DISCRETE EVENT SIMULATION TO IMPROVE CUTTING-WELDING WORKSHOP IN A SHIPYARD

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ABSTRACT
The Cutting-Welding workshop is the first step of a shipbuilding process where the basic structural elements of the ship are fabricated. It is a fairly automated process where the main operations can be automated using robots. However, the geometrical diversity of the elements produced cause challenges from an operations management point of view since the throughput rates change and depend on the ship and the block types. Modelling and Simulation provides a practical methodology for analyzing and optimizing this workshop. This paper describes the development, validation and initial results of a discrete events simulation model of a Cutting-Welding workshop. It is intended to assist in the planning phase of a new ship, particularly focused on the capacity design of this workshop. Its applicability has been tested on a realistic scenario based on an existing shipyard with the aim of evaluating the accuracy of the model. Preliminary results show that the proposed simulation framework can be successfully applied to process planning in shipbuilding providing improvements in terms of time and costs.

Keywords: Workshop Design, Discrete Event Simulation, Shipbuilding, Shipyard, Cutting-Welding.

1. INTRODUCTION

Shipbuilding is a complicated process where collaboration of many actors both intra and inter-organizational is necessary (Tann & Shaw, 2007). Nowadays, much time, efforts and resources are spent by all parties, especially by ship-owners and shipyard engineers in coordinating all design details of the ship under construction (Solesvik et al 2012). This ambitious goal needs efficient coordination activities in order to provide the complex solutions for the ship-owners fluctuating workload and strong competition in terms of price, time to market and product quality. Its relevance is reflected by the fact that up to 70 % and more of a shipyard's value creation is based on purchased equipment and services (Bronsart, Gau, Luckau, & Sucharowski, 2005).

Moreover, a large number of shipbuilding-related firms have great concern for offering complete vessels, designed and outfitted by their customers, within the previously established schedule. Therefore, in order to make shipbuilding projects successful, the optimization of quality, time and cost must be taken into account as the most important aspects to consider in the evaluation of any project.

This environment has led to the emergence of the Industry 4.0 which, as Kolberg & Zühlke (2015) state, is based on machines and devices that have their own intelligence and, as a result, a factory becomes "smart". According to this phenomena, this new Industry gives paramount importance to the optimization processes by implementing a dynamic production. Besides, it also can be integrated in Lean Production providing outstanding improvements in production processes.

In line with these current developments, some of these ship-owners have decided to invest in innovative software which aims to support design and coordination activities along the shipbuilding process. Shin et al., (2004), analyzed, using the DELMIA QUEST software, a subassembly line in a large shipyard and the different processes. They were able to simulate the material flow in the line in order to show the bottlenecks and the interferences between objects.

There are multiple difficulties when a complex system like a shipyard has to be described realistically. Mathematical analyses, most of the times, do not reflect in the best possible way all the casuistic that may occur in a huge structure like this one. Simulation enables not only to replicate the whole process (with all the particularities) but also to recognize and solve problems in the system (bottlenecks, interruptions, etc.) (Ljubenkov, Dukic, & Kuzmanic, 2008).

As a result of the importance of simulation methodologies, many efforts are being made in this field. However, these approaches are not always successful due to the requirement of much time and effort for developing a new system. In addition, it is very difficult to adapt a commercial simulation software to the process planning (CAD information, scheduling information). However, it is possible to set up accurate process planning in advance if a consistent simulation framework is developed (Cha & Roh, 2010).

Burnett et al., (2008) developed, by means of the 3D software Flexim, a discrete event model simulation with a methodology that provided a rapid generation of models from the enterprise database. This Flexim model reads data from PLM software using the standard Excel format.

Using a virtual shipyard provides a perfect testing framework to find the best solution to apply in the real world. Unfortunately, due to the efforts required to develop an efficient simulation model, many shipyards are reticent to use these techniques. But, there are some shipyards like Jos, L. Meyer and Aker Ostsee, in Germany, that already use a simulation tool successfully (Krause, Roland, Steinhauer, & Heinemann, 2004).

Simulation is also a tool for enterprises in the project planning activities. In manufacturing industry, such as ship assembling, these kind of simulation models are used successfully to improve production lines. Related to this, König, et al., (2007), proposed by means of the Plant Simulation software, a simulation framework to model outfitting processes in shipbuilding and building engineering. Using a constraint-based simulation approach, different practical outfitting schedules were created and evaluated in terms of work and material flow organization, utilization of space and worker's efficiency as well as process costs.

Thanks to these achievements, nowadays discrete events simulation has become an essential part in order to improve the overall process in a shipyard.

This paper focuses in the simulation model of a Cutting-Welding Workshop of a shipyard. This is the first stage of the manufacturing process which is required to produce in time all the components that will be assembled to build the structure of the ship. The case study will highlight the two main operations performed in this workshop: Cutting and Welding.

The products to be processed will also be of two kinds: steel pieces and structural profiles in order to assembly them to create panels and webs (longitudinal girders, web frames, double bottom girders, soled floors, bulkheads, beams etc.). The study will reflect these processes in this shipyard workshop by means of a discrete event simulation model created by a Discrete Event Simulation Software called ExtendSim.

It should be noted that a Cutting-Welding Workshop can be considered as the first one among all the others in the shipyard. The products (panels and webs) generated in this facility will be the required materials to create the rest of the blocks in all other workshops of the shipyard.

The identification of bottlenecks, the adjustment of manufacturing time and minimizing the makespan are the main objectives of this model.

The paper is organized as follows. Section 2 presents issues related to the manufacturing process in this shipbuilding. Section 3 presents the validation of the model. Then, section 4 states the results of the proposed simulation model. Finally, the main conclusions of the paper are summarized.

2. PROCESS DESCRIPTION

In order to describe the whole process in this workshop a simplified explanation will be presented in the following lines.

Two kinds of products are manipulated: structural profiles (stiffeners) and steel pieces. These products will suffer different processes depending on the element they will be part of: a web or a panel, (the intermediate and structural products that will be the base of the future block).

Cutting and Welding processes can be taken as the principal ones. First of all, the cutting process starts with the reception of the profiles and steel sheets (usually with dimensions of 12 x 3 meters). Both products are split in several pieces in order to create the intermediate ones (panels and webs).

The profiles suffer a blasting process before they are cut by an oxi-cut machine. The original steel sheet is cut by means of two plasma stations, depending on if the resultant pieces will be destined to webs or panels.

The second part consists in the welding process: the base of the merger pieces. Once the pieces are cut, there are two main destinations to where the pieces can be moved: to the Panel Line or to the Web Line. All welding processes take place in these two Lines.

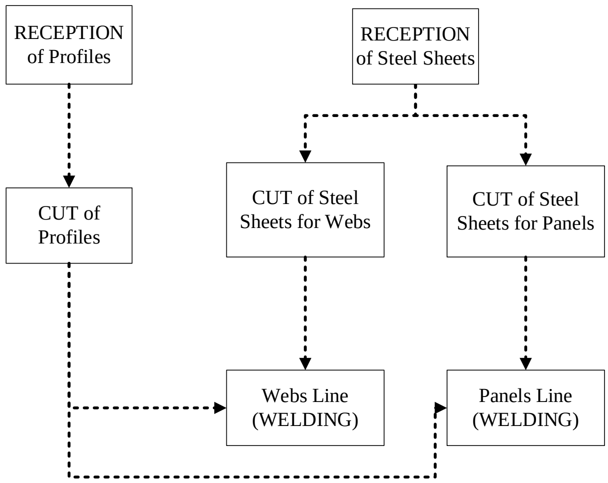

Figure 1: Main processes in cutting-welding workshop

The Panel Line can be described as a completely automated area where, firstly steel pieces (large plates) and secondly large profiles, are processed to manufacture the Panel. In the first part of the Line, the large plates are assembled in the One Side Welding station in order to create the base of the panel. In the second part, many stiffeners are welded to provide the structural strength to the panel.

The Web Line is described as an area where steel pieces and profiles go through the manufacturing process, that is, they are assembled, in order to create the structural component (web). The differences in shape between webs is a handicap in this process. Most webs are unique and vary depending on the structural function they will be destined for (longitudinal girders, web frames, double bottom girders, soled floors, bulkheads, beams etc.).
The Figure 1 shows the simplified summary of the process.

2.1. Model development

The simulation of the cutting-welding workshop has been made with the Discrete Event Simulation software ExtendSim. The high level of resolution that this model requires makes ExtendSim a perfect solution to represent this workshop.
A discrete event simulation model has been created from the information stored in an Excel file. This file contains the information related to the items represented in the model. The ExtendSim model “reads” the data stored in the Excel file with the aim of creating the attributes of the items.
Figure 2 shows a small section of the model, specifically the arrival of the steel sheets and the destination to the appropriate plasma station. After that, the cutting process takes place and multiple pieces are created.

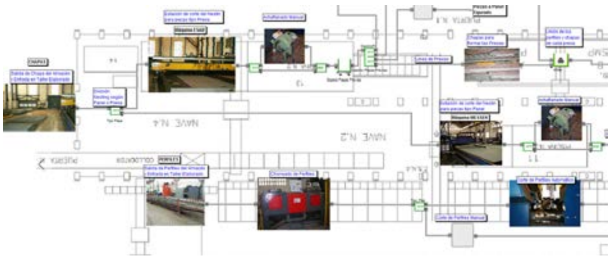

Figure 2: Section of the ExtendSim model

The data for the simulation model was obtained from historical records and visits to the shipyard. The times of the cutting and welding operations were estimated from cutting and welding lengths in the registries and engineering planes. An extensive effort in data analysis was carried out in order to fit the adequate statistical distributions for each block type. A set of correction factors were estimated to extrapolate the results from a specific ship to other ships that have different structural designs.

3. MODEL VALIDATION

Once the initial version of the model was build according to the information provided by the workshop managers and the information gathered during visits to the plant, a validation phase was carried out. The validation consisted of two related activities:

- A data based validation in which the real data from two workloads was compared to the simulated results for the two workloads.
- An experts based validation in which the results of the model were shown to a set of experts and their reviews and comments taken into account for improving the models.

The simulation experiment for the validation consisted of compering the flow times of the products of two selected workloads through different parts of the process. The flow times estimated by the model were compared to the historical data and represented in a Value Stream Mapping (VSM) type of diagram. The results for the workload 1 are shown in Figure 3. In this chart, the triangles symbolize delays between processes and the total flow time of each process is represented in the white squares. The reason for using this type of diagram was establishing the difference between the durations of the real processing steps and the delays in the historical records caused by the assignment of other orders to this process. The time units of the diagram are hidden due to confidentiality reasons and the real values of the times have been scaled by a confidential value.

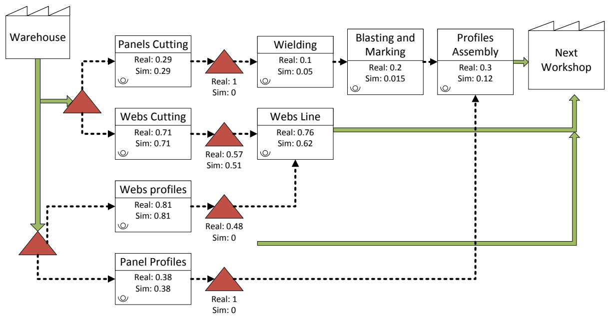

Figure 3: VSM of workload 1.

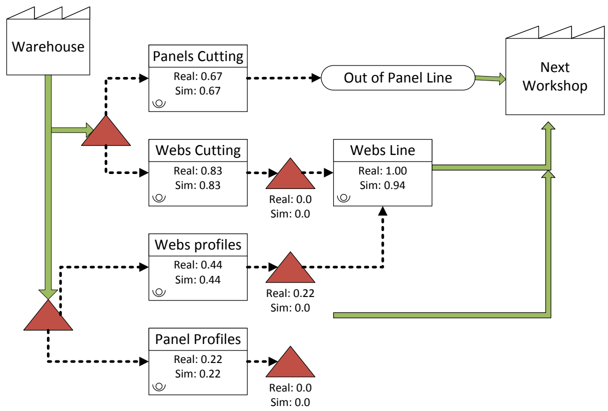

Figure 4: VSM of workload 2.

The results of this validation experiment showed differences in some of the process stages. However, once the causes of this differences were checked with the process experts, it was found out that they were caused by the assignment of higher priority orders which were not part of the experiment. Thus, the

workload 1 scenario was only used valid for checking some of the times.
The Figure 4 represents the same comparison for the workload 2 scenario. This second scenario corresponds to another case with more controlled conditions in the plant and the results show a good match between the model predictions and the historical data. The model was thus accepted as a valid representation of this workshop.

4. EXPERIMENTATION AND RESULTS

The experimentation phase presented in this paper is a preliminary analysis of the workshop evaluated with a realistic production plan. The scenario does not correspond to a real ship but to a representative mix of block types that are common in most of ships.
The main two challenges face for defining a scenario for experimentation are the following.
The goal of this workshop is to produce panels and webs in time for the next steps of the process. The composition in panels and webs of a ship's blocks is heterogeneous. Thus, the workshop never reaches a "stationary state" as in mass production processes. Hence, the simulation scenario must reproduce the workload of a ship and the response variables must be the total makespan for producing each type of product.
The objective of the simulation experiment is to provide a capacity design of this workshop to satisfy the makespan requirements at minimum cost. In mass production systems, the throughput of the line is given by the bottleneck station so the only way to improve the system is to act on it. However, in this system the requirement is to satisfy a makespan requirement and this can be achieved by acting on different stages of the process. Thus, for instance, it could be more convenient to allocate overcapacity in a low cost workstation than in a costlier one even if the second would be the stationary state bottleneck.

4.1. Capacity Design

The factors initially considered in the simulation experiment were:

- The number of cutting machines.
- The number of parallel web welding stations and shifts.
- The number of parallel panel welding lines, profiles assembly and shifts.
- The number of cranes used for internal transport.

An initial screening process was made to asses which were the limiting resources. It was found that the webs line was the slowest one. Figure 5 shows a graph comparing the number of panel and web units completed along the simulation time (which is expressed in generic time units). An important feature that can be observed in the graph is that the slope of the graph is not constant. This is caused by the variation in the types and dimensions of the webs that happen between different blocks. It shows that in this process is not possible to define a maximum throughput capacity in units of items per time because it depends of the geometry of the webs being produced.
Table 1 shows the utilization results for the webs fabrication line. It can be noticed that the Cutting process is less busy than the welding operation. Also, adding additional capacity for this step is less costly since there is the option of manual welding webs. Thus, in this case the best strategy to increase the capacity of this workshop would be to act on the welding webs station. However, the decision on whether this increase is really necessary would depend on whether the total makespan for the simulated scenario is enough or not.

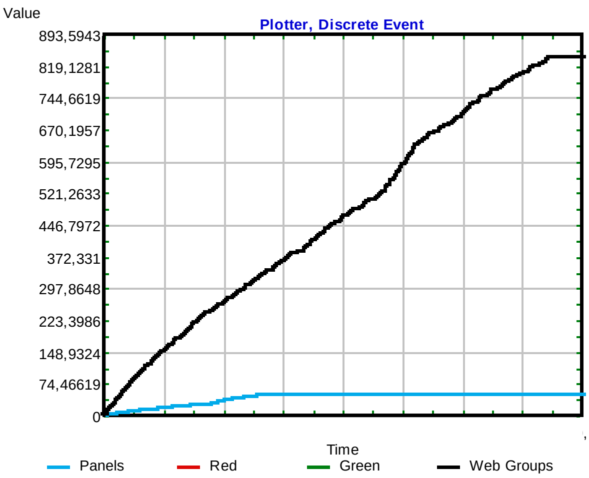

Figure 5: Number of web and panel units completed.

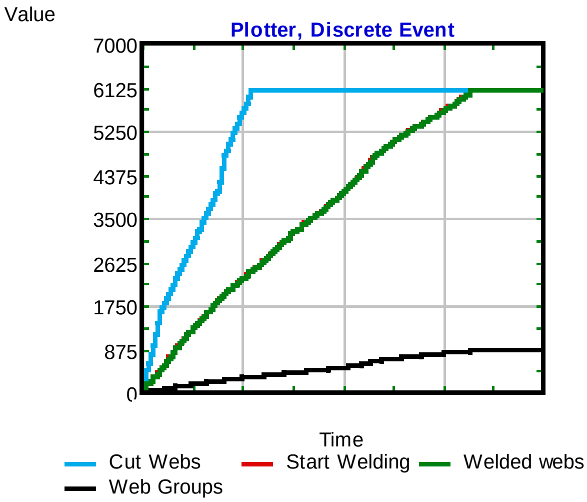

Figure 6: Number of web units that complete each step of the process.

The figure 6 displays the number of webs that have completed the cutting process, welding and which have been grouped in batches for transport to the next step of the process. From this plot, it can be concluded that the bottleneck of this process is the welding station. Table 1 supports this conclusion showing the utilization rate.

Table 1: Utilization of the webs line.

Utilization (5 runs)	
Cutting Webs	29.0%
Welding Webs	97.2%

The following heuristic procedure for capacity design was proposed for future application to this case:

1. Define a workload scenario and the maximum admissible makespan.
2. Run the simulation model and identify which are the resources or stations that delay the fabrication the most. The previously shown graphs are a useful tool for doing so.
3. Make a sorted list of the resources that could be increased or reduced. Estimate the cost of increasing it or the saving from reducing it.
4. If the slowest station is the same as the one with the lowest cost of increasing it, run the model after making this change and return to step 2.
5. If they are different, simulate the scenarios of increasing the capacity of the less costly resource and the slowest one. If the makespan constrain is satisfied by acting on the less expensive resource, select this option. If not, select the option that reduces the makespan the most. Return to step 2.
6. If no more changes are required to satisfy the makespan constraint, then reduce the capacity of the least used resources that yield the highest savings in a similar way, stopping when the makespan requirement is no longer satisfied.

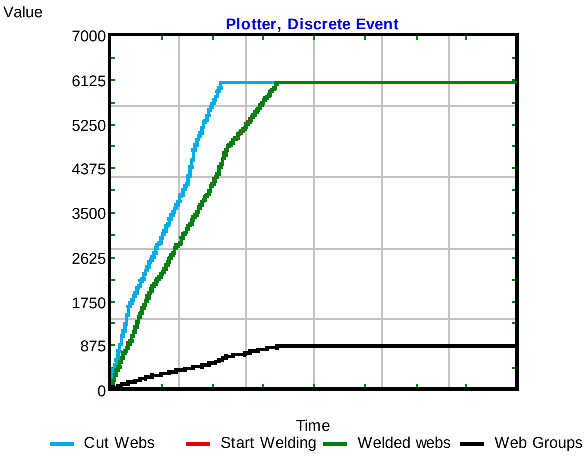

Figure 7: Number of web and panel units completed.

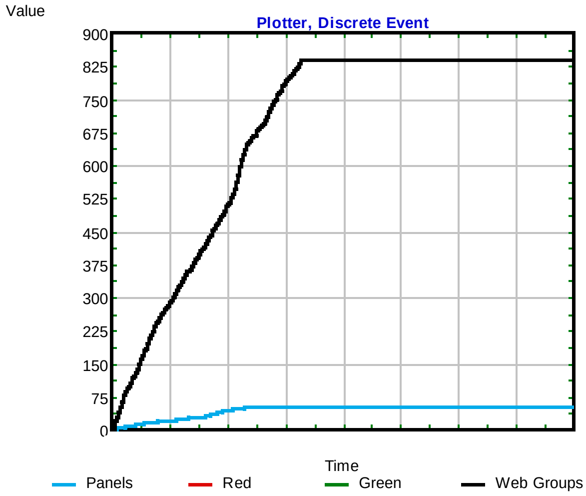

Figure 8: Number of web and panel units completed.

The figures 7 and 8 show the results after applying the procedure to increase the capacity of the welding stations. The total makespan for the cutting and welding operations could be reduced to half by acting on the critical activities of the welding process.
Thus, the throughput of panels and webs can be better synchronized. It must be noted that this results do not correspond to a real workload scenario. It is an scenario arranged for demonstrating the capabilities of the simulation model and the methodology for designing the capacity of the real workshop.

5. CONCLUSION

The simulation model of a Cutting-Welding workshop has been presented. The methods employed for validating the model have been described. They show a reasonable degree of similarity between the real data and the simulation results. Some differences were observed in some delays, but further analysis showed that they were caused by other pending workload that was blocking the process during the period analyzed.
The preliminary experimentation was focused in the capacity design. The simulation model proved to be a useful tool to select the number of required cells and how to meet the time requirements with the minimum number of resources. The plots generated showing the increase in completed elements in each stage of the process was an useful tool for identifying the bottleneck resources and selecting the proper course of action to improve them.

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REFERENCES

Bronsart, R., Gau, S., Luckau, D., & Sucharowski, W. (2005). Enabling Distributed Ship Design and Production Processes by an Information

Integration Platform. In *2005 International Conference on Control, Automation and Systems* (pp. 1–10).
Burnett, G. A., Medeiros, D. J., Finke, D. A., & Traband, M. T. (2008). Automating the development of shipyards manufacturing models. In *Winter Simulation Conference* (pp. 1761–1767).
Cha, J. H., & Roh, M. I. (2010). Combined discrete event and discrete time simulation framework and its application to the block erection process in shipbuilding. *Advances in Engineering Software*, *41*(4), 656–665.
Kolberg, D., & Zühlke, D. (2015). Lean Automation enabled by Industry 4.0 Technologies. In *Proceedings of 2015 International Federation of Automatic Control* (Vol. 48, pp. 1870–1875).
König, M., Beißert, U., Steinhauer, D., & Bargstädt, H.-J. (2007). Constraint-based Simulation of Outfitting Processes in Shipbuilding and Civil Engineering. *Proceedings of the 6th EUROSIM Congress on Modeling and Simulation*.
Krause, M. ., Roland, F. ., Steinhauer, D. ., & Heinemann, M. . (2004). Discrete event simulation: An efficient tool to assist shipyard investment and production planning. *Journal of Ship Production*, *20*(3), 176–182.
Ljubenkov, B., Dukic, G., & Kuzmanic, M. (2008). Simulation Methods in Shipbuilding Process Design 1, *54*, 131–139.
Shin, J., Lee, K., Woo, J., Kim, W., Lee, J., Kim, S., … Yim, H. (2004). A Modeling and Simulation of Production Process in Subassembly Lines at a Shipyard. *Journal of Ship Production*, *20*(2), 79–83.
Tann, W., & Shaw, H. J. (2007). The collaboration modelling framework for ship structural design. *Ocean Engineering*, *34*(5-6), 917–929.