Discrete Event Production Simulation in Shipyard Workshops

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Keywords: DES, Simulation, Optimization, Scheduling, Production, Shipbuilding

Abstract

Nowadays, shipyards are making huge effort to efficiently manage equipments and resources such as laborers, gantry cranes, transporters, steel and block stock yards, etc. Previously scheduling was manually performed by an experienced manager of a shipyard. But such a scenario leads to undesirably long times for producing scheduling results. In addition, the quality of the scheduling results was usually not optimal.

To improve the overall process, Discrete Event Simulations (DES) have been developed and recently use in shipbuilding industry. The use of simulation-based design and virtual reality technologies leads to higher efficiency in terms of work strategy planning, and offers, as a result, significant productivity gains. It gives computer-supported answers to the major questions: when and where to produce what and with which resources depending on the availability and restrictions of resources and materials.

The first part of the paper presents a multi-criteria analysis to select the most appropriate DES software for shipyards. Then, the second part of the paper shows production simulation model focusing on block erection stage. Two different blocks splitting are compared and then the results are discussed.

1 Introduction

The estimation of a successful shipbuilding realization is often linked to the project criteria quality, time and costs. Often it is not possible to find optimum solutions for all criteria. For example, an exceeding quality leads to higher costs as normal. Thus, a well-elaborated project organization that focuses on a steady work flow and efficient capacity utilization is necessary to realize a building project successfully. Hence, high competence and extensive project experience are essential.

Production simulation is a very useful tool concerning the possibilities of gains in the process of production and as result, cost reduction. In order to achieve an optimum integration design vs. production, it is necessary to model not only the ship but also the shipyard facilities and integrate them into a single simulation model. Best results are achieved when this model is linked to other optimization systems. The simulation allows finding the best workshop layout and assembly sequence according to the building strategy of the ship.

1.1 Production simulation in shipbuilding industry

The simulation of shipbuilding process can be useful to assess, decide and communicate manufacturing planning's, allowing a dynamic and transparent review of the production. The technique can help the project definition of the vessels, or the assessment of production, according of different types of vessels, *Kasemaker et al. (2006)*.

During the last decade, shipyards, research centers and universities started to use this powerful tool to analyze shipbuilding operations. The group SimCoMar (Simulation Cooperation in Maritime Industries) is an example of an initiative to accelerate the development of simulation in the industry, helping North American and European shipyards. The Flensburger Nordseewerke Emden shipyard, the universities TUHH (Technische Universität Hamburg-Hamburg), DUT (Delft University of Technology), ANAST (University of Liege), and the Center of Maritime Technology (CMT) in Germany are participating at this initiative. Besides SimCoMar, other partnerships have been established between shipyards and universities such as the University of Seoul South Korea, Japan's Kinki, Michigan University, and Federal University of Brazil (LABSEN laboratory).

In recent years, the Dutch and German shipbuilding industry is seeking to reduce delivery times, production costs and increase product quality, using the process simulation. Some German yards are well advanced in the use of simulation and integration solutions to environmental planning processes, such as Meyer Werft and Flensburger.

1.2 Layout planning and production planning

The complexity both of the ship product and the shipbuilding process makes planning tasks in the long, medium, and short term difficult and leads to serious uncertainties. Discrete Event Simulation can be used to test and evaluate different scenarios in investment planning, scheduling, and resource planning. Using a virtual shipyard environment, the cost in finding optimum solutions and the risk related to wrong decisions in the real world can be drastically reduced. In order to survive in today's shipbuilding market, it is vital for a shipyard to have optimum utilization of its resources. Therefore the greatest challenge for a shipyard as a producer of one-of-a-kind products lies in managing the complex relationship between design, production processes and resources.

Any shipyard can be divided into:

- Shipyards under planning (Greenfield) or construction and shipyards that are making retrofitting or extension of existing workshops – Layout planning
- Shipyards in operation – Production planning

1.2.1 Layout planning

The simulation for layout planning facilities can improve the evaluating of investments and of long-term strategies.

One of the most important advantages of simulation of steel processing shops is the possibility to test different equipment, different suppliers and accounting costs (acquisition, installation, etc.). Different processes (automatic, semi-automatic or manual) can be studied and lines can be integrated (cutting and fabrication of flat panels, e.g. panel line), reducing costs and integration time.

Testing different positions of machinery and material flow allows the definition of a configuration that minimizes the distances and movements before the machines are installed. After the installation of certain equipment, the repositioning could be infeasible. The simulation allows analyzing inventory levels and avoiding stops of production. The assembly blocks can be studied according of different strategies for building. Different methods can be investigated considering the inclusion of advanced outfitting.

Sharing resources such gantries, cranes and trucks can also be checked. Productivity and time, considering different demands can be estimated more accurately by providing greater support to managers. In pre-erection, large blocks of different sizes can be modeled. The physical space and resources can be defined depending of the size of blocks.

The workload in accordance with different types of vessels can be evaluated as the operational implications, such as proper inventory levels of intermediate products, and equipment parameters (speeds, etc.). The simulation of the erection could provide important information to determine the best strategy and choose the most appropriate resources. The simultaneous construction is another issue that could be addressed.

The test case presented in this paper focuses the analysis of layout planning of a Brazilian Greenfield shipyard.

1.2.2 Production planning

Unlike most applications in industries with series production the main added value of the use of production simulation in shipbuilding is obtain in the support of the production planning and control and not on the layout planning.

The existing shipyards need to constantly refine their processes and techniques to establish competitive conditions. These shipyards must adapt their operating strategies in order to achieve lower costs and production times. Transport systems for workshops can be tested under different parameters. For the steel processing process, different sequences and cutting planes can be evaluated, reducing the setup times of equipment and allowing a better use of resources, *Bentin (2006)*.

The production of curved panels and sub-assemblies can be balanced, and different assembly methods can be studied. The sequences of production (daily or weekly) can be planned in order to optimize the production. Any gaps between the planned schedule and the simulated schedule can be analyzed and solved before that the real production take place. In the pre-erection and erection process, the constraints and conflicts between the transport systems can be predicted and the time of constructions can be estimated considering risks and uncertainties.

2 Selection of a Discrete Event Simulation (DES) Software

We propose in this section a Multi Criteria Decision Aid (MCDA) method to select the most appropriate Discrete Event Simulation (DES) for shipbuilding.

Depending on the stage of analysis, the level of expected detail, the extent of available information, different production simulation software's can be employed in shipbuilding industry. Some methods are better than others depending on the context and design maturity. When data are available, all the methods could be used. But different estimation methods provide different projections of the simulation results. The projected differences could have a significant impact on the overall viability of a project or the selection of the optimal production of a ship.

2.1 Multi criteria decision analysis

In the majority of practical decision problems there is no alternative that fits perfectly all the criteria. In fact, each alternative offers both strengths and weaknesses, which must be counterbalanced. Therefore, Multi-Criteria Analysis (MCA), also called Multiple Criteria Decision Making (MCDM), approaches have been developed to support decision making problems, formalizing the trade-offs between the alternatives and fostering the transparency of the decision. Multi-criteria analysis is an especially important approach for the interpretation of the results of a comparative analysis of technological alternatives and for addressing the relevance of the different parameters of interest. Although MCDM models have been used in many applications in engineering science, *Chareonsuk (1997) and*

Treitz (2005), only a very few of these models can be found in the field of the shipbuilding industry.

We have chosen the AHP (Analytic Hierarchy Process) method in order to perform the MCDM of the production simulation software for the shipbuilding industry. This method has been developed by Thomas L. Saaty in the 1970s, *Saaty (2008)*. Rather than prescribing a "correct" decision, the AHP helps decision makers find one that best suits their goal and their understanding of the problem. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. Moreover the method can rank all the alternatives once all the parameters and the values have been presented.

2.2 Definition of alternatives

The outcome of any decision making model depends on the information at its disposal and the type of this information may vary according to the context in which one is operating, therefore it is useful for decision making models to consider all the information as a whole. In MCDM the decision procedure is normally carried out by choosing between different elements that the decision maker has to examine and to assess using a set of criteria. These elements are called *alternatives*.

For this study, we have used the following alternatives of DES software's:

- **Arena** (http://www.arenasimulation.com/),
- **Flexim** (http://www.flexsim.com/),
- **Plant Simulation** (http://www.plm.automation.siemens.com/),
- **Promodel** (http://www.promodel.com),
- **Quest** (http://www.3ds.com).

2.3 Definition of the criterion

The criterion represents the tools which enable alternatives to be compared from a specific point of view. It must be remembered that the selection of criteria is of prime importance in the resolution of a given problem, meaning that it is vital to identify a coherent family of criteria. The number of criteria is heavily dependent on the availability of both quantitative and qualitative information and data.

Currently many DES software's are available commercially. Some of them were compared with information obtained from manufacturers, users (Internet discussion groups), from articles published in congresses and from simulation manuals and white papers. Table 1

Family	Criterion	ARENA	FLEXIM	PLANT SIMULATION	PROMODEL	QUEST
Cost	Application Price	Good	Poor	Very poor	Good	Very poor
Usability	Esay to learn	Poor	Average	Poor	Very poor	Average
	Model visualization	Poor	Good	Good	Very poor	Very good
	Graphical User Interface	Poor	Average	Average	Poor	Poor
	Technical support	Poor	Very poor	Average	Very poor	Average
	Popularity (forum)	Good	Good	Poor	Good	Poor
Performance	Custom extensions	Average	Poor	Good	Average	Very good
	Technical capacity	Average	Average	Very good	Very poor	Very good
	Modularity	Good	Average	Good	Good	Good
	CAD connection	Average	Good	Good	Average	Good
	Compatibility with others soft.	Very good	Very good	Very good	Very good	Very good
	Reuse of models and objects	Good	Poor	Very good	Good	Very good
	Pre and Post processing of data	Very good	Very poor	Very good	Very good	Very poor
	Statistical Analysis	Good	Good	Very good	Average	Good

Table 1summarizes the results of the analysis of the different DES software's considered in this study, following 14 qualitative criteria. These criteria were gathered into 3 families. A preference function has been added for each criteria based on the following rule: Very Good = 0.9, Good = 0.7, Average = 0.5, Poor = 0.3, Very Poor = 0.1. The selection was made because the criterions have a qualitative form.

Considering the criterion of animation, the software Arena has two-dimensional representation and users must acquire a specific module to have the three-dimensional visualization. In the simulator Promodel the most common representation is also a two-dimensional, but according to forums the three-dimensional visualization can be configured and it is considerably more complex than the two-dimensional. The programs Flexsim, Plant Simulation and Quest have three-dimensional visualization. All programs have modules for optimization. In some software's such Arena, Plant Simulation and Promodel, the modules are coupled to data processing. Modules checking and tracking errors are common in all simulators discussed. Devices for identifying bottlenecks and streams are offered by Plant Simulation. The software Quest has a module that provides kinematic motion of machinery and equipment making the visualization more realistic. Most simulators studied shows good compatibility with programs from Microsoft's Windows platform.

Family	Criterion	ARENA	FLEXIM	PLANT SIMULATION	PROMODEL	QUEST
Cost	Application Price	Good	Poor	Very poor	Good	Very poor
Usability	Esay to learn	Poor	Average	Poor	Very poor	Average
	Model visualization	Poor	Good	Good	Very poor	Very good
	Graphical User Interface	Poor	Average	Average	Poor	Poor
	Technical support	Poor	Very poor	Average	Very poor	Average
	Popularity (forum)	Good	Good	Poor	Good	Poor
Performance	Custom extensions	Average	Poor	Good	Average	Very good
	Technical capacity	Average	Average	Very good	Very poor	Very good
	Modularity	Good	Average	Good	Good	Good
	CAD connection	Average	Good	Good	Average	Good
	Compatibility with others soft.	Very good	Very good	Very good	Very good	Very good
	Reuse of models and objects	Good	Poor	Very good	Good	Very good
	Pre and Post processing of data	Very good	Very poor	Very good	Very good	Very poor
	Statistical Analysis	Good	Good	Very good	Average	Good

Table 1 : List of the criterion

2.4 Definition of weight and scenarios

The results of multi-criteria analysis hinge on the weighting allocated and thresholds set. The weights express the importance of each criterion and obviously may deeply influence the final outcome of the entire calculation procedure. For some authors, the problem of how to determine the weights to assign is still unresolved since the different outranking methods do not lay down any standard procedures or guidelines for determining them.

In this study, 2 different weight vectors were formulated to circumvent this problem (see Table 2):

1. The first scenario W1, representing the base-case, was calculated by placing the focus equal weights to all criterion
2. The second scenario W2, representing the other base-case, was calculated by placing the focus equal weights to all family criterion

Family	Criterion	W1		W2	
Cost	Application Price	7.14%	7.14%	33%	33%
Usability	Esay to learn	7.14%		7%	
	Model visualization	7.14%		7%	
	Graphical User Interface	7.14%		7%	
	Technical support	7.14%		7%	
	Popularity (forum)	7.14%	35.71%	7%	33%
Performance	Custom extensions	7.14%		4%	
	Technical capacity	7.14%		4%	
	Modularity	7.14%		4%	
	CAD connection	7.14%		4%	
	Compatibility with others soft.	7.14%		4%	
	Reuse of models and objects	7.14%		4%	
	Pre and Post processing of data	7.14%		4%	
	Statistical Analysis	7.14%	57.14%	4%	33%
		100%	100%	100%	100%

Table 2 : Definition of scenarios

2.5 Results

Figure 2 presents the results of the multi-criteria decision analysis regarding the preferences of the various alternatives expressed numerically; the higher the value the better the alternative. In the case of the scenario W1 (equivalent weight for each criterion) the outstanding alternative is represented by Plant Simulation followed by Quest while for scenario W2 (equivalent weight for each family of criterion ➔ application cost is predominant) the outstanding alternative is represented by Arena and followed by Promodel.

This result is confirmed by the spider diagram of the ranking matrix presented in Figure 2. Note that this matrix is independent of the weighting vectors and just represent the force and the weakness off each alternative in function of the value of the criterion. Indeed, in this figure the strongest alternative maximizes the spider surface while the weakest alternative minimizes the spider surface.

For big shipyards, when the license cost is probably not the main concern, the authors recommend to choose between Quest and Plant Simulation. Plant simulation has an additional advantage because Flensburger Shipyard developed a simulation Toolkit for Shipbuilding (STS) for this software that drastically decreases the modeling time, *Steinhauer (2006 and 2011).* The STS contains a large variety of simulation tools for material flow modeling, model management, execution strategies and output analysis. The STS is programmed shipyard independently. The tools can be easily implemented in all kind of simulation models. It is further developed and used within the international cooperation SimCoMar and in the interbranch cooperation SIMoFIT, *König (2007)*.

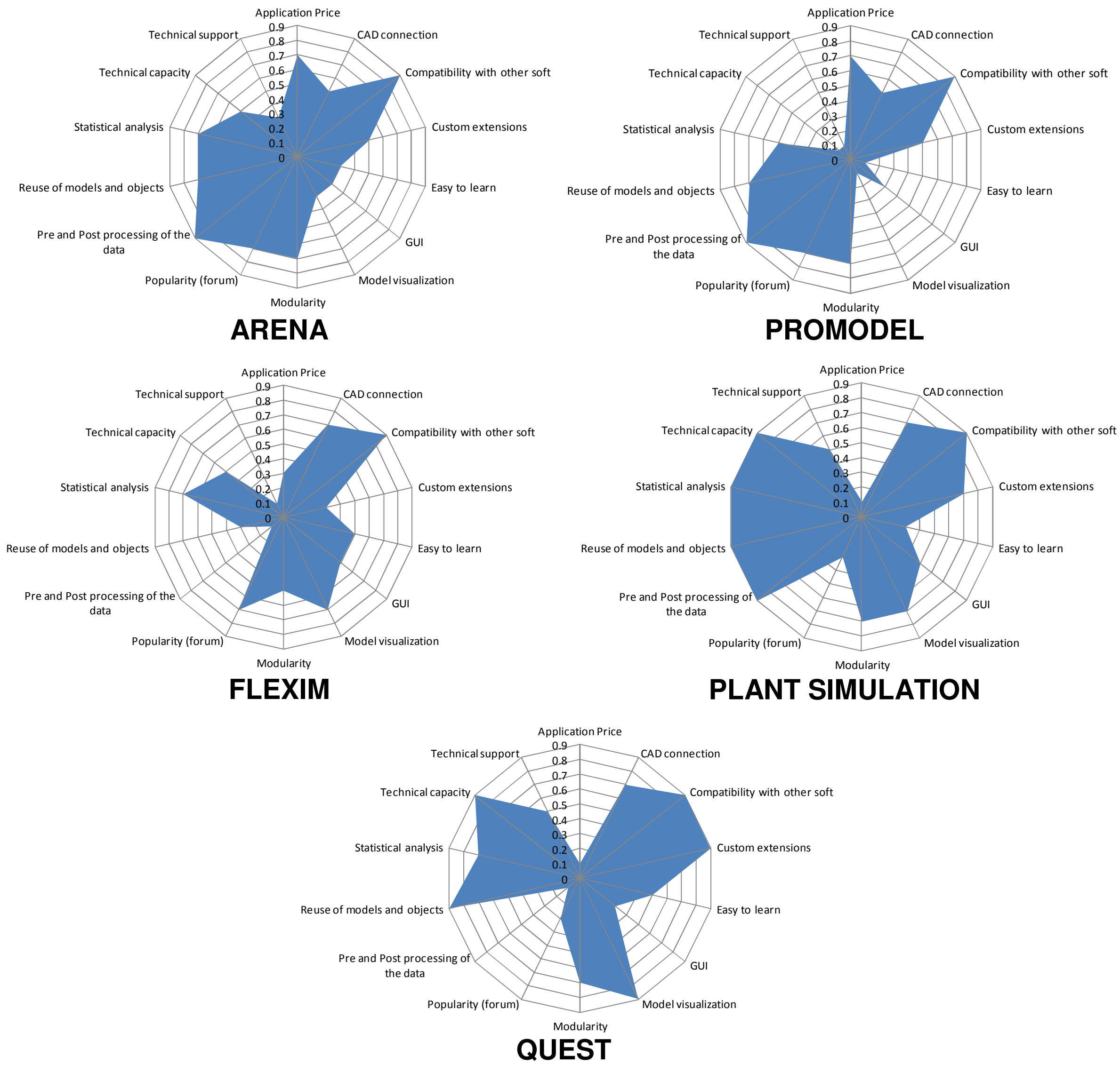


Figure 1 : Spider representation of ranking matrix for each alternative

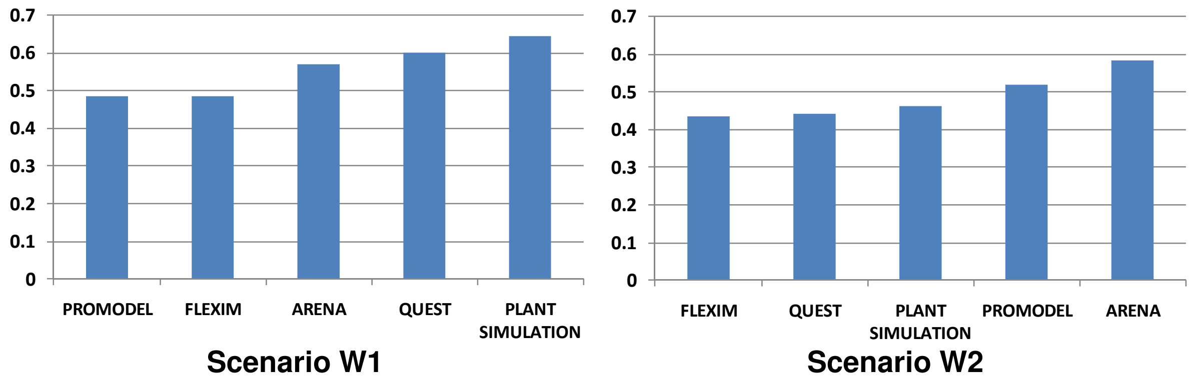


Figure 2 : Aggregated outranking flows of the alternatives

3 Case study

3.1 Block erection and assembly shop

In the shipbuilding process one of the most important workshops is the assembly shop where final blocks are assembled just before being erected in the dry dock. Planning of all the shipbuilding process is strongly linked to this workshop. Starting date and ending date of each block are imposed by this assembly shop. Consequently, the planning of all previous workshops is imposed according to these dates. In other words an improvement of the competitiveness on the assembly shop has a strong impact on the total production time of the ship.

This case study focuses on the assembly shop and the dry dock of a Brazilian Greenfield shipyard (Atlântico Sul).

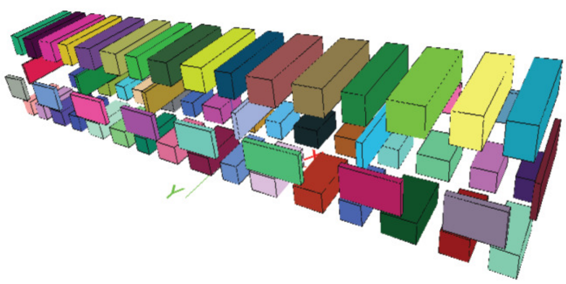
3.2 The ship

A LNG carrier of 220 000m³ have been considered for the production simulation. Only the prismatic part (5 tanks – 218.95 meter length – 22 000 tons) of the ships has been considered for the study. The fore and aft part are omitted here

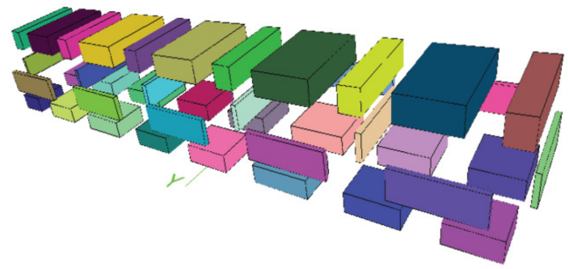
3.3 Block and section splitting

The influence of two strategies of block splitting has been studied in the production simulation. The first one considers 800 tons and the second one 1200 tons maximum loading capacity of the shipyard gantry crane. Figure 3 shows both alternatives regarding the block and the section splitting of the ship. The ship is divided respectively into 70 blocks and 174 sections for the 800 tons strategy and into 43 blocks and 172 sections for the 1200 tons strategy.

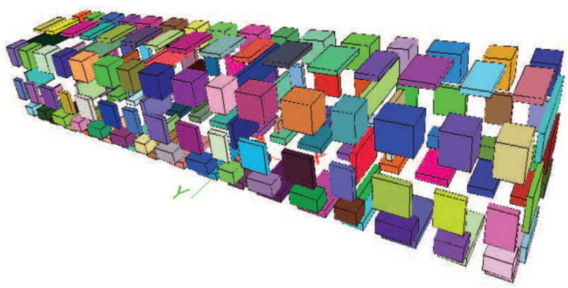
In the manufacturing process some resources have a high utilization and an influence on the whole process – also called bottleneck – e.g. a transport resource like the gantry crane or the heavy trucks. We have included this parameter in the simulation in order to analyze the impact of a new block splitting strategy on the key performance indicators – cost, lead time, space allocation, etc.



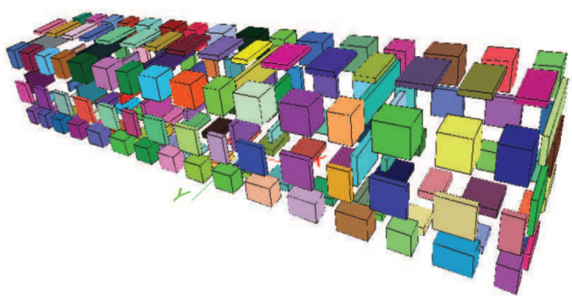
800 tons block splitting strategy (#70)



1200 tons block splitting strategy (#43)



800 tons section splitting strategy (#174)



1200 tons section splitting strategy (#172)

Figure 3 : Section and block splitting strategy

3.4 Sister ships

The production simulation requires a warm up period (the workshop simulator is fed with generated data) or initialization period (the workshop simulator is fed with real present day data or data from a real schedule) in order to have a real production situation for the simulation. Accordingly, given the choice of the implementation of a simulation focused on the long-term horizon and the lack of data, we implemented a warm up period (see Figure 4). It is a simple assumption which will avoid the problem of missing data. Indeed, based on the data of the first ship, 3 sister ships with the same design have been created and implemented into the database. The time gap between the keel laying of each ship has been chosen to be 100 days because only one dry dock is available in the model. Statistical records during simulation take place only for the second ship. The other sister-ships are there only to make the simulation as near as possible as a real production situation.

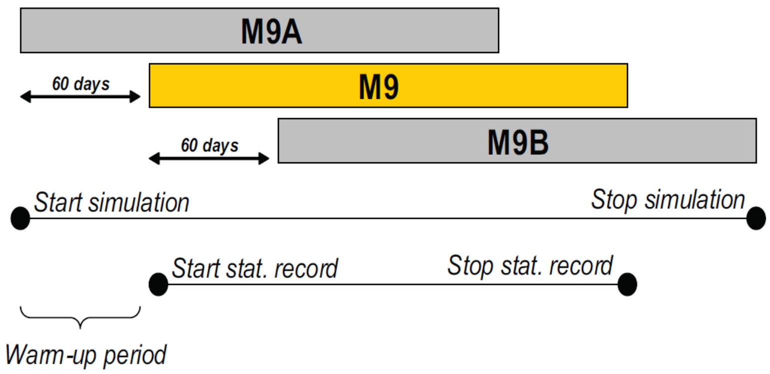


Figure 4 : Warm up period and sister ships

3.5 Process flow

Developments carried out use Discrete Event-Simulation (DES) methodology. In DES, the operation of a system is represented as a chronological sequence of events. Each event occurs at an instant in time and marks a change of state in the system. This production simulation model has been developed following 3 stages:

- The implementation of a simulation database. The simulation database stores data, which can be used as inputs or outputs for the simulation. Different data of the shipbuilding production process are stored, such as product data, planning data, resources and data of realized production. These data are needed in simulation for different purposes such as making and running a simulation model, validating a simulation model, generating data in an early stage of a building project or storing the results of the simulation. Three different databases have been implemented supporting the following data:
    - The Ship Work Breakdown Structure database (SWBS) which contains: all product data including ships, compartments, blocks, sections, activities, joins and welds, and some resources data including hourly costs and budgets.

- The production simulation database which contains: some data required for the simulation and not included in the product database, including user parameters, ship position in the dry dock, local and global constraints, assembly strategies, as well as all production simulation results.
- The production facilities of the shipyards are directly recorded inside the simulation model and include the assembly shop dimensions, the transport resources (speed, dimensions, transport strategies of vehicles, etc.), the human resources (number of workers by skills, working strategies, pool worker management, etc.), and working calendar and shift definitions.

- The implementation of a budget assessment module, *Caprace (2010)*. The purpose of this module consists in assessing the work quantity in hours for different work tasks like preparation, welding and rework. The results are provided for each section and block starting from all scantling and welding data such as the welding length, the welding position (flat, vertical, overhead and horizontal), the welding type (butt of fillet), the welding process, the plate thickness and the welding throat. Finally, this module enhances the link between design and production.
- The implementation of simulation models is based on the Discrete Event Simulation software (Delmia - Quest) working with a high degree of details and accuracy.

3.6 The simulation model

A production simulation focused on block erection stage has been developed. The model is only focused on the steel assembly of ships and not on the outfitting purpose. Within this model, the ship is first divided into a number of small blocks called sections. Sections are conveyed one by one from the end of the panel line to one of the two shot blasting workshops. Then after shot blasting, heavy trucks can transport the section to one of the four painting workshops. Finally after painting the heavy trucks transport the sections into the gantry crane working area. Then, each section is assembled in the assembly shop near the dry dock. Large blocks, which are called erection blocks, are made by joining several small sections together. Then, the erection blocks are moved onto the dock and welded to each other according to a suitable sequence, which is called the block erection, to complete the final assembly to the ship. That is, the construction process of the ship is similar to the process where a large product is made up of a number of parts like Lego blocks. A 3D model has been developed – see Figure 5. This figure shows the evolution of the block erection in the dry dock and in the assembly shop. Big halls in the top of the figure are simple representations of workshops providing sections i.e. the panel line while the halls in the upper right corner are the shot blasting (#2) and painting shops (#4). Outfitting has not been integrated in this simulation.

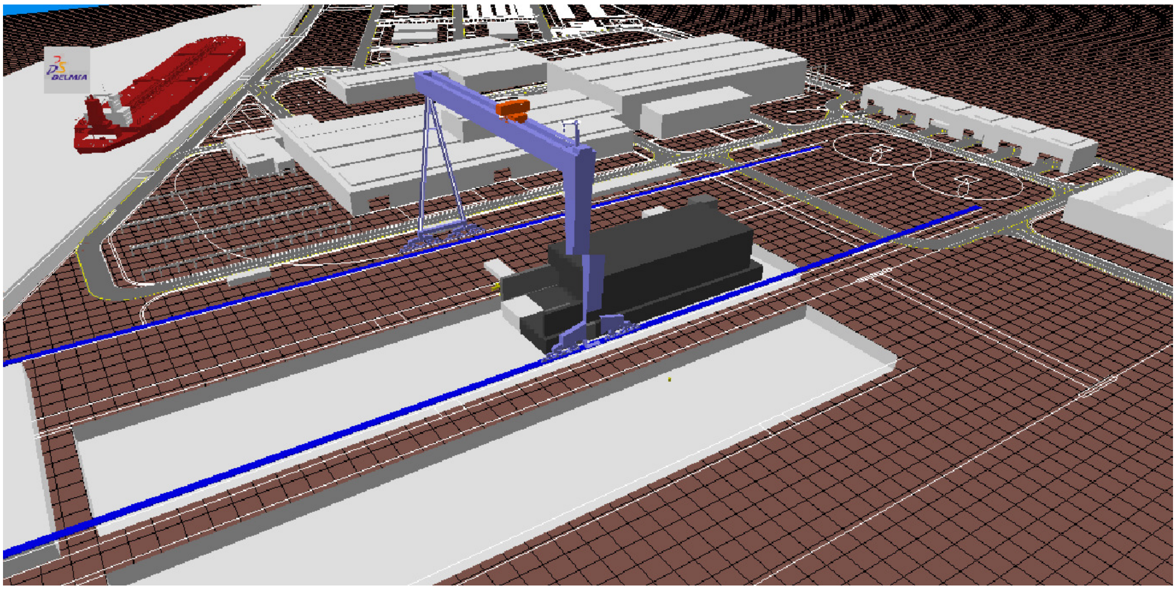


Figure 5: The simulation model

The following production stages are implemented inside the production simulation:

- The generation of sections at the end of the panel line (simulation source) taking into account the shipyard capacity of 70 000 tons/year and the weight of each section.
- The transport of sections by heavy truck from the panel line workshop to the shot blasting shops.
- The transport of sections by heavy truck from the shot blasting shops to the painting shops.

- The optional transport from one workshop to the storage area and vice-versa in case that all the workshops are busy.
- The transport of the sections by heavy truck from the painting shops to the influence area of the gantry crane.
- The transport by the gantry crane from the heavy truck to the good position in the assembly area along the dry dock. The position of blocks in the assembly shop is currently predetermined with a basic allocation rule. A possible improvement of the model could be the implementation of a dynamic allocation of the blocks in the assembly area.
- The assembly of sections to make block in the assembly shop. Preparation, welding and rework are considered taking into account of a detailed budget assessment between each sections. Different teams of worker working in parallel are also considered.
- The transport of blocks to the dry dock with the gantry crane (block erection)
- The assembly of blocks to build the ship in the dry dock. Preparation, welding and rework are considered taking into account of a detailed budget assessment between each block. Different teams of worker working in parallel are also considered.

3.7 Results

The aim of this test case was to support the planning of a building program of a big shipyard through production simulation assisting the managers to take the decision to buy a gantry crane with higher capacity. A production simulation prototype has been developed in order to achieve this objective. The influence of 2 different block splitting strategy on the lead time and budget has been tested (800tons vs. 1200tons) while the resources (numbers of workers, of cranes, of trucks, etc.) are fixed and will not be changed between each scenario. It is important to note that no major bottlenecks or saturated working areas and storage have been detected for the two simulation scenarios.

3.7.1 Budget assessment

Table 3 presents the results of the budget evaluation. The two key factors influencing these results are the block splitting and the scantling of the ship steel structure. The block splitting strategy includes many restrictions (dimensions of steel plates and parts, dimensions and capacities of workshops, loads of cranes, etc.) and has a significant impact on the workload division into workshops and on the cost of the ship. The dependence of the ship budget the block splitting is clearly demonstrated by the following example. Making a weld in flat position in a workshop is much cheaper than doing the same weld in the dry dock for various reasons; worse access conditions, welding at the ceiling, slower welding process, and so on.

The key finding highlighted in Table 3 is that we observe a gain of 3% between the 800 tons block splitting and the 1200 tons block splitting.

Description	Stage	Units	Alternatives	
			800 tons	1200 tons
Welding budget	Block erection	Hours	35 988	24 328
Preparation budget	Block erection	Hours	14 526	11 437
Welding budget	Block assembling	Hours	15 572	25 995
Preparation budget	Block assembling	Hours	6 675	8 550
Total budget		Hours	72 761	70 310

Table 3 : Result of the budget assessment

3.7.2 Lead time assessment

The lead-time is one of the most important key-factors to compare the different results. A simple definition of the lead-time is: “The amount of time between the placing of an order and the receipt of the goods ordered”. In practice in this simulation lead time is the time measured between the first erected block and the last erected block in the dry dock. In this project we do not modify or optimize the number of resources. Consequently, the goal is mainly to minimize the lead-time with the resources given.

	Alternatives	
	800 tons	1200 tons
Average lead time of 20 simulations in days	132.44	108.5
Convergence variation ratio after 20 simulations	0.17%	0.003%

Table 4 : Result of the lead time assessment

The computation time of one simulation run is about one minute in a conventional computer.

Discrete Event Simulation is based on stochastic process (Monte Carlo). Indeed all process times of preparation, welding and reworking have been introduced in the simulation model as normal distributions with an average value and a related standard deviation. So that several simulations are required to reach the convergence of the average of the lead time (see Figure 6). In this present case we considered 20 iterations.

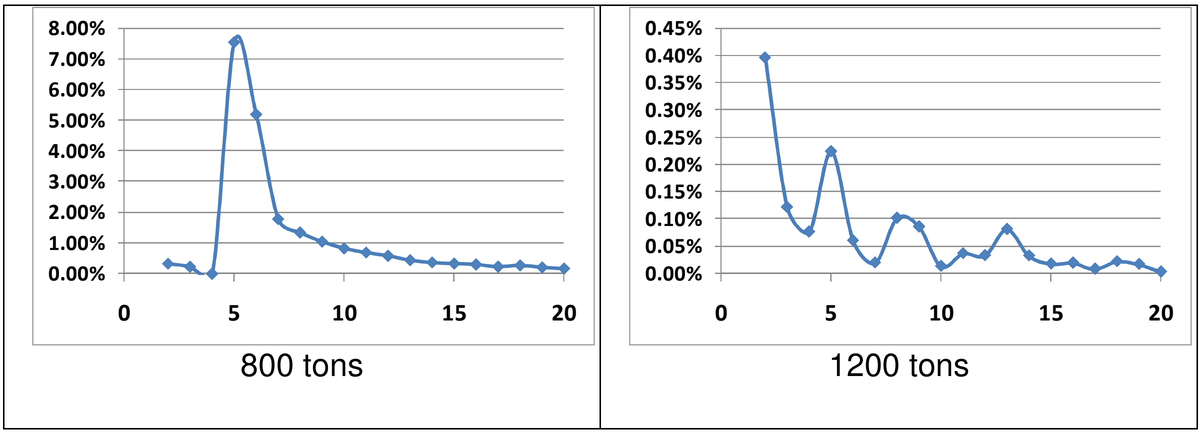


Figure 6 : Convergence of the average lead time

As expected the 1200 tons block splitting strategy has a smaller lead-time than the 800 tons block splitting strategy (see Table 4). This difference is about 18% keeping the human resource constant (same number of workers). A new block splitting, using blocks with higher dimensions, can generate some additional gains especially for the lead-time. This gain would be much greater once the outfitting is considered. The integration of the outfitting inside the simulation is a further potential improvement.

4 Conclusions

Simulation support in production optimization is widespread through every industry, because the reliability of the consequence of a design alternative on the production can be drastically increased. Nevertheless, the methodical development of a simulation module has to be accurately controlled. Huge quantities of data and a high number of constraints and interdependencies have been considered and required time consuming developments.

The budget assessment is an essential element in shipbuilding production and therefore an important development for the shipbuilding industry. The current production simulation model can highlight the effect of different design alternatives on production. Additionally, the use of simulation-based design technologies facilitates higher efficiency in terms of work strategy planning, and offers, as a result, significant productivity gains. However, this solution is impractical at the early stage of a design process due to the high development costs and the quantity of data considered. But in the near future, application of simulations will be more and more integrated into the early design phase trough the development of continuous and automatic acquisition of the design and production data.

Technical hitches of the process have also been highlighted, such as the difficulty in making a simulation model identical to reality. For example, the difficulty in managing subcontractors has been highlighted. A planner can easily try to find a solution to avoid using subcontractors. However, modeling all the possible situations and correlated solutions is very difficult and time consuming. Simplifications must be done and these simplifications can have an important impact on the final solution.

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