DES TECHNIQUES APPLIED TO THE DESIGN OF A TRAINING SESSION ABOUT LEAN METHODOLOGY IN A SHIPBUILDING PROCESS

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ABSTRACT
The aim of this work is the application of a discrete event simulation tool for the design of a learning sessions based on Lean Manufacturing techniques applied in a shipbuilding processes. This tool based on DES could serve us for teaching the possibilities of apply the lean manufacturing concepts in a shipyard where this type of techniques are unusual, except for a very specific purpose and on rare occasions.
To do that, an effort will be made to design the training session as feasible and realistic as possible by using DES techniques modelling a real shipbuilding process taking into account the existing restrictions related to the fabrication period and resources available.

Keywords: Lean, shipbuilding, discrete event simulation

1. INTRODUCTION
The shipbuilding sector has its own characteristics that make it different from the rest of the industry, such as the fabrication of a single or several units of one product for a particular customer and a specific purpose. This makes that the finished products have a high customization and a large technological component, in addition to having a high economic value and a very long manufacturing process that can even last for years.
The economic crisis in recent years and the current slow economic recovery result in an excess of productive capacity. In addition, a strong global competition and a very tightly cost strategy, focused on attracting new customers, put the shipyards in a critical situation where the majority of the orders had been awarded by Asian shipyards that absorb 83.3% of the world's contracting, 81.9% of the product portfolio and the 84.4% of production in 2011 (Suaz González 2012).
This skill of Asian shipyards to lead the shipbuilding industry has reduced the market share of European shipyards, passing from 25% of the world market in 1994 to 2.7% in 2009 (CC.OO. 2013). This situation has been particularly hard in Spain, which had been one of the main producers in the world, reaching almost 20% of the world orders in Europe, went through a difficult situation after the opening of the file and the subsequent problems happened in 2011 by the European Commission due to the tax breaks of shipowners.
This caused a delicate state in shipbuilding and based on the situation of the referents shipyards, Lean techniques are recommended for a more rational and efficient use of its resources, making our shipyards more competitive and attracting new customers.
However, although Lean techniques have not been fully implemented in any of the shipyards studied, they have been used by using tools designed only to solve specific problems.
This need for change the approach to apply Lean techniques to the entire manufacturing process has motivated this work, since most authors point out the need to actively involve all the staff in this process because they are the ones who really know the process and will coexist with these changes. Therefore, we must seek their participation, searching for the solutions so they must be involved and trained in this new philosophy of work.
Undoubtedly, another of the most important changes that will affect all industries is the use of new tools more in line with Industry 4.0. This new industrial revolution starts with the Smart Factory which it is defined as a "*manufacturing solution*" (Radziwon et al. 2014) that provide us a quick and flexible response to the changing market conditions. This new revolution will pass not only to a process automation, we are talking about a new cooperative factory between machines and humans, the interaction about real and virtual world…And a way to achieve this optimized factory is the use of simulation process and virtual tools in order to reduce waste (Turner, Hutabarat, and Oyekan 2016).
Therefore, in this work we try to facilitate this transformation by creating a tool based on simulation and Lean manufacturing techniques.

2. STATE OF THE ART

The aim of this work will be design Lean manufacturing training techniques tools based on the utilization of DES concepts.

(Padilla et al. 2016) study the need to create some tool for the training of employees in DES techniques, proposing the design of two games with a very different topic from the usual to attract their attention.

This rising trend to use games in the company is also shown in several articles of the prestigious magazine Forbes, highlighting the potential they have to involve the staff in the process. It is also possible observe the application of games in sectors with a varied objectives like the military (Raybourn 2014; Yildirim 2010), sanitary (Diehl et al. 2011; Ushaw, Eyre, and Morgan 2017) or safety (Silva et al. 2013). Even in the maritime sector you can find some example of the use of games and simulation as in (Longo et al. 2015) where a simulator is used to represent as complex situation as the arrival of a ship to the port and the interrelations between ship pilots and port traffic controllers.

In recent years we can observe an increment of the use of games and new technologies in classrooms too.

(Aldrich 2006) debates about the use of new techniques in teaching, such as simulation and video games, as well as the importance of "Learn by doing", demonstrating the importance of simulation to learn and understand complex processes that otherwise would be impossible.

(Page and Kreutzer 2006) treats the simulation as one of the main techniques of E-Learning, looking for understand very difficult and abstract ideas or scenarios with the use of these techniques.

A review of the use of simulations games at the Industrial Engineering universities was made in (Deshpande and Huang 2011), where the greatest disadvantage observed is the reticence to change by some trainers. The authors express the necessity to meet the needs of the new generation (the "*digital natives*"), aimed to solve the new problems of the industry. By this reason they show some real cases applied to any field of engineering (mechanics, electrical, logistics, etc.) highlighting as an important advantages: teamwork, better conceptualization and analytical thinking, etc.

(Liane Márcia, Marcel, and Subramanian 2007) apply the discrete event simulation for training engineering in production process, highlighting the possibilities for students to modify parameters and visually see what happens with their modifications.

(Standridge 2000) discusses about the advantages of simulation for the active training of engineers in a university through the development of a series of case studies prepared to represent the reality of their closest companies and skilling them for their next reality.

Another interesting work is (Van der Zee and Slomp 2005), where an explication of the complete creation process and the result obtained from the application of simulation and gaming to a real case of the manual assembly line was made. With this work they try to demonstrate the viability of the Lean implementation in a real company and the improvements produced in the motivation and the assimilation of concepts by the participants after some repetitions.

(Constantino Delago et al. 2017)proposes the creation of a virtual game based on the PBL (Problem Based Learning) methodology, using a DES 3D software for teaching the basics Lean concepts. Thanks to the use of these techniques, the authors express the possibility to analyse complex and realistic situations (the most important problem teaching engineering) and predict future situations, better than using traditional methods.

3. REAL PROCESS AND SIMULATED PROCESS

The complete process of shipbuilding is very complex with a large number of stages between the different processes. In addition, these stages differ significantly depending on the degree of evolution of each shipyard, such as the capacity of pre-outfitting before assembly that are able to reach.

We could say that the fabrication strategy usually applicable in shipbuilding is based on an integrated construction and has undergone no significant variations in the last 30 years, except some isolated cases that try to use robotic methods.

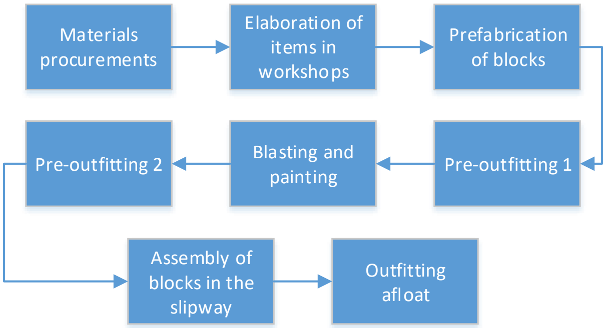

Figure 1: Usual Workflow in a Shipbuilding Process.

In the previous figure the main stages of a shipbuilding process have been represented, although these can be called differently depending on the shipyard to which we refer and, as we mentioned before, its degree of development.

The purpose of this work will not be to represent a process as complex as it is because we look for describing it in a training session, where the time and resources we have is significantly limited.

This is the reason why we have proceeded to search and define the main activities of each of these fabrication stages with the aim of showing, through a simplified representation, the main phases of the construction process of a ship, focusing in particular on a constructive process of an accommodation vessel.

In addition, to carry out this work, and to apply Lean techniques in a shipyard, we must discriminate between the elements where its application is most appropriate so, we distinguish the following elements:

Unique elements: are those products that go through an exclusive manufacturing process, which is not similar to

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any other product. One example of this is the machinery room.
Repeatable elements: are those whose manufacturing process goes through the same stages although these stages do not have to be identical.
Experience has shown that around 35% of the ship's blocks could be defined as unique (singular) element; however, the remaining 65% could be classified as repeatable, distinguishing between different families.
Therefore, this work will deal with the construction process of repeatable elements as it represents the largest quantity of building blocks in a ship and is the natural way to implement Lean Manufacturing in the shipbuilding industry.
In addition, to facilitate this training for all the employees, regardless of their educational level, it has been proposed the creation of a physical model that allows all employees to interact with it and thus make easier the transition between the physical and the digital model without losing our goals.

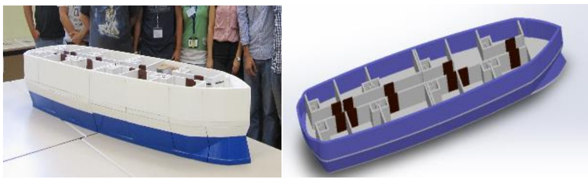

Figure 2: 3D Model Made for the Training.

These characteristics described in the paragraphs above, oblige us not only to clearly identify the repeatable elements and the main stages. In addition, thanks to the historical data of an important European shipyard and by consulting experts, we proceeded to perform a kind of scaling between reality and simulation to process times and their costs as well as the number of resources needed.

Table 1: Market Requirements.

Cost	Deadline
170 M€	26 weeks

Table 1 shows the assumed hypothesis regarding the term and cost demanded by the market, based also on historical data.
Therefore, these requirements will be the cost and maximum term that the shipowner would accept to this project, since another shipyard would be able to do it in those conditions. In consequence, if our cost exceeds this, we will not be competitive and the possibilities of our shipyard to award the contract will be reduced dramatically. On the other hand, a non-fulfilment in the delivery milestones failure to comply with the deadline will incur in penalties in addition to a poor image and reputation for our company.

4. MODEL DEVELOPMENT

Once the objectives of this work have been established, it has been decided to use a simulation software called ExtendSim whose versatility has led it to be used in various applications and even for the training of future professionals in the universities, as is the case of the University of A Coruña.

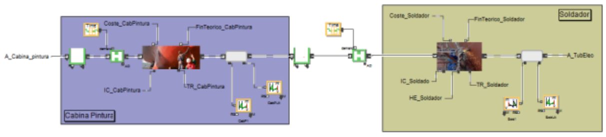

Figure 3: Part of the Model Made in ExtendSim.

Based on this, we have decided to use two models, one of them which represents the current manufacturing system called traditional method and, on the other hand, a more modern model where different Lean techniques are applied, adapted to the characteristics of the naval sector that has been named Lean method.
The different models will include, among others, the following parameters:

- Process time and its variability.
- Relationship between activities.
- Material and labour cost.
- Theoretical start and end time per activity.
- Real overtime limit:
  - Four hours during the week.
  - Twelve hours during the weekend.

4.1. Traditional method

Initially, we will have some operators to carry out this work according to the traditional method which is characterized because the activities will focus on the construction of large blocks, setting an individual objective to achieve our highest productivity which will lead to a search of our local optimum.
An easy example of this is the cutting process where the search for a local optimum would lead us to focus our work on the cutting of pieces according to the thickness, so we can cut as many pieces as possible trying to reduce the setup times of the cutting process.
Figure 4 shows the construction strategy based on large blocks and how this decision in the cutting stage affects the next operation (shipbuilder) that is lead to work with the resources available.

Figure 4: Training Session, Traditional Method.

Another characteristic of the traditional manufacturing method is the application of a push system where we try to perform our work in the best possible way without thinking in what is happening in the rest of the activities

and producing as long as there is material and no matter how the entire manufacturing process goes downstream.
In addition, it will be assumed that the quality of the processes will be evaluated only when the manufacturing process is completed.

4.2. Lean method

As an alternative to this traditional method we propose the possibility of applying a new culture of work in our manufacturing process. To do that, we will no longer focus our activity on the large blocks construction but we will focus on subblocks, proceeding therefore to the use of a reduction of batch size.
In addition, we will focus our activities on the fulfilment of the different requirements of all the stages, always taking into account the state of the workshop (queues, failures…). For this reason, we will have to include the concepts of internal customer and the quality integrated in the fabrication process named also jidoka (Lean concept).
We will also focus our activity on the search for the global optimum against the local as happened in the previous case.
If we focus now on the cutting activity, the difference would be that we would now cut the pieces according to the assembly needs of each subblock regardless of the thickness of the piece (ceiling panels, linings and bulkheads). This lead us to reduce the setup time in the tools which would be addressed for instances, through SMED techniques (a Lean concept).

Figure 5: Training Session, Lean Method.

Figure 5 shows how our activity is now focused on the fabrication of subblocks, also establishing a one-piece flow that all activities must respect.
In summary, the main differences between these two models are:

- Assume a certain versatility of workers.
- Search for global optimum.
- Waste reduction.
- Rational use of resources.
- Reduction of the batch size, from working by blocks to subblocks.

5. RESULSTS OBTAINED FROM THE MODELS

After doing all this work and creating our models with a discrete event software, we will now focus on the results obtained from both models, focusing especially on the fabrication period, customer´s milestones and costs.

5.1. Traditional method evaluation

To analyse the traditional method, it has been proposed the evaluation of different scenarios, assuming as the first hypothesis the impossibility to do overtime, allowing observing the real influence of overtime in this model.
This first hypothesis assumed would prevent us to achieve the markets goals established in terms of time and cost. If we assume the penalties for deviations in time, we would see that this would lead to a total cost of the project of 302.29M€, delivering our ship in week 36.02, something completely unviable.

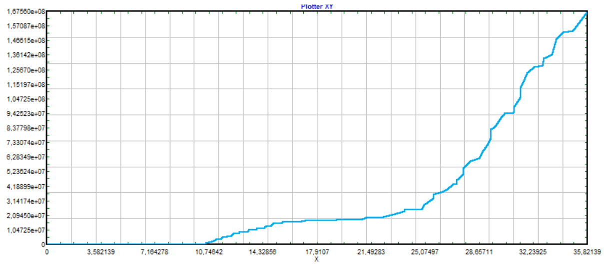

Figure 6: Accumulated Costs by Penalties.

After this situation, it was suggested the possibility of using overtime from an initial moment, assuming the limits established in the reality and commented previously. The results are shown below:

Table 2: Economic Result for the Traditional Method.

	Without overtime at the weekend	With overtime at the weekend
Material cost	80.686.760 €	80.686.760 €
Labour cost (without overtime)	67.404.942 €	67.259.853 €
Extra labour cost	39.069.472 €	27.793.817 €
Penalties cost	1.497.145 €	- €
Total cost	188.658.319 €	175.740.430 €

Table 2 shows our breakdown of costs allowing us to compare both situations, seeing that the main differences will be the amount of overtime required and the shipowner´s penalties but we do not obtain any benefit in any case, having a financial loss of 18.66M€ or 5.74M€ in the best case. As you can see, the best result is obtained by using as many overtime hours as possible, since in this way we would be able to achieve the milestones related to the delivery date of our accommodation vessel (without penalties) and reduce waiting times between activities and therefore those unnecessary costs.
In this case, thanks to the use of this type of DES software, it has been easy to identify the bottlenecks activities in our process (shipbuilder and bricklayer), which has led us to consider what would happen if we decide to increase our staff by doubling the employees available in these activities.

The simulation shows us that this increase in the personnel is not enough to achieve our objectives in terms of cost and time, requiring a reduction of 13% of our operating time to accomplish the requirements related to the fabrication period and delivery date.
In this case, we have significantly improved the workshop operations thanks mainly to the waiting times reduction between the activities which translates into a considerable cost reduction.
However, if we do not have the capacity to reduce our processing time, we would require using overtime to reach our goal.
In spite of this situation, the economic results improve considerably as we showing in the costs shown in the following figure:

Table 3: Economic Result for the Hiring Case.

	Without overtime	With overtime
Material cost	80.686.760 €	80.686.760 €
Labour cost (without overtime)	77.029.647 €	77.023.942 €
Extra labour cost	11.015.715 €	10.798.592 €
Penalties cost	2.859.227 €	- €
Total cost	171.591.349 €	168.509.294 €

With these results we can conclude that the non-use of overtime would mean a loss of 1.59M€, mainly due to the delivery date penalties.
However, the use of overtime would mean a considerable saving, achieving an estimated profit of around 1.5M€ in these two situations.
This case is especially significant because we do not need to use the temporary safety cushion we use through overtime on the weekends, so we will have enough time for temporary and economic contingences.

Table 4: Comparison Between the Use of Overtime.

	Without overtime at the weekend	With overtime at the weekend
Total cost	168.539.428 €	168.509.294 €

5.2. Lean method evaluation

As an alternative method, the use of Lean tools was proposed with the objective of reducing costs and lead-time and assuming the previously established hypothesis.
The simulation allow us to identify an underutilized resource as the painter who, through a brief training and the similarity between guilds, will become bricklayer. In addition, it will be assumed that the welder, considering his certifications, will be able to assist the shipbuilder when he needs it.
The simulation results show a significant cost reduction, mainly thanks to the reduction of the waiting time between activities which translates into a better overall economic result (Table 5), estimating the profit in this case in the 16.18M €.

Table 5: Economic Result for the Lean Method.

	Lean method
Material cost	80.686.760 €
Labour cost (without overtime)	72.632.651 €
Extra labour cost	497.900 €
Penalties cost	- €
Total cost	153.817.311 €

The extra labour cost shown in the Table 5 are due to the variability of the model and the consequent need to correct those deviations that are insignificant comparing them to the traditional method.
In total, a cost reduction of about 14.7M€ with respect to the case previously evaluated was achieved. In other words, we obtain a reduction of 20.1% in the labour costs which representing a reduction of 9.55% in the project cost.
These differences are even more significant if we evaluate the case in which we have the same number of employees, where we achieved a saving of 21.92M€.
In addition, in this case we will need to use a total of 24.9 weeks in our manufacturing process (4.6% time reduction) despite not having to employ overtime, so we will have an important safety cushion.

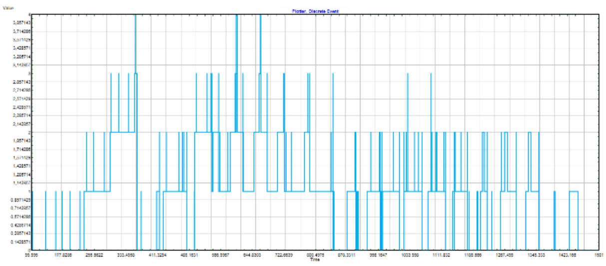

Figure 7: Quantity of Items in Buffers Waiting to be Processed.

In the previous figure, we show the items waiting to be processed in some stage. In this case, as can be observed, we would have a maximum of only four items waiting whereas in the traditional method it would be a total of six. This supposes a considerable reduction of the space required in the shipyard temporarily store blocks.

6. CONCLUSIONS

The use of the DES techniques for our purpose has given us significant benefits because, thanks to them, we have been able to create a realistic and viable Lean manufacturing training tool for all staff, regardless of the starting educational level that will show them the advantages of the process, involving them during their training.
On the one hand, for a higher level of training and with the intention of implementing simulation techniques in the company, they will serve as a starting point or as reference for employees to make their own models or

complete those exposed here. This is undoubtedly the great advantage of the creation of these models which can be modified and evolve according to the progress of the students.
In addition, it would be possible to create some interfaces that allow the modification of some predefined parameter and see how the system changes according to the results obtained by the simulation, considerably reducing the time necessary for the session.
If we try to do this by using the created physical scale model, obviously its realization would need a lot of time and it would not be possible to evaluate as many scenarios as in the simulation, because the limited time and available staff. Therefore, DES not only serve us to build the base of the scale model (planning, costs, etc.), but also this training tool could be complemented by the presentation of various scenarios studied thanks to the simulation, improving this training too.

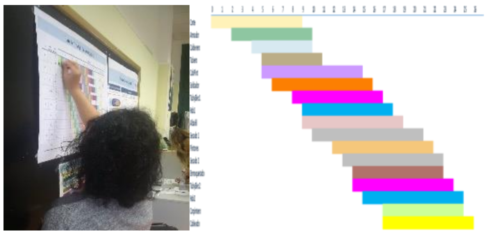

Figure 8: Monitoring the Progress of the Project During the Training Season (left) from a Planning Doing with the DES Simulation (right).

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