IMPROVING PLANNING AND RESOURCE UTILIZATION OF A SHIPBUILDING PROCESS BASED ON SIMULATION

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ABSTRACT

This paper presents the experience obtained from the initial steps of the development of a simulation model of a shipyard. Shipbuilding is one of the most complex manufacturing processes due to the high number and diversity of elements that must be assembled. The process can only be partially automated and it requires the coordination of many resources and the resolution of complex scheduling algorithms. Modelling and Simulation M&S is a methodology suited for studying complex systems and as such, it offers a great potential for improving operations in this sector. The paper is focused in describing the general steps of the process and the difficulties found during the model development along with the solutions adopted. The preliminary results obtained emphasize the need for studying and applying scheduling methods in order to maximize the utilization of the resources and reduce the duration of a project.

Keywords: discrete events simulation, modelling and simulation, shipbuilding, scheduling.

1. INTRODUCTION

Shipbuilding of medium and large size vessels is a complex manufacturing process which is usually managed in a project-oriented approach. Each individual ship (specially for military applications) has some degree of customization and there are only few units based on the same design. Thus, from an operations management point of view, shipbuilding has probably more common features with the construction sector than with mass production processes.

Still, efforts for applying Lean principles and standardizing processes have led to a modular approach in which each ship is subdivided in fairly standard blocks which are assembled in the so-called block erection process. Under this approach, common in the sector already for many decades, the unit of production is the “block” for most of the steps of the process.

The competitiveness of a Shipyard is determined by its ability to make offers minimizing costs and the project duration. This requires to optimize the production process of the blocks as well as ensuring that they are available for the erection process in time and in the proper order.

The processes involved to produce a block span cutting and welding of steels plates and profiles to form structural units as well as outfitting operations and painting. Ideally, the blocks assembled should contain all the structural elements as well as all the systems and equipment installed on them. In practice however, not all the elements can be effectively mounted before the block erection process due to physical constraints, availability of materials and time requirements. For instance, the tubes located in the union of two blocks are often mounted after the block assembly process since the tolerance control required to ensure that they match could be too high and require reworking.

The large number of operations required to produce the blocks of a ship, the necessity to synchronize multiple workflows and numerous resources make the management of such a production system very challenging. Modelling and Simulation M&S provides a powerful tool for analyzing decisions in such systems. This paper describes the main elements required to build a simulation model of a shipyard which can be applied for evaluating the effect of different blocks characteristics, planning methods and resources. The

2. M&S IN SHIPBUILDING

Process simulation began to develop in the 60s, when languages of discrete event systems appeared on the market. Since then, there have been significant advances in this field that have transformed the simulation in an indispensable tool for optimizing production processes. The simulation as a tool for improving systems, can be included within the practices or thought "Lean".

The shipbuilding industry has seen a mixed degree of extension of M&S tools. Some of the best shipyards adopted this technology at least since the 90s. However, many shipyards are not still aware of these tools and their potential. For instance, in the Spanish shipbuilding sector, in despite of being one of the countries with highest market share, M&S is in general an unknown technology for process optimization.

M&S technologies help to evaluate, decide and make production plans while enabling a continuous and transparent review of the performance. This useful tool improves the project definition and the evaluation of the production of each type of vessel (Kasemaker, 2006).

In the shipbuilding industry, simulation models can be used as a tool to analyze the impact of programing a new workload, evaluate different scenarios and identify the resource constraints. Likewise, it can be used to analyze the expected results of the integration of new technologies or equipment in a shipyard, with their impact over the operating costs and on the planning processes (Mclean, 2001). In fact, "the National Research Council (NRC) has repeatedly identified M&S as a high priority area… one of two breakthrough technologies that will accelerate progress in addressing the grand challenges facing manufacturing in 2020" (Leong, S., Y.T. Lee, 2006).

A peculiarity of shipbuilding is that manufacturing is not repetitive and hundreds if not thousands of different operations, labors and resources distributed along different workshops need to be synchronized. This causes high costs for developing simulation models which is a factor that makes difficult the application of M&S in this sector.

Due to the high costs of development and maintenance of the simulation models, cooperation among companies, universities and research centers is convenient. The group SimCoMar (Simulation Cooperation in Maritime Industries) is an example. 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) (Caprace, Jean-David Moreira Freire, Assiss, Martin Pires, & Rigo, 2011).

In 2006 the SIMoFIT is founded (Simulation resourcing in shipbuilding and Civil Engineering) as a professional collaboration between shipbuilding and civil engineering (Steinhauer, 2007). The shipyards Flensburger, the Bauhaus-Universität Weimar, the Ruhr University of Bochum and SimPlan AG as a consultant simulation joined this cooperation (Steinhauer, 2011). Other examples are the Meyer and Flensburger shipyards (Caprace, Jean-David Moreira Freire et al., 2011).

In addition to the high costs, model generation is "knowledge intensive, time consuming, and error-prone" (Lee & Kang, 1996). The time required to build accurate models is a barrier to the use of discrete event simulation in the shipyards (Medeiros & Williams, 2000). One way to face these challenges is using automatic programming techniques. According to Madden & Neill, 2005, the use of auto-generated models allows the simulation tool to find more widespread usage among the project managers.

Another problem is how to store and read the simulation data. Although there is not any standard format to store simulation data, some formats have been proposed such as SDX. Microsoft Excel spreadsheets are often used because they provide a simple and convenient interface to store and represent the system data (Burnett, Medeiros, Finke, & Traband, 2008).

In this paper, the ExtendSim software was chosen to focus only in the analysis of the process and not in the way of automatically processing process' data. Microsoft Excel is used to store all the data that configures a simulation scenario.

Some of the aspects that have been more extensively researched are the block erection process and the capacity design of the previous block production workshops.

The block erection problem can be seen as an assembly jobshop schdulling problem with additional constraints imposed by the ship geometry and the stability requirements of the erection process. To optimize the blocks schedule, one of the earliest works proposed the use of an algorithm called the constraint-directed graph search (CDGS) (Jae Kyu Lee, 1995). Other authors have opted for genetic algorithms (Okumoto, Yasuhisa, 2002 and Bao Jinsong, Hu Xiaofeng, 2009). Although the initial works focused on this problem separated from the blocks schedulling in the rest of the proces, in the recent years some authors have adopted a global approach employing different techniques of optimization (Jean-David Caprace, Clarice Trevisani Da Silva, Philippe Rigo, 2011).

The determination of the optimal number of cells in the previous workshops has been approached as a task scheduling problem. Scheduling problems with the jobs grouped in batches and spatial constraints are generally the most studied in the literature. The main research work about the spatial schedulling problem for shipyards was done in the context of the DAS project (Kyoung Jun Lee and Jae Kyu, 1996).

3. PROCESS DESCRIPTION

The manufacturing process in the shipyard studied includes the following steps: cutting-welding, assembly, outfitting 1, blasting and painting, outfitting 2, block erection and finally the ship is launched where the out fitting works are finished. Figure1, shows the shipbuilding process.

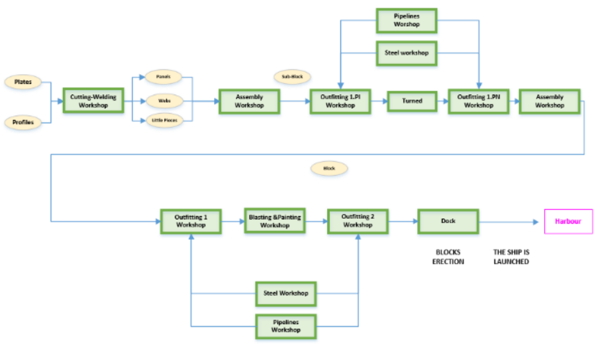

Figure1: Shipbuilding process

Firstly, steel plates are cut into small parts in accordance with the specified design in the cutting-welding workshop. The plates are then used along with metallic profiles to form the smallest assembled units that will constitute the structural elements of the blocks. Two main types of structural components are defined: panels and webs. The panels are large steel plates that can be curved in some cases and make up the hull, the deck and the different levels of the ship. The webs are smaller parts that provide resistance to the main structure and also divide spaces or perform other various functions.

The next step of the process is the sub-blocks assembly in the "assembly workshop" followed by the first outfitting process (Outfit 1). The assembly process mainly consists of welding operations among the panels and the webs, according to the constructive strategy designed for the sub-block. The outfitting process mainly consists of installing pipes, brackets, equipment and other auxiliary components inside the sub-block.

Then, contiguous sub-blocks are positioned together and welded to form the blocks. Other outfitting operations are performed thereafter. The next operations are blasting and painting the blocks in the painting stations. The high costs associated with this facilities and the long painting times mean that this is often a bottleneck.

After painting, the second outfitting process takes place (Outfitting 2). It involves installing wires and diverse equipment. In general, all the components that could be damaged in the blasting and painting process are assembled in this step. Finally, the blocks are transported to the dry dock to build the ship. The ship is then launched and the process is finished at the harbor.

Critical planning stages to be performed are splitting the ship in blocks and defining the optimal erection sequence. The erection process is a very complicated operation that involves decision-making taking into account a lot of structural items and the different erection strategies. On the other hand, it is not possible to optimize the assembly sequence in the blocks erection if the principal workshops do not have the appropriate number of cells in order to have the different blocks that are necessary on time and in the correct order.

4. MODEL DEVELOPMENT

The established goals for the development of this simulation model were:

- To provide an analysis tool capable of estimating the total makespan of building a ship from the beginning of the cutting operations to the launching and the lead times of each block at each workshop.
- To provide a tool capable of reproducing the effect of different numbers of workshop cells, internal transports vehicles, schedules, machines operation rates, welding rates, workshops productivity and erection sequence and constraints.
- To design a flexible and parameterized model that is capable of simulating the building process of different ships.

Thus, a shipyard employing this model would get an important analysis tool to optimize for planning and capacity design. The model has been designed to provide an overall view of the shipyard, without entering into the details of the workshops. Thus, the capacity parameters are the number of cells in the main workshops of the shipyard (assembly, outfitting 1 and outfitting 2). Planning of all the shipbuilding processes is strongly linked to these workshops. Starting date and ending date of each block are imposed by these steps.

As pointed out before, the simulation software employed was ExtendSim. A screenshot of a part of the model is shown Figure 2. Although ExtendSim provides some 3D visualization features, they are not used at this stage of model development. The purpose is to obtain a model valid for conducting preliminary analysis of the shipyard which should later be refined by more detailed models of the workshops.

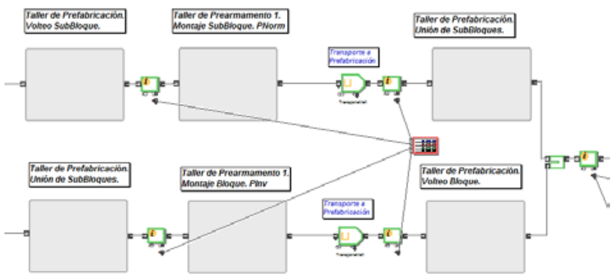

Figure 2: Model Simulation Shipbuilding Process

The main components of the simulation model are shown in Figure 3. The model starts its execution by reading data from an Excel file were the list of blocks along with their characteristics to be produced. The blue arrows and blocks indicate the steps of the process included in the simulation model. The green blocks and arrows are used for the scheduling and planning elements. The data in the Excel file also includes a schedule that determines the times from which the different blocks are allows to initiate each step. When two blocks are available, the priority is given to the earliest one. The red blocks and arrows show the main resources which are shared among the different steps of the process and which are included in the model.

During the model development phase several challenges were faced. The first one is the high number of components types and diversity of elements that must be manufactured for building a ship. Just building the structure requires several types of steel components with diverse geometries. The most common types of processes are welding operations whose times depend on the welding lengths. Characterizing the welding lengths of the numerous elements is a time consuming process which requires detailed engineering plans of the ship. However, this plans are not usually available at the early stages of planning for which this aggregated model is most useful. Due to this reason, during the model development a simplified approach was taken which consisted of employing different equations that estimate the total duration of each step as a function of some block features. The block's features used are:

- The block size in the three axis.
- The block type (according to a classification defined by the shipyard).
- The number of structural elements that form each block (such as the number of panels).
- The quantity of elements assembled in the outfitting process.
- The block's weight.
- Other specific attributes.

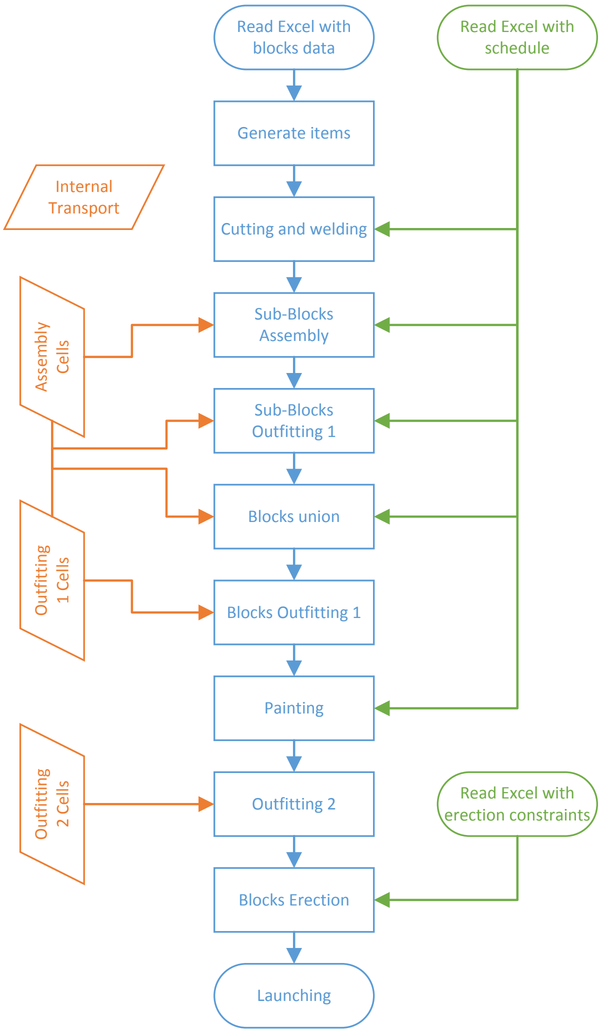

Figure 3: Simulation Model Components

Thus, in general, the model used for estimating the duration of the process step i is:

$$\overline{t_i} = f(Size, Type, Elements, Weight, \dots) \quad (1)$$

The uncertainty in the duration estimated by the previous equation and the variability due to the process and the manual tasks is taken into account by a statistical distribution. In this model, Lognormal distributions are used. The reasons for this decision (supported by the experience of the team that developed this model) are the following.

- The lognormal distribution is a simple distribution with two parameters that allow to specify the mean and the variance, which are the two main parameters that affect the performance of a queuing system.
- The lognormal distribution is one the distributions that often fits well real data.
- The lognormal distribution arises from a random process of multiplicative variations of a variable. Thus, it reflects well the variability in production times whose variance grows with the mean values. For instance, the standard deviation of the duration of long tasks is usually larger than that of short tasks.

Thus, the model used for simulating the times of the processes in the model is:

$$t_i \sim ln\mathcal{N}(\overline{t_i}, CV \cdot \overline{t_i}) \quad (2)$$

Where CV stands for the coefficient of variance of the process.

Another critical challenge faced in the model development was the need to generate all the elements that will form the blocks' structure and that will be outfitted. A simple solution could be to define a single item in the model that represents all the elements that will be matched to form a block. However, this approach would reduce the capabilities of the model since it would not reflect properly the capacity constraints of some processes and the effects of batching. For instance, the assembly process of a block could start even if not all the panels and webs that will form it are available yet. Thus, it is necessary that the items that flow through the initial steps of the process are the single entities that represent the webs and the panels.

However, the level of detail in data available at early stages of the project planning does not allow to know the specific parts that will be necessary to manufacture in order to build the ship. Thus, the solution adopted consisted of designing a first component that generates in a random but realistic way all the individual elements that will need to be produced to assemble each block. The model starts with information at an aggregate level which is read from an Excel file and then it disaggregates this information splitting the items that represent the blocks into increasingly smaller units that correspond to the all the parts that need to be manufactured for building the ship.

The requirements for designing the disaggregation process were:

- To generate the number of items of each type randomly with a realistic distribution that depends on the block type and dimensions. To do so, different statistical distributions were fitted for different block types and a procedure was designed to correct the estimations based on the block's length. To do so, a naval architect was in charge of defining the rules on how the size attributes affect the number of elements.
- To automatically generate unique ID's for each part and for each part within each group and count them. This is necessary in the ExtendSim model in order to know in later steps how many items need to be assembled and exactly which parts need to be matched to each block.
- To group the parts in the production batches that are used for production planning in a realistic way. This step matters since the lead times of the products in the different workshops are mainly affected by the batch sizes. The designed model uses a heuristic algorithm to generate batches of similar parts that are usually grouped to specify which model items will be matched together. However, since the times of the assembly steps are not defined at the group level but at the block level, a procedure was devised to distribute randomly the total assembly time of a block among the groups of parts that will form it proportionally to the workload that each of them requires.

Another great challenge which has only partially solved at this stage of the model development was the production planning. The simulation model developed represents the real processes of a shipyard and thus optimizing the schedule is a complex combinatorial problem. As in the real shipyard, the synchronization of the flow of items, the assignment of priorities and the definition of the sequences of blocks and batches is a big challenge that affects the results of the model. Actually, there are two main issues involved in this subject.

The first issue is how to reproduce the real dynamic planning that happens in the shipyard. The construction of a ship may take several months or even years so deviations from the original plan are common. The rescheduling decisions are made by the directors of the workshops or by the project managers depending on the issue and thus are subject to their personal criteria as experts which is not easy to implement in a mathematical model. Thus, it is impossible that the simulation model fully represents the reality of how the system is managed.

The second issue is that no optimal efficient algorithms are known to schedule the production in the simulation model. Thus, the results of the model are only as good as the methods implemented for scheduling. This means that if the model is intended for planning purposes but the scheduling methods used are inefficient, the model will forecast longer durations than actually should be achieved.

So far the planning methods implemented in the model are simple:

- There is an initial schedule that defines the start times for cutting and assembling each block. This schedule is defined outside the simulation model and imported through an Excel file.
- The workshops follow FIFO rules for managing all the queues. This means that whenever two blocks are available to enter the next step of the process, the priorities will be assigned based on the earliest arrival. This is an aspect that must be improved in further refinements.
- The shared resources (such as assembly cells or the painting cabins) are assigned in following a FIFO order.

5. EXPERIMENTATION

This paper presents the preliminary experiments conducted with this simulation model. The scenario designed does not correspond to a real ship but it contains a representative mix of block types. The real time values and time units are omitted due to confidentiality reasons. The results displayed have been modified in such a way that are valid for supporting the conclusions but do not allow to know the real duration of the process.

The analysis has been focused on inspecting the model results in order to obtain a list of measures for future improvement.

The response variables used are:

- The makespan of each stage of the process.
- The time that the blocks take to complete each processing step.
- Graphs that show the number of blocks that have completed each step along time.

The utilization rate of the different resources was inspected to check for possible lacks of capacity. However, its average value is not a useful indicator in this process because the utilization of some resources are very high in some specific stages that cause delays in the production but very low during the rest of time. Thus, it is not a sufficient indicator of where to act for improving the system.

The figure 4 shows an example of the average utilization of the assembly cells during the simulation time. It can be noticed an initial phase in which the blocks are mainly going through the cutting and welding operations and this workshop is idle. Then, occupation grows as new blocks become available until it reaches a maximum. Then, there is a period in which the last blocks leave this process and the average utilization reaches an final value of 70%.

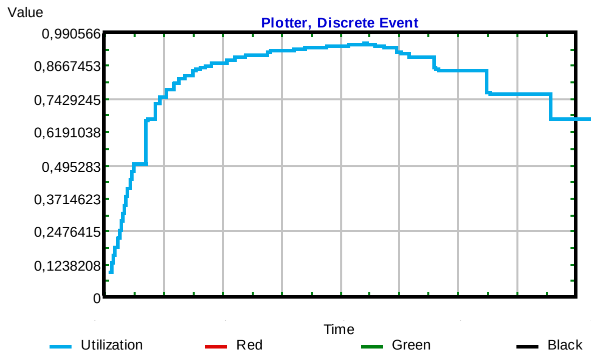

Figure 4: Utilization graph of the assembly cells.

The Figure 5 shows the evolution of the number of completed blocks on the main stages of the process. The blue line corresponds to assembled sub-blocks, the red line to assembled blocks, the green one to painted blocks and the black one to erected blocks. The gaps between the lines indicate the time passing since a block completes a processing step and the next. Thus, it is an important tool for detecting where the problems occur.

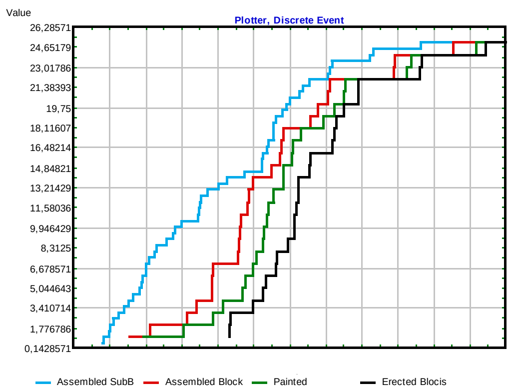

Figure 5: Simulation Model Components

This graph corresponds to the preliminary results obtained before applying optimization techniques and optimizing the schedule. As noted in the previous section, it is not a realistic representation of the planning procedures at the shipyard and thus the conclusions from the analysis cannot be directly extended to the real plant. The conclusions withdrawn must only be circumscribed to the simulation model developed.
The following measures were proposed to improve the model in further simulation studies:

1. Long delays between the sub-blocks and the blocks assembly times were observed in the initial 50% of the blocks and also in the last 20%. This indicates that a production plan that equilibrates better the workload in this process could help to smooth the workload and reduce the total timespan.
2. A 30% of the total makespan was caused by the last blocks. This suggests that optimizing the schedule could lead to a great improvement in the duration of the project.
3. Even if the painting step was initially regarded as the system bottleneck, the results suggest that the initial processes are not capable of reducing the makespan under the current scheduling methods implemented in the model.

6. CONCLUSION

Shipbuilding is a complex manufacturing process that requires big efforts in project planning and scheduling. Project planning is even more difficult at the initial stages of a project (when engineering plans may not yet be fully available) because of the high number and variety of parts that need to be assembled to build a ship.
Modelling and Simulation M&S offers a practical tool to cope with this complexity. However, great challenges are faced in the development of these kind of simulation models. This paper has described the experience gathered in the initial steps of the development of a simulation models and offers some solutions to deal with them.
The preliminary results demonstrate the necessity for implementing appropriate planning methods and scheduling algorithms when building the model. Without them, a non-optimized sequence causes delays and inefficiencies in the system. Although this represents a challenge for applying M&S, it offers the opportunity of learning about the behavior of the real system and designing measures of improvement.

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