Model to Forecast Times and Costs of Construction of Ship Blocks

André Lopes de Oliveira  
*Instituto Superior Técnico, Universidade de Lisboa, Portugal*

ABSTRACT: Nowadays, European shipyards suffers serious pressure to implement automatization and alternative production processes in the construction sequence, in order to become more competitive in the global market. The trends towards the implementation of this new processes are risky and costly, hence it is important to make sure that a given proposal of new technologies implementation produce positive outcomes for the shipyard. A less correct implementation of new processes and technologies is possible and can be very harmful to the shipyard in terms of productivity and quality. The block production sequence is made by several phases of construction processes, all linked together, and the steel cutting, as well as the panel line, are key stages of the construction sequence. In this work it is studied both steel cutting and panel line process, divided into two different chapters, with particular focus on the industrial case study of the WestSea Shipyard S.A., in Viana do Castelo, Portugal. A program is also being developed to forecast times and costs of construction of ship blocks, for implementing the most advantage approaches into production of a block, in order to minimize the production time, thus becoming more competitive. Part of the aim of the program is the study of the panel line production, and its relation with the others block production phases.

1 INTRODUCTION

Today the mainstream ship production scheme is, undoubtedly, the construction by blocks. This type of construction allows a faster production flow, with better quality, mainly due to the possibility of the inside covered areas construction, and also due to the application of production lines of the different production stages (Storch, Hammon, Bunch, & Moore, 2007).

The main stages of the block construction sequence are shown in the Figure 1:

![Block production sequence main stages scheme](Image)

Figure 1 – Block production sequence main stages scheme

As one can see, the block construction sequence is a complex scheme of various stages, each one of them fundamental for an efficient and quality block production process. The present paper will discuss the steel plate cutting stage, as well as the flat panel line, individually, characterizing them and studying the consequences of the implementation of some small changes in the processes.

Till this day, the main cutting technology applied in the ship construction industry was, and continue to be, the oxy-fuel cutting. However new developments on the past few decades have turned possible the implementation in the shipbuilding industry of new technologies, like the plasma cutting, the laser cutting and the waterjet cutting.

Today the cutting processes implemented in the construction shipyard are a key factor in the important process of turning the shipyard into a more competitive company (Cahill, et al., 2000). The developments of newer and better cutting techniques and technologies allow also the implementation of new construction concepts and sequences (Guluwita, Faizer, & Dharmarathne, 2014).

In order to study the characteristics of the various cutting processes there are today at the disposable various published data, either studies or manufacturers product information, however it is very important to, as ever as possible, take the data from the real cases, in order to comprehend parallel events that are attached to the cutting process itself and can condition the activity. Hence, this paper portrays and process the data collected from some cutting activities during a ship construction in the WestSea Shipyards, in Portugal.

Like the steel plate cutting, the panel’s line is also a key phase of the construction of the block and an important production area in the shipyard.

The monitored panel line of this case study is restricted to stiffener welding, i.e., the web fitting and welding is done posteriorly in the block construction shop.

The panel’s lines were implemented in the European and Japanese shipyards in the 1960’s, in way to respond to the increased demand of very large crude carriers (Cahill, et al., 2000). Since then, the panel’s line was developing into a more flexible equipment, lower acquisition cost and higher productivity (Andritsos & Prat, 2000).

The characteristics of this construction stage make it very straightforward to apply the lean techniques, hence improving the production and its efficiency (Kolich, Storch, & Fafandjel, 2016).
2 CUTTING PROCESSES

2.1 Cutting process flow

Due to the presence of cutting process in the panel line work sequence it is understandable to be the steel plate cutting process the first to deal with in the present study. The data presented in the next chapters, although its differences, such as speeds and technologies applied, prove that both process sequences are similar and can be generically characterized by a flow chart scheme, divided in twelve stages, as presented in the Figure 2, although the present study is restricted to the analysis of the stages comprehended between the cutting preparation stage and the transport of the processed steel plates out of the cutting table.

Figure 2 – Generic cutting process flow chart

Need to stress the importance of the cutting technology on the post work manual beveling activities. This secondary work is needed in situations of oxy-fuel cutting machines that do not allow beveling of the steel piece, increasing drastically the man-hours needed to accomplish the final cutting process with the expected cutting characteristics and quality. Also in the gridding stage the cutting technology applied in the process is key to improving the process production, both total process time and man-hours, for example, the quality allowed by the plasma cutting technology grant much smaller times in the grinding activity stage, in a factor of three to one when compared to the usual oxy-fuel method (Hypertherm, 2016).

2.2 Oxy-fuel cutting process data processing

2.2.1 Oxy-fuel specific characteristics

The followed oxy-fuel cutting process, which belong to the panel’s line, present the listed characteristics:

- It is incorporated in the panel line flow, and because of that the possible bottlenecks in either previous stages or next stages of this production line present serious contingencies to the oxy-fuel cutting, e.g. reduction of the working force available to perform the cutting activity and, consequently increase the needed time to accomplish the work.

- The quite old age of the panel line oxy-fuel cutting gantry has visible consequences, like the fact that the CNC information for the process is physically transported to the machine, and sometimes the interruption of the process leads to “memory loss” and some work, like the steel marking must be repeated;

- Considering that the horizontal transport of the panel into the cutting area is not a preparation activity, other activities can be identified as that. Stabilize the panel with steels chocks in each corner of the panel is a job that can be performed either by one or two workers, the CNC information introduction in the cutting machine computer is a one-man activity, such like the monitoring of the process (both marking and cutting activities);

- The large dimensions to be cut in this panel line stage make important the possibility of interruption of the cutting process, because it can happen that the work to perform is not possible to finish during the work shift.

2.2.2 Oxy-fuel cutting speed and consumables

The oxy-fuel cutting process, incorporated in the panel line production, was studied only as function of the length, since all the panels monitored were formed of small thickness steel plates (5 mm and 6.5 mm) (check Table 1).

Before the cutting activity itself there is the panel’s marking, with propane as the main consumable. The linear regression obtained through a set of observations is shown the Figure 3:

![Marking time vs Marking Length](image)

The linear regression presented in the Figure 3 is given by:

$$T_m = 0.08L_m + 23.00$$  \hspace{1cm} (1)

where $T_m$ stands for the marking time, in min, and $L_m$ is the marking length, in m. Hence, the linear regression of the marking gives us a marking speed of approximately 6.0 m/min, being important to stress that it also includes the marking head movement to the various locations without being actually marking.
Through careful observation and measurements, the authors had obtained the speed of the marking action itself, being approximately 6.8 m/min. So, we can easily conclude that around 12% of the marking process time corresponds to the marking torch movements without being marking.

2.2.3 Oxy-fuel cutting process stages time distribution

The oxy-fuel cutting process is constituted of various stages, each one of them fundamental for a correct quality work. In Figure 6 is presented a pie chart of one panel cutting process example that illustrate the time division of the various stages of the complete process.

The data collected of the oxy-fuel cutting process, shown in the Figure 4, allows to build the followed linear regression:

\[ T_{of} = 3.42 \times L_c \]  \hspace{1cm} (2)

where \( T_{of} \) stands for the oxy-fuel cutting time, in min, and \( L_c \) is the cutting length, in m.

Applying the same analysis type to the cutting process, we take a process cutting speed of 0.31 m/min, and the oxy-fuel cutting itself present a speed of 0.41 m/min. Hence, 25% of the time is due to procedures other than cutting itself, e.g. movement of the cutting head and the pre-heat of the steel plate.

For future cost analysis studies is interesting to present the consumables data, that were obtained empirically by the shipyard in one of their automatic oxy-fuel cutting machine, shown in Figure 5:

The data from Figure 5 show different values of speed cutting for 5 to 6 mm thickness, when compared to the ones obtained from the Figure 4. This can be explained due to the fact of being data taken from two different oxy-fuel automatic cutting machines, and explained also on the basis that the cutting speed is not a ruled value, i.e., the speed can display fluctuations as function of the quality cut required and worker experience.

2.3 Plasma cutting process data processing

2.3.1 Plasma specific characteristics

The plasma cutting process present the listed characteristics:

- Although the plasma cutting gantry system only presents one cutting head with only one torch, this torch has a very wide movement range possibilities, so it can also perform beveling cutting works;
- The CNC nesting files are loaded in the machine’s computer trough the internal informatics share system. However, some problems were detected, like the fact of the requirement of conversion of a LANTEK made file to a specific CNC file extension compatible with the plasma cutting computer, and, sometimes, conversion errors occur, blocking the cutting work execution;
- The cutting operation is performed by two works, one introducing the CNC files in the cutting machine computer and also doing the monitoring of the cutting operation. Other worker is responsible for the triage activity of the previously cut pieces and also performs the steel plates transportation for the cutting table, with the aid of the shop’s gantry cranes;
- Although it is an air exposed plasma cutting process, the fumes resulting from the plasma cutting are exhausted under the table from one side of the cutting table, hence decreasing the health and safety risks.

2.3.2 Plasma cutting speed

The process of plasma cutting was also monitored. The works followed were diversified in various steel plate thickness, allowing to estimate the plasma cutting speed as function of the thickness, as seen in the Figure 7:
The collected data also allow to obtain a better understanding of the cutting costs related to the steel cutting process in shipbuilding.

Leal & Gordo (2017) conducted a study related to the shipbuilding distribution costs structure. One of the activities studied was the steel cutting process. However, only the stages of effective cutting were analyzed, leaving out other stages of the cutting process.

Through the data collected and presented in this paper the cutting costs structure can be completed, as follows:

\[
C_{\text{Cut Process}} = C_T + C_{\text{ACprep}} + C_{\text{AM}} + C_{\text{AC}} + C_{\text{DC}} + C_{\text{MC}} + C_{\text{MM}}
\]  

(4)

where

- \(C_{\text{Cut Process}}\) – Costs of the entire cutting process;
- \(C_T\) – Costs of the electric transport inside the shop;
- \(C_{\text{ACprep}}\) – Costs of the automatic cut preparation activity;
- \(C_{\text{AM}}\) – Costs of the automatic marking activity;
- \(C_{\text{AC}}\) – Costs of the automatic cutting activity;
- \(C_{\text{DC}}\) – Costs of the dimensional control activity;
- \(C_{\text{MC}}\) – Costs of the manual cutting activity;
- \(C_{\text{MM}}\) – Costs of the manual marking activity.

Leal & Gordo (2017) deduced the elements of the formula \(C_T, C_{\text{ACprep}}, C_{\text{AM}},\) and \(C_{\text{MC}}\). Need to say that the cost estimation associated with the cut preparation is identical to the cost estimation of generic work preparation.

Assuming the costs of the manual marking are only labor associated costs and that the cost of the consumables can be neglected, then the \(C_{\text{DC}}\) and \(C_{\text{MM}}\) elements of the sum presented in formula (4) can be merged as follows:

\[
C_{\text{DC}} + C_{\text{MM}} = n_m \cdot S_m \cdot (h_m + h_d)
\]  

(5)

where

- \(n_m\) – number of manual marking and dimensional control activities workers;
- \(s_m\) – Marking workers wage [€/Mh];
- \(h_m\) – marking time [h];
- \(h_d\) – dimensional control time [h].

The costs of the automatic marking activity, performed by the cutting machine, and monitored by the worker, can be given by the following formula:

\[
C_{\text{AM}} = [(n_{am} \cdot S_{am} \cdot h_{am}) + (K_e \cdot P_e \cdot h_{am}) + (K_p \cdot P_p \cdot h_{am}) + (C_d \cdot h_{am})]
\]  

(6)

where

- \(n_{am}\) – number of marking technicians;
- \(S_{am}\) – marking technicians wage [€/Mh];
- \(h_{am}\) – automatic marking time [h];
- \(K_e\) – electricity consumption [kWh];
- \(P_e\) – Electricity price [€/kWh];
- \(K_p\) – Propane consumption [kg/h or m3/h];
- \(P_p\) – Propane price [€/kg or €/m3];
- \(C_d\) – Cutting machine depreciation cost [€/h].

The linking of the present study and the study carried out by Leal & Gordo (2017), associating the cost estimation formulas present there with the time estimation formulas here developed, can be performed, allowing a faster and more direct understanding of the final costs of the cutting process, as function of the cutting technology.

3 PANEL’S LINE PRODUCTION

3.1 The current panel line

The current panel line here analyzed comprehends four main stages: plate butt welding; oxy-fuel cutting of the plate’s blanket; stiffeners fitting and tacking; stiffeners welding.
In Figure 9 is presented a scheme of sequence of workstations.

![Scheme of workstation’s sequence](image)

Figure 9 – Scheme of workstation’s sequence

### 3.2 Panels monitored

In order to study the production flow in the panel line, five different stiffened panels were monitored. All these five panels are different from each other, as we can see in Table 1, although all their steel plate have small thickness, usually five millimeters.

<table>
<thead>
<tr>
<th>Panel</th>
<th>Area [m²]</th>
<th>Number of steel plates</th>
<th>Stiffeners</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>31</td>
<td>3</td>
<td>$3 \times (8 \times 200)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$12 \times (6 \times 80)$</td>
</tr>
<tr>
<td>P2</td>
<td>87</td>
<td>5</td>
<td>$23 \times (6 \times 60)$</td>
</tr>
<tr>
<td>P3</td>
<td>145</td>
<td>5</td>
<td>$41 \times (6 \times 60)$</td>
</tr>
<tr>
<td>P4</td>
<td>117</td>
<td>5</td>
<td>$2 \times (8 \times 200)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$30 \times (6 \times 60)$</td>
</tr>
<tr>
<td>P5</td>
<td>26</td>
<td>4</td>
<td>$13 \times (6 \times 60)$</td>
</tr>
</tbody>
</table>

Table 1 – Characteristics of the monitored panels

In Figure 10 is possible to check the example of panel P2, one of the monitored panels.

![Stiffened panel P2](image)

Figure 10 – Stiffened panel P2

### 3.3 Panel’s line data processing

#### 3.3.1 Butt welding of the steel plates

The joining of the steel plates is done through a one-side submerged arc welding, thus avoiding the additional work of turn around the plate blanket and weld in the opposite side, hence obtaining significant less man hours required to perform the butt weld.

Previously to the welding process itself, it is important to consider the phase of align and tack weld the plates, whose data collected allow to dictate the following time formula:

$$T_{al},_t [\text{min}] = 0.7 \times L_p + 10.78$$  \hspace{1cm} (7)

, where the plate’s length, $L_p$, in $m$, stands for plate’s weld length. The data collected from the welding processes observed also allowed to build a linear regression, Figure 11, in order to obtain an expression of the time required for a given welding length, for thin steel plates.

![SAW time linear regression](image)

Figure 11 – SAW time linear regression

The linear regression presented in the Figure 11 can be expressed by the formula:

$$T_w [\text{min}] = 3.1x L_p - 6.9$$  \hspace{1cm} (8)

The formula above shown gives different speed for different length, what actually is acceptable, because the greater the distance to weld, the greater the possibility of events requiring to stop the process. It is important to stress that all the butt welding processes observed were for 5 mm thickness steel plates.

Other two phases of this workstation are important to take into account, namely the time required for the preparation of the weld and the post weld phase of checking the weld quality. The first operation is considered independent of the weld length, taking on average 20 minutes per welding. Although some of this
work of preparation can be done at the same time of the alignment and tack welding, this simultaneous period can be considered as being only 5 – 7 minutes. The quality control of the butt weld does not vary much with the weld length, taking the average value of 9 minutes.

For a weld length of 12 meters, and considering that a previous mechanical cut is not required, the expected time distribution of each phase of the butt weld process is show in Figure 12:

3.3.2 Marking and oxy-fuel cutting
After the butt welding of the total plates of the panel, the plates blanket is processed in the second workstation where it is marked and cut, by oxy-fuel technology.

In the precedent chapter 2.2 it was analyzed the oxy-fuel process, where the cutting process in the panel line sequence was discretized. The formulas for the marking speed and oxy-fuel cutting speed for small thickness (5 – 6 mm) are previously presented in equation 1 and 2.

Other phases of this workstation are also important to take into account: the work preparation, that is independent of the cutting length and is about half an hour; the manual marking, because the equipment do not mark text, is performed manually by a worker, taking usually no longer than five minutes; and the dimensional control of the final piece, that is made in 8 – 10 minutes. Considering this, is possible to illustrate the cutting process stages time distribution for the panel P2, as shown in Figure 6.

3.3.3 Fitting and tack welding the stiffeners
The third workstation is responsible for the manual distribution of the stiffeners, and is usually done by two workers. There are four main work phases in this station: distribution of the stiffeners according with the marking done in the previous workstation; attach the reinforcements with a first tack weld in each stiffener; tack weld the stiffeners along their length; dimensional angular control of the stiffeners, checking their perpendicularity.

According with the monitored work, the time spend on the reinforcements distribution do not vary much with its length, and consumes on average half a minute per stiffener of the panel.

The collected data of the second work phase, i.e., the first tack weld of the stiffeners, allow to create a function of the expected time of the first tack weld, in min, to the stiffener’s length, \( L_{st} \), in m, as presented in Figure 13:

The expected first tack weld time, \( T_{ftw} \), can be estimated by:

\[
T_{ftw} [\text{min}] = 0.2 \times L_{st} + 2.4
\]

By similar analysis, the third operation’s expected time in \( \text{min} \), i.e., the complete tack weld time, \( T_{ctw} \), along the stiffener, is given by:

\[
T_{ctw} [\text{min}] = 2.0 \times L_{st} + 2.0
\]

The last operation, checking the perpendicularity of the stiffeners, is a relatively fast work, taking in average 40 seconds per stiffener.

3.3.4 Welding the stiffeners
The last workstation of the panel line consists on the semi-automatic MAG welding of the stiffeners. The first phase is the welding preparation of the stiffener side without the tack welds, i.e., blow the dust in order to decrease the possibilities of dust contamination during the weld process. After the cleaning, the second phase is the MAG welding of the stiffener side without the tack welds. The cleaning of the surface and deburring the tack welds is the third operation. The fourth operation is the semi-automatic MAG weld of the side of the stiffeners where originally were the tack welds. Finally, the last phase of this workstation is the quality control of the welds and its correction, if required.

The first operation does not change significantly with the stiffener’s length, being on average performed in 5-7 minutes.
The second and fourth operations, i.e., the welding of both sides of the reinforcements, can be analyzed as the same action. So, performing a similar analysis like the ones before, it can be created a simple linear regression presented in Figure 15 and allowing to estimate the time required to MAG-weld, as function of the weld length.

\[
T_{MAG} = 1.4 \cdot L_{w} + 2.2
\]

where \(T_{MAG}\) stands for the MAG welding time, in min, and \(L_{w}\) stands for the welding length, in m.

The time required for the third operation, where the previous tack welds are deburred, can be estimated by the following formula:

\[
T_{tack \text{ deburring}} = 0.9 \cdot L_{\text{stiffeners}} + 1.9
\]

where \(T_{tack \text{ deburring}}\) is represented in min, and the length of the stiffeners, \(L_{\text{stiffeners}}\), is in m.

The last operation is the weld quality control and correction. Although its required time depends on the welder experience and many other parameters, it can be estimated by the following expression:

\[
T_{\text{quality check and correction}} = 0.9 \cdot L_{\text{stiffeners}} + 1.9
\]

where the time for quality check and possible corrections is given in min.

Figure 16 exemplifies with a seven-meter stiffener, its time distribution of each operation at this workstation is shown below.

3.3.5 Non-productive times

The previous analysis of the expected times for each one of the four workstations comprehend only the productivity times, i.e., do not take into account the periods that do not generate direct increased value on the product, in this case, the panel. These time periods can be exemplified with situations where the workers are waiting for the equipment availability, waiting for instructions, resting, equipment transportation, problems with the equipment, and other similar situations.

The following Table 2 presents the amount of non-productive time in each workstation although not all the global times of each workstation for each panel were available to collect, we can still build a table showing the amount of non-productive time in each workstation.

<table>
<thead>
<tr>
<th>Panels</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
</tr>
</thead>
<tbody>
<tr>
<td>W.S. 1</td>
<td>-</td>
<td>-</td>
<td>62%</td>
<td>71%</td>
<td>-</td>
</tr>
<tr>
<td>W.S. 2</td>
<td>-</td>
<td>17%</td>
<td>45%</td>
<td>6%</td>
<td>23%</td>
</tr>
<tr>
<td>W.S. 3</td>
<td>59%</td>
<td>32%</td>
<td>33%</td>
<td>34%</td>
<td>-</td>
</tr>
<tr>
<td>W.S. 4</td>
<td>22%</td>
<td>55%</td>
<td>38%</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The values not shown indicate situations where it was not possible to collect the total times, or these were not feasible.

The values presented allow to conclude that, clearly, the first workstation, where the steel plates blanket is assembly, is where the non-productive time is larger. The workstation where less time is spent with non-productive activities is the marking and oxy-fuel cutting workstation. The stiffener related workstations have both a similar average of 40% time of non-productive time.

4 NEW PRODUCTION PROCESSES ANALYSIS

In order to study the consequences of possible processes changes in the block construction process, a program was developed allowing to analyze the consequence of implementation of different production technologies in the block production stages. With such program type, the cutting process and the panel’s line production can by studied.

4.1 Implementation of alternative cutting technologies

In order to run the developed program and analyze the results as function of the technologies specified, one needs to characterize in the program the blocks to study. For the present analysis, it was studied two blocks: The Block A, shown in Figure 17, belongs to a pontoon, with a length of 20.78 m, breadth of 9.86 m and depth of 1.42 m, with 41 tons. The Block B, illustrated in Figure 18, is a midship double bottom block of a chemical tanker, with a length of 10 m, breadth of 13 m, and depth of 1.5 m, with 47 tons.
For the analysis of the different cutting technologies, four situations will be studied:

- **Situation 1** – All the cutting processes are performed through oxy-fuel cutting;
- **Situation 2** – The panel line cutting stage and profiles cutting are execute with oxy-fuel, and the steel plates cutting process, to generate pieces, is performed by plasma cutting. This is actually the most similar situation when compared to the actual WestSea Shipyards S.A. production process.
- **Situation 3** – All the steel cutting processes are performed through laser technology;
- **Situation 4** – All the steel cutting processes are performed through abrasive water jet technology.

The time and cost values obtained by running the developed program are presented in Table 3:

<table>
<thead>
<tr>
<th>Block</th>
<th>Situation</th>
<th>Cutting processes</th>
<th>Assembly and welding processes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Time [days]</td>
<td>Cost [€]</td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>24.5</td>
<td>3017</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>21.0</td>
<td>2656</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>19.9</td>
<td>4469</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>29.0</td>
<td>8371</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>11.4</td>
<td>1836</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>7.3</td>
<td>1428</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>7.1</td>
<td>1965</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>16.9</td>
<td>6917</td>
</tr>
</tbody>
</table>

Table 3 – Cost analysis on the implementation of different cutting technologies

**Cutting, assembly and welding costs of block A**

<table>
<thead>
<tr>
<th>Situation</th>
<th>Cutting, assembly and welding costs [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Situation 4</td>
<td>8371</td>
</tr>
<tr>
<td>Situation 3</td>
<td>4469</td>
</tr>
<tr>
<td>Situation 2</td>
<td>2656</td>
</tr>
<tr>
<td>Situation 1</td>
<td>3017</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Situation</th>
<th>Cutting, assembly and welding costs [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Situation 4</td>
<td>6917</td>
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<tr>
<td>Situation 3</td>
<td>1965</td>
</tr>
<tr>
<td>Situation 2</td>
<td>1428</td>
</tr>
<tr>
<td>Situation 1</td>
<td>1836</td>
</tr>
</tbody>
</table>

Figure 19 – Cutting costs, in [€], of the implementation of different cutting technologies in block A

Figure 20 - Cutting costs, in [€], of the implementation of different cutting technologies in block B

Needed to say that the calculations were conducted in a way that the differences presented in the various assembly and welding phase time and cost values are only justified due to the decrease of the gridding stage (see Figure 2), due to the increase of cutting quality that the several cutting technologies allow. Analyzing the results is possible to comprehend that although some decrease in the assembly and welding cost values, whose cost savings are mainly due to the reduce man-hours needed in the gridding process, are not so large as one would expect, reaching the most, at a value of 5%. This cost saving due to the reduction of work in the gridding phase do not justify per himself the increase of the cost of the cutting technologies with better cutting quality. However, is important to stress that a better cutting quality also allows important improvements in the dimensional control, decreasing possible re-works or corrections in the assembly and welding stages, although those savings are hard to estimate and, by that reason, were not consider in the developed program.

Considering only the analysis on the cutting costs values, the values obtained are in line with the actual industry of the construction shipyards, where the plasma cutting is the more attractive technology. The cutting speed of the plasma saves precious man-hours, hence balancing its higher operational costs when compared to the oxy-fuel technology and even obtaining cost savings.

As expected, the high operational costs of the laser and the low cutting speed of the waterjet cutting do not, yet, allow to present that technologies as economically feasible for its large-scale implementation on the ship production process.

### 4.2 Implementation of alternative technologies in the panel line

For the panel line sequence production, it was developed a different program of that used in chapter 4.1, this small and rather simple program is specific for the study of the panel’s line. The panel’s line analysis allows to realize an integrated study of all the production sequence workstations.

#### 4.2.1 Implementation of plasma technology in the cutting workstation

Applying the collected data of the earlier chapter 3 is possible to understand its effects on the integrated panel’s line production, through outputs of the program, as is shown in Figure 22.

The first study on panel’s line production is related with the possibility of implementation of plasma cutting technology in the second workstation. The analysis will deal with the production of the five panels summarized in Table 1. The results of such implementation can be sum up in Table 4:

<table>
<thead>
<tr>
<th></th>
<th>With oxy-fuel cutting</th>
<th>With plasma cutting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total production time of the panels [days]</td>
<td>15.3</td>
<td>14.1</td>
</tr>
<tr>
<td>Total cutting time [hours]</td>
<td>81.3</td>
<td>66.0</td>
</tr>
<tr>
<td>Total cumulative waiting times between workstations [hours]</td>
<td>163.4</td>
<td>144.3</td>
</tr>
</tbody>
</table>

Table 4 – Implementation of plasma cutting
The above values show a positive earning on the production flow, namely the shortened period needed to perform the construction of the five panels, a difference of more than one day. The smaller waiting times due to bottlenecks is also important, decreasing periods of non-productive of the panel’s line workers due to the congestion of the production flow.

4.2.2 New solutions for the 3rd and 4th workstations

Despite the current activity of the stiffeners fitting is very obsolete when compared with process implemented in the today’s state of the art building shipyards, we will firstly maintain it and analyze the consequences of the implementation of new solution on the stiffener welding workstation.

![Parallel weld carriage, and single weld carriage](image)

Although the stiffener mounting and welding gantry systems can be a very complex transformation on the panel’s line, carrying considerable sum of investment, other solutions are cheaper and more flexible, like the implementation of parallel stiffener automatic welder, instead of the single side welder currently used.

Despite some not very significant procedures differences, we can consider that the welding rate will be the two times faster with the parallel automatic stiffener welding. Assuming the new welding speed, the next table displays the time values differences between the original stiffener welding situation and the parallel welding solution. Important to stress that the others workstations remain without alterations (current SAW welding, oxy-fuel cutting, manual stiffener tack welding, etc…).

<table>
<thead>
<tr>
<th></th>
<th>Current stiffener welding process</th>
<th>Parallel stiffener welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total production time of the panels [days]</td>
<td>15.3</td>
<td>14.0</td>
</tr>
<tr>
<td>Total stiffener welding time [hours]</td>
<td>83.1</td>
<td>68.5</td>
</tr>
<tr>
<td>Total cumulative waiting times between workstations [hours]</td>
<td>163.4</td>
<td>148.2</td>
</tr>
</tbody>
</table>

Table 5 – Implementation of parallel weld carriage

Even though some important time reducing on every item was accomplish, the time reduction of the stiffener welding station in only 17%, justified on the percentage of the other phases of this workstation, shown in Figure 16.

The trend of increased automation of the shipbuilding processes also apply on the panel line stage. The current state of the art European building shipyards leaders had successfully implemented automatic panel’s line. Although in most cases all the line is fully automated, we will limit the study on the installation of fully automated production in workstations 3 and 4. The installation of fully automated process would merge the 3rd and 4th workstation in one single stage.

![Panel’s line production, in original shipyard situation](image)

![Panel’s line production, due to the implementation of a fully automatic stiffener fitting and welding](image)

Figure 22 – Panel’s line workstation distribution times, in minutes
For this study, it is considered a twice as fast tack welding process (Mun, et al., 2015), through an automated system to place and tack weld the stiffeners, and a four times faster stiffener welding, considering a parallel system torch, able to weld on both sides two stiffeners simultaneously (Santiago, 2012).

Table 6 presented values show significant gains on the period needed to conclude the construction of the five panels. However, the most important concerns the huge decrease on man hours needed to build the panels.

<table>
<thead>
<tr>
<th>Current stiffener fitting welding</th>
<th>Automation of the 3rd and 4th workstations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total production time of the panels [days]</td>
<td>15.3</td>
</tr>
<tr>
<td>Sum of 3rd and 4th workstation activity time [hours]</td>
<td>1113.3</td>
</tr>
<tr>
<td>Total cumulative waiting times between workstations [hours]</td>
<td>163.4</td>
</tr>
</tbody>
</table>

Table 6 – Implementation of fully automatic

Through a fast analysis of the scheme of Figure 22, that presents the workstation distribution scheme of the situation where the 3rd and 4th workstations were automated, one can easily realize that the new system of fitting and welding of the stiffeners is not being fully used due to the long period of the oxy-fuel cutting process. Hence concluding the importance of the considerations of the integrated factor of all the workstations while doing an improvement project of the panel’s line, avoiding to undergo on a great improvement on only one of the workstation without considering the production flow weight of the other ones.

5 CONCLUSIONS

The steel plate cutting process and the panel’s line are crucial stages of the block construction in the shipbuilding process, assuming a decisive factor in the entire flow production. The case study carried out and presented on the first part of this paper aimed to serve as a reference and tool on the optimization process of both production phases.

On the subject of steel plate cutting, the case study presented in this paper, although rather simple, takes a significant value proving the higher cutting speed of the plasma technology, when compared to oxy-fuel cutting. The studies already taken when comparing oxy-fuel and plasma cutting find their certification in this case study, relatively to the value of five times faster process of plasma cutting (GmbH, 2005) (Gordo, Carvalho, & Guedes Soares, 2006).

Although the analysis done in the second chapter of this paper prove the higher cutting speed and quality of the plasma cutting, their implementation in the shipyard should be previously studied, analyzing its role in the block production flow, such as the one implemented in the fourth chapter. This analysis had proven the advantages, mainly from the cost analysis point of view, of the plasma cutting technology, when compared to the more traditional oxy-fuel cutting process. The laser and water jet cutting technologies still present unattractive costs, considering the results obtained in the developed program.

Concerning the panel’s line, as it is show in the second part of the study, small changes on the workstations may have significant improvements in the flow production, e.g., the implementation of a welding carriage able to do a parallel welding on both sides of the stiffener, instead of the current single side welding carriage.

The analysis of implementation of different solutions on the panel’s line presented also showed that the proposed changes in the production line must be analyzed as a whole, instead of the assumption of individual workstations, independent from the other ones.

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REFERENCES


