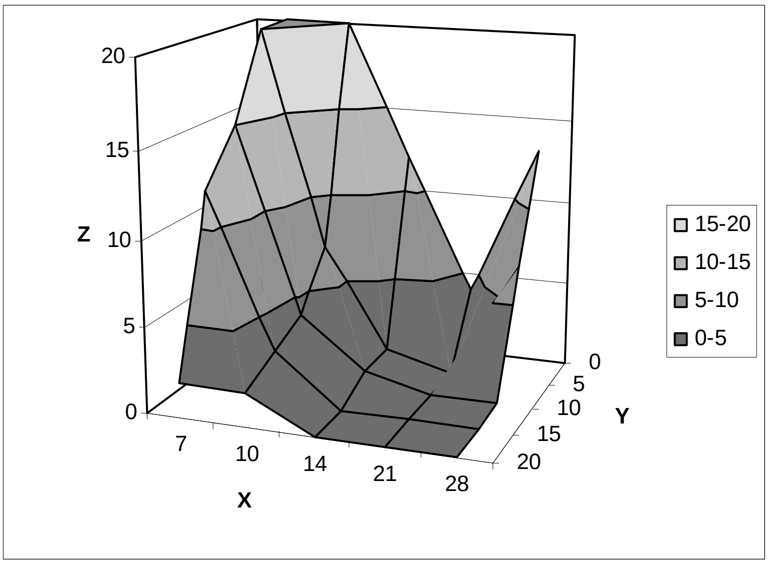


Fig.6: Results of various surface allocation optimisation

Fig.6 shows the results of various surface allocation optimisation where the two parameters (Δ and δ) are modified:

- X axis – Represents the number of working days between the production start of each platform - (Δ);
- Y axis – Represents the number of available working days between earliest start date and latest start date of each sub block (see Fig.7) – (δ);
- Z axis – Represents the number of blocks that could not be placed in the workshop because there was not enough space.

Each point of the surface represents an optimisation result with OptiView. Naturally, we have an admissible solution when Z is equal to zero.

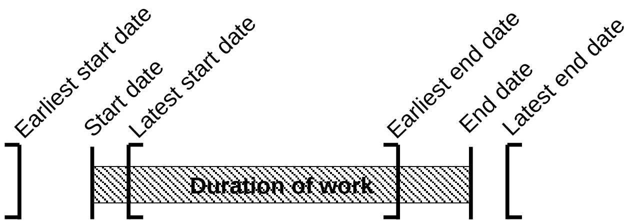


Fig.7: Date and duration of work

The best scheduling solution is obtained for a Δ =14 days and δ =15 days. Comparing to the worth admissible solution we have a gain of surface utilization about 5.5% and a reduction of lead time of 78 days.

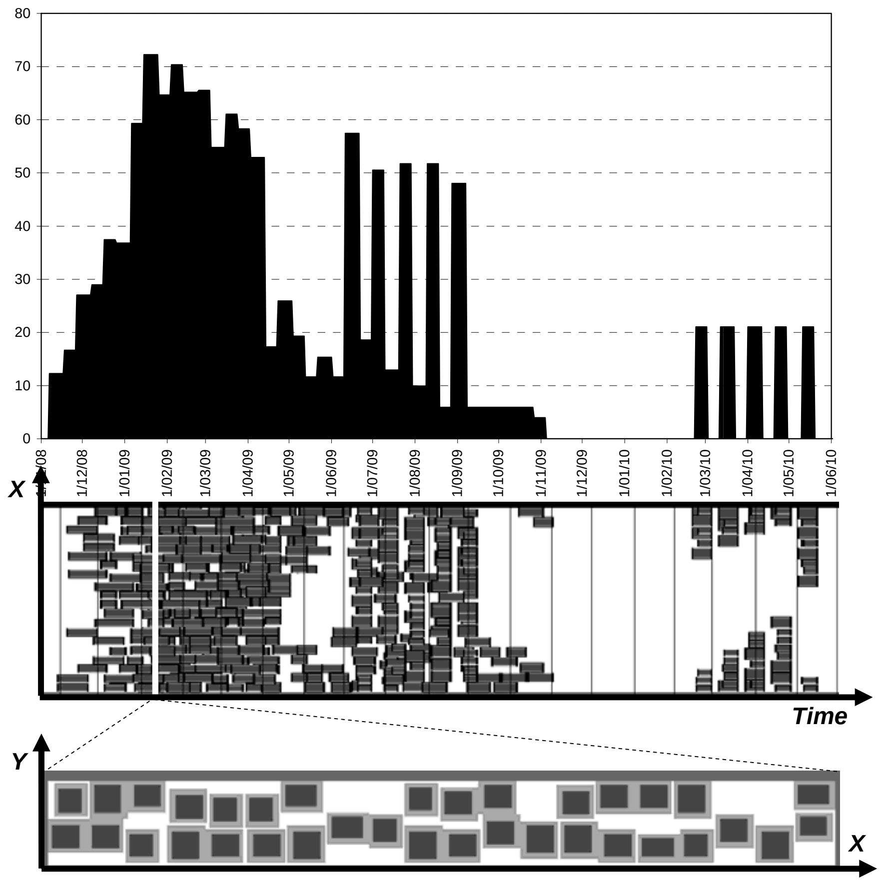


Fig.8: Ratio of workshop utilization for the solution with Δ =14 days and δ =15 days:

Fig.8 indicates the space utilization of the workshop along the time. If we select a specific date we can see the top view of the workshop at that day. Due to the time to assembly sub blocks to make block, element's pillars can be made only at the end of the project. This phenomenon explains the lack of workload in the figure.

In that project the interest of using OptiView is not only to improve the space utilization but mainly to be able to establish a scheduling in a very short time. A manual scheduling can take one week, with OptiView it takes only some hours. In other words it would be completely impossible to do that parametric study (twenty five scheduling) without the help of a powerful scheduling tool.

4 Part 2 – Erection sequence optimisation

4.1 Erection sequence issue

After the block splitting, the next scheduling stage to be performed is the definition of the optimal erection sequence. The erection process is a very complicated and highly networked operation involving decision-making interlinked with a lot of structural items. Manual solutions are often inadequate for optimising the process, *Souza et al (2006)*.

The main issue of erection sequence is that this process follows a huge number of implicit physical and production rules. During the definition of block sequence, consideration must be given to:

- Physical constraints, such as some blocks are supposed to support other ones and have therefore to be positioned before.
- Planning and production control constraints, such as the desire for constancy of work inside the workshop.
- Block assembly constraints, such as the minimum time between the laying of blocks. This time is required in order to tack and weld the block on the ship. Another very restrictive constraint is that it is usually impossible to insert a block between two blocks already erected. Indeed, it would increase the complexity of block assembly stage. Moreover, the required gap necessary to insert the block is not compatible with the minimum welding gap.
- Erection constraints, such as the first's blocks to be placed. The blocks contain the engines are often the first blocks to be placed because they require time for assembly and outfitting much higher than others.
- Erection strategies, such as the laying of ship blocks starting from the middle, fore or aft part of the ship; by layers or by slice or finally with a pyramidal strategy.

Each of these sets of constraints comes from a different constituency within shipyard, and the definition of block sequence has traditionally involved a process of iterative definition, review, and negotiation. Depending on the shipyard, this process may be well defined or somewhat inaccurate. Even when the process is well defined, it involves multiple channels and cycles of communication, and as a result it can be not only lengthy but also subject to errors and omissions that results in less than optimal block sequence.

The intent of this study is to examine how various computer-based analysis and simulation techniques might be used to improve the efficiency of the block sequence definition process.

4.2 Approach

The purpose of this module is to generate one/several feasible sequence according to the assembly technical requirements (production rules). The sequence is filled up with the blocks one by one. It is based on successive decision stages. The algorithm is launch recursively to choose the next bloc in the sequence.

The algorithm determines at each bloc selection step the neighbour blocs of the partial solution. Among them, the algorithm chooses only the blocks fulfilling the technical constraints. Finally, he can select heuristically one of the block providing a technical feasible sequence.

If we wanted to generate all possible sequence, there would factorial n, where n is the number of blocks. One of the advantages of the technical constraints is the fact that they are extremely selective, and the number of feasible sequences decreases hugely.

The principle is the following. Blocks are selected one by one to be erected on the dry dock. As n blocks have to be erected, n decision steps have to be executed. At each step of the selection process, another block must be chosen among the blocks not already welded. For that purpose, a list of potential neighbours, which could be chosen as the next block in the sequence, because satisfying the technical conditions, is filled up, Fig.9. Finally, a block is selected heuristically in the list of potential neighbours satisfying the technical conditions to be the next in the sequence.

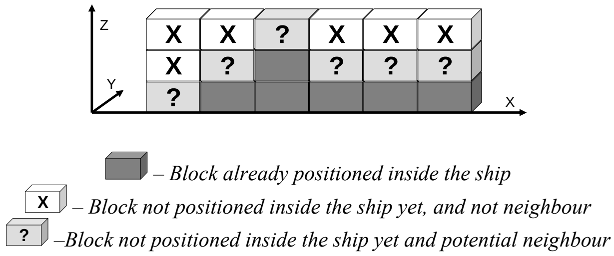


Fig.9: Blocks selection step for the sequence generation

At each new block insertion in the sequence, the list of potential neighbours has to be updated, taking into considerations the presence of the new block in the assembly sequence. For that purpose, it is necessary to check if the blocks, which are neighbours, but not already in the erection sequence, satisfy the technical conditions of assembly. An algorithm was implemented in order to checks if all the production rules are satisfied. Moreover three progression rules are available, the "*horizontal rule*" which erect the blocks layer by layer, the "vertical rule", which erect the block slice by slice and finally the "*combined rule*", which erect the bloc equally in vertical or horizontal direction as a pyramid structure.

The principal purposes of the algorithm are:

- to check that the blocks of the lower level are erected before the blocks of the upper level, Fig.10
- to check that is not require to insert a block between two others during the assembly, Fig.11
- to select the blocks that respect the selected progression rule (*vertical*, *horizontal* or *combined*).
    - For *vertical* rule, we prefer blocks that have *vertical* connections with the blocks already placed
    - For *horizontal* rule, we prefer blocks that have *horizontal* connections with the blocks already placed
    - For *combined* rule, does nothing

For all rules, we prefer always blocks which have the greatest number of connections with the blocks already placed. This rule is applied in order to avoid the generation of holes inside the structure where we should place blocks between several blocks already placed, Fig.11.

If the technical constraints are not observed, the block considered will not be added to the list of the potential blocs ready to be assembled.

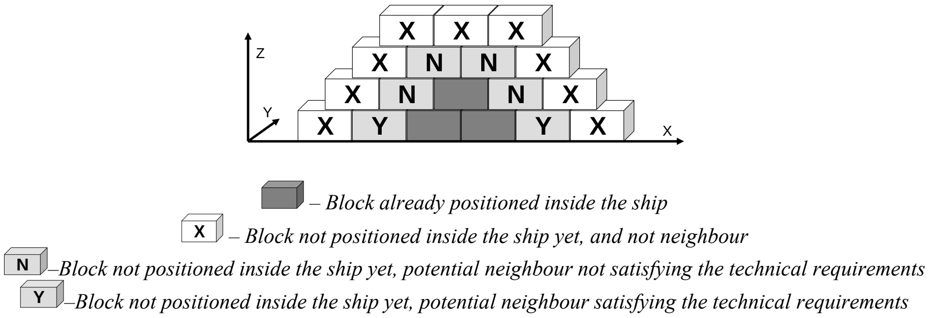
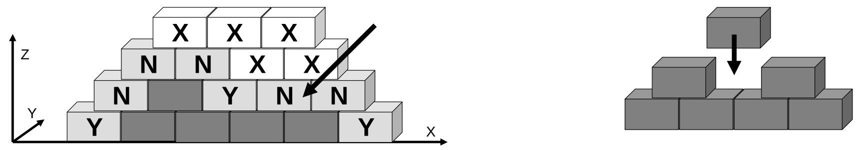


Fig.10: Blocks of the lower level are erected before the blocks of the upper level



(a) Arrow shows the interesting block (ARROW SHOWS A N BLOCK)   *(b) Not allowed solution*

– Block already positioned inside the ship

X – Block not positioned inside the ship yet, and not neighbour

N –Block not positioned inside the ship yet, potential neighbour not satisfying the technical requirements

Y –Block not positioned inside the ship yet, potential neighbour satisfying the technical requirements

Fig.11: Gap between bocks have been left in the structure during the assembly

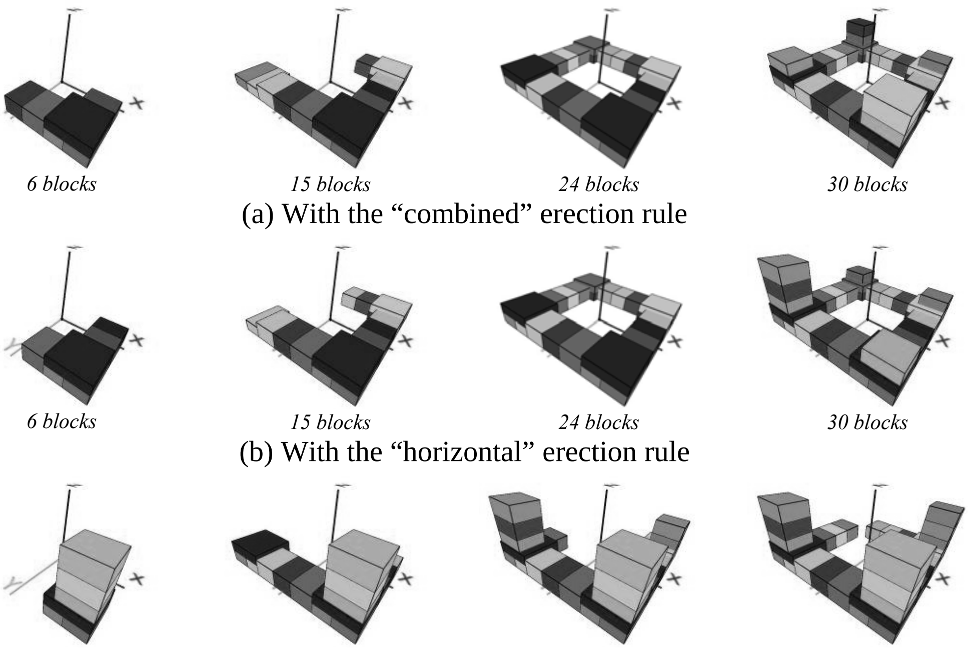
This erection sequence generator has several advantages like the:

- Automation of the block erection sequences
- Very fast process (< 1s)
- Generation of multiple feasible sequences with the same starting point (first block)
- Possibility to start with different initial blocks (or sequences)
- Possibility to add other production rules
- Input and Output text files
- Independent Java modules (Multi Platform)

Nevertheless some limitations are remaining. It seems very complex to take into account all production rules simultaneously during the construction of the erection sequence. It follows that some situations are not yet solved by the algorithm.

4.3 Application case on the Lower Hull of a Semi-Submersible Platform

Fig.12 is given three solutions of assembly sequences of the lower hull of the semi-submersible platform. The initial first erected block is the same for the three presented results. In Fig.12 (a), the platform is assembled with the “combined” erection rule while the Fig.12 (b) shows the result for “horizontal” erection rule and Fig.12 (c) shows the sequence of the “vertical” erection rule.



(c) With the “vertical” erection rule

Fig.12: Assembly sequence example

After several simulations runs with different set of values as input data (erection rule, first block to be placed), it is possible to generate a huge number of feasible erection sequence.

The aim of this study is to improve the efficiency of the block sequence definition process and the optimality of the resulting block sequence regarding the lead time of the erection process. The previous sequence generator is only a part of the development required to reach this objective.

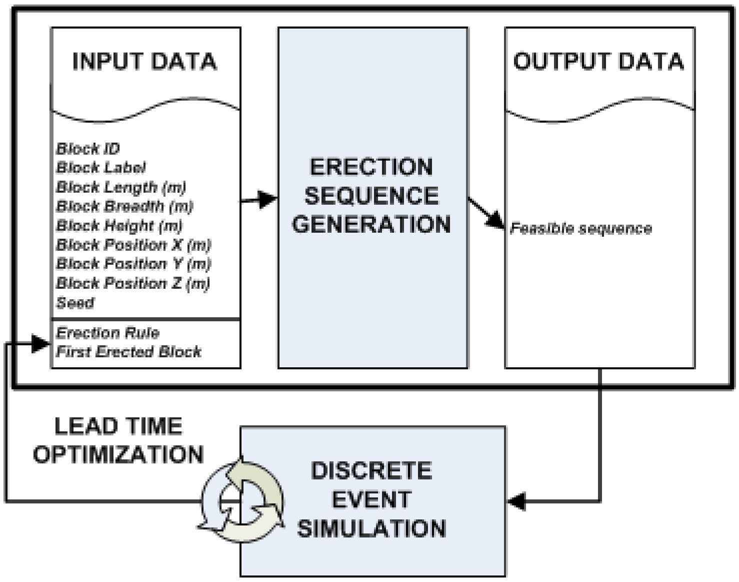


Fig.13: Workflow of the optimisation process

The selection of a right erection sequence seems to be a great potential to improve the manufacturing lead time. Therefore, in the near future, we will integrate this erection sequence module inside an optimisation loop of a DES model where the input data of the erection sequence module will be defined as optimisation design variables and the objective function will be the lead time of the erection process, Fig.13.

5 Conclusion

An application of this tool related to the fabrication of five off-shore platforms is presented in the paper. The study aims to show the impact of parameters (precisely fabrication time margins) on the optimised space allocation in order to point out which fabrication strategy minimizes the lead time. In the second part of the paper, authors present a block splitting algorithm and demonstrate that the parameters of blocks slitting and blocks sequence can have a significant impact on the productivity.

Acknowledgements

The authors thank University of Liege and Atlantico Sul Shipyard for the collaboration in this project as well as the European Marstruct project (n° TNE3-CT-2003-506141) and the European IMPROVE project (n° 031382- FP6 2005 Transport-4).

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