Application of Lean Manufacturing methodologies in the maintenance of aeronautical components

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Abstract

The presence of increasing competitiveness in the aeronautical sector forces different companies to develop strategies and move forward to get ahead of their competitors. To do this, it is necessary to reduce unnecessary costs that do not add value to the final product. It is here that the Lean methodology is born, which is based on finding the different waste that can be in any situation, to finally eliminate them by different techniques.

Following the principles of this methodology, it is intended to reduce the time it takes for engines to be repaired in OGMA, as there will be an increase in the volume of engines received and it becomes necessary to achieve that forecast. To do this, are analysed which activities are those that currently have a higher lead time and it was concluded that they were those that were part of the repair processes. An analysis was then carried out to check which engine parts were the most critical considering different criteria such as the time it took to repair them, their probability of being repaired and their final assembly order in the engine.

Once these parts were identified, their respective repair flows were carried out by the different work centres to identify the bottlenecks in said processes. Once identified, various solutions were proposed to eliminate them, resulting in a reduction of approximately 70% in waiting hours.

Finally, with the completion of this thesis and the results obtained, is highlighted the importance of applying lean methodologies in companies to reduce costs and stay in competitive positions.

Keywords: Lean Manufacturing, wastes, bottlenecks, engines, maintenance.

1. Introduction

Globalization is a tangible phenomenon in recent years, being a dynamic process of increasing freedom that has facilitated the global integration of different labour markets, goods, services, technology and capital. This wave of continuous change has forced companies to develop and implement new organizational and production techniques that allow them to survive and evolve in the face of incessant business competitiveness, the changing mentality of customers and the instability of demand.

That is why, in order to get to the forefront in an increasingly competitive aeronautical market, the implementation of Lean Manufacturing’s ideas and principles is gaining importance, whose objectives are focused on customer needs and try to eliminate all actions that do not add value to the product.

Therefore, the main motivation of this project is to try to improve the efficiency of the entire maintenance process of the different engines repaired in OGMA, implementing Lean strategies based on continuous improvement, in order to increase the competitiveness of the company in the aeronautical market, whose vision is to increase the volume of engines that repair annually. For this reason, the following actions will be carried out:

- Analysis of the maintenance processes of the different components to discover potential improvements;
- Propose improvements using Lean tools to eliminate waste;
- Reduce the TAT of the engines to cope with the increase in future volume.

2. Literature Review

2.1. Lean definition

Lean Manufacturing can be defined as “a systematic to identify and eliminate waste, which are those activities that do not add value to the product, and it could be possible through continuous improvement of the product flow in the customer pull, seeking the perfection” [5].

This process management philosophy stems from Toyota and is the means by which processes are
managed synergistically, providing immediate feedback on efforts to turn waste into value [1]. There are three types of waste: Muda, are those activities that consume resources without creating customer value; Mura is defined as any unforeseen variation that produces process irregularities and causes imbalance; Muri, this term refers to the overload of equipment or operators [6].

The Lean Manufacturing philosophy is based on a series of principles to achieve your goals. These principles are the followings [1, 8]:

1. Value. Specify correctly what adds value in the product or service to the customer.

2. Value chain. Identify all steps in the value stream for each product family and remove those steps that do not create value.

3. Create flow. Make the value-creation steps take place in tight sequence so that the product flows smoothly towards the customer.

4. Pull. As flow is introduced, produce customer pull only.

5. Perfection. As value is specified, value streams are identified, wasted steps are removed, and flow and pull are introduced, begin the process again and continue it until a state of perfection is reached in which perfect value is created with no waste.

In addition, as mentioned earlier, this philosophy derives from the Toyota Production System (TPS), which is structured based on two basic pillars: JIT and JIDOKA.

JIT (Just In Time) means performing only what is necessary when necessary. This method is intrinsically related to concepts such as continuous flow, pulled production, Takt Time, which is the period of time between the start of production of a product and the next, depending on customer demand; and Heijunka, a tool that serves to level constant production levels based on variations in that demand. On the other hand, JIDOKA is a way of detecting problems and taking immediate action to correct failures at any stage of the production process [7].

2.2. Tools and techniques

Following are some of the tools and techniques used in this project:

- **Process mapping** describes the flow of actions and events that occur during the production or repair process of a product. Through this technique you can more quickly identify those steps where queues and bottlenecks originate, as well as tasks not needed in the process, to eliminate waste, allowing you to reduce costs, automate routines and have more control through process monitoring [4].

- **Value Stream Mapping (VSM)** is a graphical representation of the entire value chain that shows the flow of materials and information from all stages through which the product goes from supplier to customer. Also allows you to display inventory levels, management, processing times and other information that can be used to analyse everything or the process flow. An important aspect is that it allows the identification of activities that add or do not add value to the final product, being a potential indicator to improve productivity and the flow of productive and administrative activities.

- **Swim Lane Diagram**, which is basically a less detailed flow diagram than the previous one, where each track represents a department, function, office, etc.

- **Spaghetti Diagram** is a representation of the path taken by parts or technicians in an enterprise while performing tasks in a given process.

- **Why?**. It is a simple problem solving tool used to research the causes of an anomalous phenomenon through a series of consecutive questions. It consists of asking the “Why” question five times to understand what happened and determine the root cause of the defect or problem.

- **Yamazumi chart**. Stacked bar chart where the cycle time of a given process is represented. Its name comes from Japanese, a word meaning stacking. In it, the tasks of each process are represented individually stacked in a bar and can be classified as Value Added, No Value Added or Waste. Each task in the process is stacked to represent the entire process. In addition, a line indicating the desired Takt Time is also included. This graph allows to identify which operations are overloaded, ergo above Takt Time, or underused. That’s why it’s a great visual tool to show where delays, wastes and bottlenecks are occurring [3].

- **5S**. Helps to organize the workplace cleanly, efficiently and safely to improve productivity, visual management and ensure the introduction of standardized jobs. For its application follows a methodical and permanent procedure, divided into 5 phases, each named after a different Japanese term that begins with the letter “S”: Sciri (Sort), Seton (Set in order), Seiso
(Clean), Seiketsu (Standardize) and Shitsuke (Self-discipline) [4].

3. Case study framework
OGMA - Industria Aeronutica de Portugal, S.A. is a Portuguese company that provides aeronautical maintenance and manufacturing services. 65% of the capital is held by the Brazilian aeronautical company Embraer, with the remaining 35% held by the Portuguese government. It is an authorized maintenance centre of Rolls Royce in which the maintenance of T56 military engines, AE 2100, AE 3007 and AE1107 families is performed [2]. The phases that form this process are: reception; disassembly of all modules and components; cleaning of said parts; then they are subjected to non-destructive tests (NDTs) to evaluate the properties of each component without causing damage or deterioration in them and which consists mainly of inspection with fluorescent liquids; then a dimensional inspection is carried out in Metrology; followed by a final evaluation to determine which parts are in good condition, which need to be repaired or which are discarded. Together with this report, a cost estimate, CE, is made and sent to the client. Once the budget is accepted, the repair of the indicated components begins, each of which will follow a different path depending on the needs of the repair.

Once all the parts are serviceable, the modules are assembled individually to then perform the final assembly on the engine, which is followed by a functional test to finally be issued to the customer.

In order to focus the study, the future market forecast regarding the reception of new engines in the company will be considered. Table 1 shows the number of engines currently repaired (Scenario 0) and the forecast for next year (Scenario 1). In addition, it includes the Takt Time that would be necessary to adopt to achieve that number. It is observed how it is intended to double the company’s capacity.

<table>
<thead>
<tr>
<th>Motor</th>
<th>Scenario 0</th>
<th>Scenario 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE 2100 A</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>AE 2100 D</td>
<td>35</td>
<td>65</td>
</tr>
<tr>
<td>AE 3007</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>T56</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>AE 1107</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>83</strong></td>
<td><strong>163</strong></td>
</tr>
</tbody>
</table>

| Takt Time | 3 days | 1.5 days |

Table 1: Number of engines repaired at OGMA in different scenarios

In order to achieve this goal, the concepts of Lean Manufacturing will be applied to eliminate waste. But, first, it is necessary to determine which area the efforts will focus on. That is why a study was carried out of the average time it took for the engine in each of the phases of its process described above and shown in Figure 1. It can be seen how most of the operations would exceed Takt Time desired and precisely in the phases of repair is where the biggest jams are.

Therefore, in the first place, the repair processes of the components will be analysed, although, it is true that due to the quantity of parts that make up an engine it is tedious to accompany the repair processes of all the parts that form it. That is why another study was carried out to determine which engine parts are the most critical, that is, those that present more difficulties in their repair. For this, the following criteria were considered: (i) the probability of being repaired; (ii) the duration of their repairs and the worst-case scenario; (iii) the priority in the final assembly order of the engine.

Based on these criteria and with the repair history from 2018 to June 2019, 5 parts were determined as the most critical: Compressor Air Inlet Housing (CAIH), which is the part where the air enters to the compressor; Rear Turbine Bearing Support (RTBS), is part of the Low Pressure Turbine (LPT) and directs the air towards the nozzle; Propeller Gearbox (PGB), part external to the motor core responsible for adjusting the torque provided by the turbine shaft to move the propellers; Main Drive Gear (MDG), main gear of the PGB; and Compressor Rotor, which is the moving part of the compressor.

Once the most critical parts have been determined, their repair processes will be studied in order to determine what the main bottlenecks are in order to reduce waste. It should be noted that, although only 5 parts are studied, the rest parts and components follow similar processes and also go through the same work centres, so the solutions that will be tried to find will also affect the rest of the engine’s repaired parts, since all the processes are interconnected.

4. Diagnostic and Analysis of Results
4.1. Repair flow of the most critical parts
In order to analyze the different stages of the repair process of the parts, a Swim Line Diagram was built for each of them in order to visualize their flow. In addition, the spaghetti diagrams of each of them were also created. Figure 2 shows the Swim Line Diagram of the PGB, as it is the most transported piece between work centres.

It should be noted that a VSM was carried out for the compressor rotor, since it was found that the biggest jams were outside the repair processes, so it was necessary to broaden the focus of study towards operations prior to rotor repair.
Next, the main waste found in the different work centres will be exposed after the accompaniment of the previous pieces.

- **Metrology**: (i) High Lead Time (waiting lines) due to the high accumulation of parts caused by (ii) a non-optimized layout; (iii) non-use of a machine for 3D measurement.

- **NDTs**: High 48-hour Leat Time due to the lack of priorities and the high volume of parts with which they work from all areas of the company (not just engines).

- **Lathes and Milling**: Use of conventional machines, which leads to a lack of precision in the relevant measurements and a longer machining time.

- **Cleaning**: The pieces take a long time to reach this area because it is located too far from the rest of the work centres.

Additionally, it should be noted that, in the areas of Metrology, NDTs and Cleaning, parts from the preliminary phase of the initial inspection are found when the engine is disassembled together with those parts that are being repaired and in their repair letters indicate that they have to go through these centres at certain stages. Therefore, bottlenecks are created here because the volume of pieces that these centres have is much greater than the rest. This is reflected in the times that the pieces must wait (WIP) before performing any task in these centres, being 48 hours in the case of NDTs. Therefore, there is a clear opportunity for improvement here to try to drastically eliminate these waiting times, as all engine parts go through them.

Next, the repair flows of the different parts were studied, which are similar, where the piece goes through the different work centres depending on the requirements of the repair letters, as shown in Figure 2 for the case of the PGB.

Different possibilities for improvement can be extracted from them. In many cases, when the pieces carried out non-destructive tests on NDTs, the manual indicates that a complete immersion of the part in the fluorescent liquids must be carried out, but this process was already carried out in the preliminary evaluation, so that this operation could be modified for the Spot Check technique, where only liquids are applied to damaged or repaired areas already known. On the other hand, sometimes the first stage of the repair is a cleaning or NDTs tests, which is redundant because the different parts have already undergone cleaning processes and NDTs tests in the preliminary phases, and it would be enough to attach a report of said preliminary test indicating the dimensions and location of the cracks discovered. It was also observed on numerous occasions that after the pieces go through the NDTs they returned to be cleaned. This fact is also unnecessary since the same NDTs process includes a cleaning of the remains of liquids that remain after the tests, so it would simply be enough to optimize this removal of the material after the test.

In the specific case of the PGB it was also observed that the technicians of the different centres had to move to the production area to collect the specific tools to work with the PGB, and that when these tools were not available they had to wait of them, causing delays in the repair of the PGB. In addition, there were also problems with the installation and machining of some plugs inside the piece, as the processes took too long. And, a problem was found in the installation of studs, because when performing the inspection in Metrology it was found that the level was not correct, and the piece had to return to Locksmith again to correct it.
In the case of the rotor it was necessary to carry out the cleaning of the pieces after a type of test, since it was inefficient, and it was not possible to completely remove the material with the solvent used.

4.2. Compressor Rotor

In the case of the rotor it was necessary to carry out a larger study that covered more phases than part of the repair, since the main jam was not here, but in earlier stages, like shown in Figure 3.

First, delays in disassembly were observed due to the lack of horizontal carriages, which is where the rotor is placed once disassembled. This fact was due in turn to the small number of existing horizontal cars, the number of waiting rotors and these cars were also used to place the Low-Pressure Turbine (LPT).

On the other hand, the main problem that was generating the delay in the assembly of the rotor in the engine was related to the order of material. In practically all the rotors it is necessary to replace the blades of some wheel of this, so that an order of material is made indicating the number of blades needed. But the problem is that the reception of this material took place more than 30 days later, during which time the rotor was waiting, because it could not move forward with its process.

Parallel to this, waiting rows were also observed in the use of the GER machine, where the measurement of the blades’ dimensions and the run out of the wheels is performed, as well as the relevant rectification of the blades. This machine is used in preliminary inspection and repair processes, and there are only two qualified technicians for handling, so the capacity of said machine is not enough for demand.
5. Proposed Solutions
5.1. Work centre solutions
Once the diagnosis was made, the solutions proposed for the work centres are:

1. Modification of the Metrology layout to allow a better organization of the pieces.
2. Use of the 3D measuring machine in Metrology through the corresponding programming of the set up for the parts.
3. Creation of new Metrology, NDT’s and Cleaning work centres on the lower floor, in order to speed up certain repair tasks and increase the capacity of these centres to reduce Lead Time in each of them.
4. CNC industrialization of tasks performed on conventional mills and lathes.
5. Implement a parts tracking system that allows determining the location of the pieces at every moment.

With the implementation of these measures, it is possible to drastically reduce the waiting time (WIP) of the centres. In Figure X you can see the new times for each one.

5.2. Repair flow improvements
In response to the repair flows, several improvements have been made to reduce the TAT of each piece.

In the first place, those cleaning tasks and NDTs that occurred at the beginning of the repair of some parts have been eliminated, since these tasks were already carried out previously in the preliminary phases. In addition, in the NDTs phase a report will be included indicating the size and location of the cracks, if any.

In addition, cleaning tasks have also been eliminated after performing NDTs, as the objective was to eliminate the remains of previous fluorescent liquids. So now we will try to optimize this elimination of the material used in the same task of NDTs without having to move the piece to the cleaning area.

On the other hand, those tasks of NDTs that indicate submerging the part totally in the fluorescent liquids are modified for only a local inspection called Spot Check when necessary. In addition, this task will be carried out in the new work centre located on the lower floor, reducing the displacements of the pieces.

On the other hand, in the PGB the way of tightening the plugs was modified (Figure 4), because now they will have a hexagonal head to allow installation with an automatic tool. In addition, the size of said head will be smaller to reduce the elimination of material carried out in subsequent processes.

![Figure 4: Modificao da cabeca do plug instalado na PGB](a) As Is (b) To Be

Moreover, in order to solve the problem of measuring the dimensions of the studs installed, a GO NO GO tool is created (Figure 5) which allows the matching of the two dimensions between the measurements established by the manual.

![Figure 5: Pressure distribution.](image)

Finally, to eliminate the rework that occurs in the cleanliness of the MDG, the type of solvent used is changed, proving that with an immersion in acetone and its subsequent drying in the oven the MDG is completely cleaned, reducing the reworking.

5.3. Proposed improvements for the compressor rotor
1. Creation of horizontal and vertical transport cars.
2. Standardization of the measurement of the blades in the GER machine, so that it can be performed by technicians from different areas.
3. Advance of the blades order right after the measurement in the GER machine instead of waiting until the end of the preliminary phase.
4. Creation of a monthly blades stock based on the historical blades consumed.
5.4. Analysis improvements

The following table shows a summary of the improvements achieved with the implementation of the solutions described above, where you can verify that it has been possible to reduce an average of 70% in the waiting time in which the parts were not being repaired, time due to the change between work centres and the high Lead Time that existed in them. With these improvements, the lead time has been reduced in the most critical workplaces, having an impact on the ability to repair the parts faster, since these wastes have been eliminated. In addition, as a result of the creation of the new work centres on the lower floor, as well as the elimination of those redundant tasks, the distance travelled by the pieces is also reduced by approximately half, avoiding this loss of time in the displacements. It can also be observed that in the Working Hours (WH) a reduction has not been carried out as markedly as with the waiting time, but still, if it has been possible to reduce a certain number of hours, which remains satisfactory.

Analysing the measures implemented in the Rotor Compressor, it has been verified that the Lead Time of the entire process described in Figure X can also be reduced by 70%, since with the creation of the monthly blades stock, it is no longer necessary to have the rotor waiting for a month. This fact allows the immediate repair of the same, and together with the rest of the measures adopted, allows the elimination of the waiting times associated with it.

<table>
<thead>
<tr>
<th>Part</th>
<th>WH</th>
<th>WIP</th>
<th>TAT</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHH</td>
<td>-8%</td>
<td>-73%</td>
<td>-68%</td>
<td>-55%</td>
</tr>
<tr>
<td>RTBS</td>
<td>-7%</td>
<td>-84%</td>
<td>-78%</td>
<td>-56%</td>
</tr>
<tr>
<td>PGB</td>
<td>-8%</td>
<td>-78%</td>
<td>-70%</td>
<td>-45%</td>
</tr>
<tr>
<td>MDG</td>
<td>-2%</td>
<td>-67%</td>
<td>-56%</td>
<td>-11%</td>
</tr>
</tbody>
</table>

Table 2: Summary of the improvements obtained in the different pieces

6. Conclusions

After observing the results obtained in the TAT improvements of the most critical pieces, it can be concluded that the objectives have been satisfactorily achieved, since it has been reduced by around 70% of the waiting time that did not add any value to the final product. In this way, the company can also increase the number of engines repaired per year, which allows OGMA to increase profits.

On the other hand, it shows the importance that Lean Manufacturing methodologies currently acquire in order to make companies more and more competitive and to be able to place them among the first market positions. This philosophy of thoughts and methodologies allows to bring to light problems or wastes that are occurring in the company and that can go unnoticed by workers because they are accustomed to working with them. That is why it is important to carry out a detailed analysis and from outside of all the processes to be able to find these losses of any kind, because in the future their consequent elimination will result in profits for the company.

References


