More Checks for Less Waste in the Lamination Process of a Shipbuilding Company Pursuing Lean Thinking

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Abstract. Lean Thinking is a management philosophy that aims to do more with less through a process of continuous improvement. By employing Lean Thinking principles, the project presented in this article aimed to obtain improvements in the boats' hulls and decks lamination process of a shipbuilding company. After analysing the current process, some problems were identified. To solve these problems, suggestions were developed, such as the use of checklists, the introduction of quality checkpoints along the production line and a VBA tool for the correct management of the dies. Through the implementation of the suggested proposals, it was expected a decrease in the number of defects and a reduction of the bottleneck cycle time from 90 to 20 minutes. Interesting findings of this project were that the improvements implied more quality checkpoints in the process, what seems contradictory as checkpoints are considered as non-value activities. This was a remarkable lesson learned by the team of Industrial Engineering and Management students that developed this project in the context of Project-Based Learning active methodology.

Keywords: Lean Thinking, Shipbuilding Industry, Project-Based Learning, Industry-University partnership.

1 Introduction

In an increasingly technological world, the competitive capacity in the business environment is one of the differentiating factors between the success and failure of the business. Thus, companies increasingly pursue new approaches to change the management paradigm by changing the usual cost-based thinking to a speed-based strategy.

Lean Thinking seeks to reduce waste, especially the time of activities that do not add value to the process from the point of view of the client [1]. This goal can be achieved by reducing the 3M's: *muda*, *mura* and *muri*. This reduction in 3M's, however, considers crucial aspects in the industry, such as the possibility of producing customized products responding to customer needs. In the context of the non-value-added activities, it is important to distinguish two types: the ones that are pure waste as waiting and the ones that do not add value to the product but are necessary attending to the current situation of the process, as quality inspection [2]. For such identification and wastes reduction, many tools could be used such as value stream mapping (VSM), visual management, standard work, *jidoka* or *autonomation*, checklists, among others [3].

The project presented in this paper aimed to improve the lamination process of a production line in a shipbuilding company, through the implementation of Lean Thinking principles. This project was developed in a company from September 2020 to January 2021 by a team of eight Industrial Engineering and Management (IEM) students in a context of Project-Based Learning (PBL) active learning methodology. This methodology was used in a course named Integrated Project of Industrial Engineering and Management II (IPIEMII). The IPIEMII was supported by five courses: Production Systems Organization II, Simulation, Ergonomics Workplace Analysis, Integrated Production Management and Production Information Systems [4]. The team was supervised by a tutor. The company under study is a leader of the production of the leisure vessels market.

This paper is structured in six sections. After a brief introduction, where the objective of this study is introduced, it is described the methodology followed in the second section. The third section is related to the company's presentation, followed by the analysis of the current situation. The proposed improvements are presented in the fourth section and the expected results in the fifth section. Finally, the lessons learned are described in the sixth section.

2 Research methodology

As referred to in the introduction, this research was developed by a team of eight IEM students in the context of PBL active methodology. After a first meeting with the company, the visits plan, and the sector to analyse were defined. All visits included *Gemba* walks, observation and informal interviews with all stakeholders [2]. For team communication and document repository sharing between members, professors, and company representatives, many tools were used, including video-conferencing tools due to the pandemic situation that ravages the world since 2020, March [5]. This had an impact on the team organization and in the visits to the company, as fewer team members were allowed to visit the company.

In order to follow a structured approach, the team used the phases of the Action-Research methodology: 1) Diagnose, 2) Plan alternatives actions, 3) Implement the action selected, 4) Discuss and analyse the results and 5) Specify the lessons learned [6]. Given the limited time and the availability of the company, the implementation phase was not fulfilled and, therefore, the results were estimated.

In the first phase of diagnosis, the current state of the lamination process was analysed, and the existing problems were identified with VSM to obtain an overview of the process. The company's quality reports were also used to understand the most frequent type of defects throughout the production process. In the second phase, an improvement plan was drawn up to overcome the difficulties and problems identified in the previous phase. To achieve this, Circular and Pareto charts were used and analysed.

Other visual production tools, checklists and computing tools, such as Visual Basic for Applications (VBA) were also used. Changes to the production line were suggested, such as the introduction of new quality control points. In the lessons learned phase, the expected results and the main conclusions were identified, and new challenges were indicated to the company.

3 Company presentation, description, and critical analysis of the current situation

The company was created in 1845 and evolved until later becoming a world-renowned company. It is a leader in recreational boats, engines, accessories, and other marine vessel components. The company currently operates in 24 countries and its products are sold in more than 170 markets around the world. The Portugal-based company is currently dedicated to the manufacture of rigid vessels in fiberglass, which requires the successive application of fiber and resin.

The Portugal-based company currently has about 500 employees, producing a total of 30 different boat models with a daily production capacity of 10 boats. The production lines are supported by sections such as carpentry, small parts, and pre-assembly, which produce the necessary components for the main production process. It begins in the Lamination section and ends in the Assembly, followed by a quality inspection, packaging and dispatch. This company usually works in a make-to-order strategy producing by demand. The pandemic situation had a positive impact in the company demand since it increased due to the travel restrictions that expanded the boat market.

3.1 Description of the lamination process

Lamination is the production process of the boat's hull and deck, through the successive application of layers of fiberglass and resin, to increase its mechanical resistance. This process is performed in a section with the same name, i.e., Lamination section, and it is divided into two production lines: 1) for the hull (bottom of the boat) and 2) for the deck (top of the boat). All the supply to the lines come from the support sections (carpentry and small parts) and it is carried out using only one cart for each, which is left in one of the stations and then follows its hull or deck.

The process begins with the Dies Preparation, through its cleaning and application of wax. It continues with the Gelcoat Application (paint layer applied in the painting booths). These operations are common to both parts, with a painting booth for the hulls and another for the decks. After painting, the process is divided into the two lines mentioned above.

The line of the decks has the following workstations: P1 - Skin, P2 and P3 - Stiffen and P4 - Structures. As the deck line, the hull line begins with the Skin process, but in this case at P5 workstation. This is followed by the P6 workstation - Lams, P7 - Foams/Stringers and P8 - Foam lamination and Wood installation.

Later, after the end of its respective line, each part is transported to the demould zone (Pop-Up), where there is only one line. The parts then proceed to the Cutting Booth.

After the cutting operation, the parts proceed to a Quality Control station, where, if there are any defects, these are to be repaired in the Repair station localized in the Lamination section and then proceed to the next production process.

3.2 Identified problems and wastes

A VSM was developed to represent the production of the hull and deck since its operations differ slightly. It should be noted that all the data and values used were provided by the company. For both VSMs, the system's cycle time (CT) was 90 minutes. The takt time (TT) was 96 minutes, fulfilling the requirement that CT ≤ TT.

For both hull and deck's activities, the percentage of added-value activities was significantly low, being 28% and 34%, respectively. An activity that represented, in a negative way, a great weight in these values was the activity performed in the Repair station (the last station of the process). This activity had a high number of operators (47 in a total of two shifts) and did not add value to the final product. Nevertheless, it represented a waste, and it was one of the main causes for the CT to be very close to the TT since it was the bottleneck of the system.

The VSM also proved to be a useful tool for determining the throughput time. Throughput time is the time that a hull or deck takes to go through the lamination process, corresponding to 700 minutes (≈ 12 hours) and 795 minutes (≈ 13 hours).

The high number of defects. Due to the results of the VSM, it was decided to analyse the defects caused throughout the process, the areas where they were most significant and the operations that originated them. Through the analysis of audits and quality reports carried out by the company, it was identified in which station the defects usually appear. Unequivocally, it was concluded that most of these were located in the Repair station. Through several graphs, provided by the company, presented in Fig. 1 (period of 6 months), it was possible to verify that the Repair station had an average of 120 defects per unit (DPUs), a value much higher than the other sections.

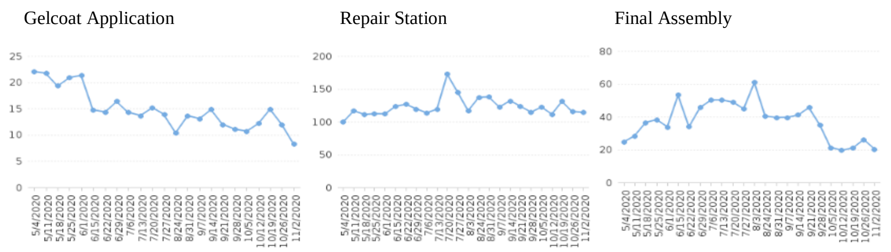

Fig. 1. Number of defects per unit found at different stations.

It was decided to examine more accurately the defects found at the Repair station. As it was determined, there were several possible sources of defects, and the one that stood out with the highest number was the dies (Fig. 2), which had an average of 20 DPUs. According to these data, particular attention was given to the dies as a source of defects. It was found that some of the most frequent and severe defects, originated due to the dies problems, with the appearance, in parts, of ledges, scratches and dull areas or stains.

Thereafter, it was found that the appearance of defects arising from the die was directly related to the non-compliance with the maintenance of the die at the due time. The lifetime of the dies was about 20 uses, and after this, they should go through a process of maintenance, which takes three days.

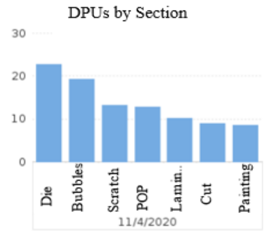

Fig. 2. Daily analysis illustrating the number of defects per unit originated by different sources of defects.

The company counted the number of uses of each die manually and, thus, the number of uses of the die was not considered in the production planning. As a result, dies were used as often as planned productions (although this means that the 20 recommended uses were exceeded), and a stop period was not planned for their maintenance at the correct time.

It is important to highlight that in the company there was no system for the identification of components. This contributed to the possible appearance of defects. These were related to the wood components with similar geometries and sizes. Consequently, it caused the risk of the wrong installation in the hull and deck since operators had difficulties in distinguishing the components from each other.

Checkpoints scarcity along the line. The high number of defects was also due to the lack of control points along the line of the lamination process. All defects were only detected in the Quality Control Repair station, as already mentioned. In addition, it was missing the application of tools available for this purpose in the workstations.

4 Improvement proposals

4.1 Boat division in quadrants, colour code and components coding

Considering the situation of a single supply cart to the lines, it was decided to modify the supply of components to them. This way the components would be delivered to the workstation where they must be. Each station had a significant variability of components, so, to facilitate the work of the operators, a division of the boat into quadrants was proposed, assigning a colour to each one by creating a colour code (see Fig. 3), i.e., using visual management. This way, the supply to each workstation would be performed through coloured boxes, each representing the quadrant where its contents would be applied. The division in quadrants was carried out considering the technical drawings of the hull and the deck, to make clear the need for components in each part of the boat and to make a more equitable division.

To circumvent the lack of identification of the components, it was suggested to assign a code to each component. This code should be printed on each component using the existing CNC. It should be noted that it would also be beneficial to include in its codification the quadrant where the component will be installed.

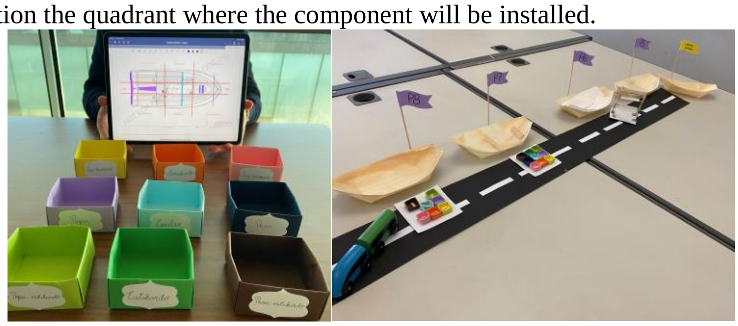

Fig. 3. Physical representation of the hull and deck division in nine quadrants and colour code (left) and its use in the production line (right).

Demonstrating this physical representation to the company's production director, he referred that it had been something he desired for a long time. By having this physical representation in a visual format, he was more motivated to present it to his team in order to get more support to implement the idea.

4.2 Implementation of checklists

Regarding the large number of defects in the vessel components, resulting from the non-use of the thickness gauges of the Chop layers (fiberglass + resin), it was suggested to implement checklists. Thus, with the inclusion of measurement tools used in a possible lamination process' checklist, not only its use would be guaranteed, but also many of the defects would be avoided promptly. This was due to the fact that the main benefits of this tool are the reduction of variability and/or irregularity (*mura*) and the prevention of recurrent errors.

4.3 Introduction of checkpoints along the line

Since there was only one checkpoint at the end of the lamination process, the team proposed the inclusion of control and repair points throughout the production line to reduce the high number of defects, the reparation time and the number of employees required in the Repair station.

In the past, it was normal to have assembly lines with a final checkpoint in the end of it. Nevertheless, Toyota Production System (TPS) revealed the need to have mechanisms along the process to stop the line when something goes wrong [7]. This is the main objective of one of the most important pillars of TPS, i.e. Jidoka or *autonomation*. Having more checkpoints seem contradictory to the key idea of "doing more with less" that was the motte for the Lean Production designation to TPS [8]. However, having them will avoid having more defects and lost time in reparations and rework and, even, lost material by sending the unrepaired product to scrap.

Since most of the errors that occurred in the first stages of the process were solely corrected at the end of the line, with the implementation of a checkpoint in each workstation, it would be possible to do each repair in less time, since it would not be necessary to redo all the work that had been done. With this measure, it would also be possible to change the Repair station, turning it into just another control point for the cutting operation.

4.4 Dies maintenance guarantee

Related to the appearance of a high number of defects in the hulls and decks, it was developed a VBA code for the correct management of the dies. Thus, a spreadsheet tool was developed that is represented in Fig. 4. This spreadsheet allowed the validation of a production sequence introduced by the user, considering the limit of 20 successive uses for each die. In this way, it was also considered the required maintenance period of three days, as well as the current number of uses of each of them.

Validate Production Sequence

Clean Sheet

Day	Model	Production Line
39	T59	B
39	555OP	A
39	675OP	A
39	T53	B
39	605OP	A
39	555CAB	A
39	675PH	C
39	605BR	B
39	505CAB	A
39	D65	B
40	675SD	A
40	675WE	C
40	D59	B
40	875SD	D
40	S45	A
40	605PH	C
40	555OP	A
40	675OP	A
40	T59	B
40	555OP	A
41	T53	B
41	605OP	A

Boat	Die 1		Die 2		Die 3		Die 4	
	Number of Uses	Number of Maintenances	Number of Uses	Number of Maintenances	Number of Uses	Number of Maintenances	Number of Uses	Number of Maintenances
D59 / S59 / T59 / 605BR / 605CR	20	1	20	1	20	1	20	1
S65 / D65 / T65 / 675BR / 675CR	24	1	20	1	20	1	-	-
505OP / 505CAB	20	1	20	1	15	0	1	0
555OP / 555CAB	24	1	20	1	20	1	20	1
605OP / 605SD	20	1	20	1	9	0	1	0
675OP / 675SD	20	0	21	0	1	0	1	0
S53 / T53 / 555BR	40	2	20	1	20	1	-	-
455CAB	1	0	1	0	-	-	-	-
455OP	12	0	1	0	-	-	-	-
605PH	20	1	4	0	-	-	-	-
675WE / C70	20	1	16	0	-	-	-	-
755OP / 755SD	20	1	5	0	-	-	-	-
16EL	11	0	1	0	-	-	-	-
18EL	20	1	1	0	-	-	-	-
675PH	16	0	-	-	-	-	-	-
805SD	6	0	-	-	-	-	-	-
875SD	20	1	-	-	-	-	-	-
705PH	4	0	-	-	-	-	-	-
755CR	1	0	-	-	-	-	-	-
625PH	1	0	-	-	-	-	-	-
D70	1	0	-	-	-	-	-	-

Fig. 4. Excel excerpt of VBA code for the correct management of the dies.

Regarding the limitations of this program, the user needs to re-enter all the data and run the program again if any changes arise within the production sequence entered, which is not desirable. These changes might resulted from adjustments caused, for example, by production delays or delays in the maintenance period of the dies. Additionally, the time from which it was necessary to replace the dies, since it was no longer possible to perform further maintenance, was not considered.

5 Expected results and impact of the proposals

5.1 Results

Easier identification of components, fewer defects and less time. The division of the boat, and, consequently, the hulls and decks as well as the adoption of a colour code, would allow an easier differentiation and identification of the different components. Also, it would facilitate the work, reducing the search time by the operators. Another advantage would be the possibility for each operator, per station, to take the box destined to the area of the boat where he is working.

In addition, the division into quadrants and the fact that the components contain their code (including the quadrant where they will be installed) previously printed by the CNC, would also allow to increase the accuracy of the place destined for each component. This is an extra aid, both to the employees of carpentry when dividing the components by the different boxes, and to the workers of the Lamination section in the identification of the exact location of the boat where each one must be installed. Thus, the hulls and decks' defects number of components would decrease. In consequence, it would be required less time and tools for the rework related to these defects.

Reduction of variability and error prevention. The implementation of checklists in the different stations of the lamination process could guarantee the use of the tools for measuring the thickness of the layers of fiberglass and resin by the operators, ensuring that they had the ideal thickness. In this way, it would be possible to avoid promptly many of the defects caused by the irregularity between layers. The checklist should be reviewed with some frequency in order to identify future improvements.

Fewer defects and repair time. The inclusion of control and repair points along the different workstations in the production process would allow defects to be repaired immediately after the execution of the operation that originated them. Thus, the Repair station, which was the bottleneck of the Lamination section, would be no longer the only control point of the process. In this way, the time previously spent for rework at this station would be reduced considerably. Furthermore, it would not be necessary to redo the work of all workstations following the one where the defect occurred, as was the case.

The implementation of a checkpoint at each workstation involved adding a few minutes to the time of each operation. However, as already mentioned, the time of the last inspection would be substantially reduced, and the Repair station could be changed, becoming just another control point. In this case, it would correspond to the control point of the Cutting Operation, and it would also be used for a final review of the entire hull or deck.

The number of operators required for intermediate inspections, would not undergo major changes. Due to the unevenness between the cycle times of each workstation, the "dead time" could be used to carry them out, so it would only be necessary to train the employees. The number of workers required for the final inspection would be reduced by 75%, as it would suffer a decrease in time and difficulty.

Reduce the appearance of die problems. Ensuring that dies were maintained before or at 20 consecutive uses and that they complied with the stipulated duration of three days, it would be possible to reduce substantially the appearance of die problems. In addition, it would be important to consider this situation when planning the production schedule. In this way, the various defects that arise from their poor state of conservation would also decrease.

Since dies flaws were the main source of defects in the hull and deck, this solution would have a notorious impact on reducing the defects number. Consequently, all the problems that came from this, namely the number, time and operators destined for the Repair station, which was a non-added value activity, would also be reduced.

5.2 Impact

The improvement proposals' impact was estimated based on the experience and knowledge of the company managers and operators. Regarding the division of the boat into quadrants, creation of the colour code and coding of the components, it was estimated that the CT of this station would decrease in about 10 minutes due to the easier task to collect components out of boxes and identify their position in their hull or deck.

Furthermore, the suggestion to create checkpoints after the execution of each activity would have an impact on the CT of the remaining activities increasing them in about five minutes. It should be noted that "dead times", when necessary and if possible, would also be used to include the new inspections.

Concerning the Repair station, the number of operators would reduce about 75% and the time required for its execution would be about 20 minutes. Nonetheless, the last quality inspection must be done to control the components that came out of the Cutting Booth. This quality inspection also must ensure that the defects originated by the previous tasks were corrected and fully identified and eliminated. The creation of checklists for the use of measurement tools and the guarantee of maintenance of dies at the correct time would reduce the number of defects. This would have an impact on the estimated times. With this awareness and attending to the Industry 4.0 technologies, such checkpoints should be integrated in the lamination process as making part as a more integrated project that promote modern *Jidoka* systems [9].

Regarding the hull production, the system's CT would decrease from 90 to 55 minutes, creating a higher difference for TT. This means that the Repair station would no longer be the bottleneck of the system. The uptime of the different activities would also increase, as would the percentage of activities that add value (from 28% to 30%). The value stream of the decks would also suffer similar changes, regarding the uptime of some activities, which would be higher, and the percentage of activities that add value, which would also be increased (from 34% to 36%).

Finally, it was possible to verify that the throughput time would decrease from, approximately, 12 to 11 hours in the hulls case, and from, approximately, 13 to 12 hours in the decks case, representing a significant improvement in comparison to the initial situation.

6 Conclusion

This paper reports a project that was developed in the context of the PBL developed in the course IPIEMII by a team of students in a shipbuilding company. Lean Thinking principles and tools were implemented to improve the manufacturing sector of two critical components of the final product – hulls and decks, through the reduction of *muda*. The main waste identified was the high number of defects, whose reparation required a considerable amount of time and manpower. To reduce this number and, consequently, the repair time and workers need, it was proposed, among others, more checkpoints along the line. This could be seen as contradictory to Lean philosophy.

The expected benefits of implementing the mentioned proposals were estimated and discussed with the company. The expected success will depend on the company's need to continue pursuing the goal of zero defects, focusing on the reduction of *muda*. In addition, it was necessary to consider the aspects related to *muri* and *mura,* so that the quality of the product and the performance of the production process were even more valued.

For the company, it was a beneficial experience as the company was not aware of Lean Thinking principles and its potential to improve processes. This project was the beginning of a Lean journey in the company, that started by recognizing the value and wastes concept and applying basic Lean tools to achieve good results. For the students, learning by doing was a rich experience and an opportunity to apply the course contents immediately after or, even, before the classes. As future work, it was advised to the company to implement the proposals not yet implemented and the integration of a Smart Manufacturing System.

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