Application of Lean Manufacturing in the maintenance of propellers

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Abstract

The current global market, with a high level of competitiveness, forces companies in the aeronautical sector to constantly revalue business processes and seek new ways of optimizing them in order to maintain leadership. Lean Manufacturing principles and methodology seek the reduction of any waste in the processes involved, thus maximizing production capacity, reducing waiting times and operating costs; also increases in quality, safeness and employee engagement are commonly achieved. This thesis aims to improve the Overhaul process of propellers at OGMA company through the implementation of different techniques and concepts of Lean Manufacturing.

An analysis and diagnosis of the current situation has been carried out, using diverse Lean tools such as, Lean Audit of the 5S status, Bottleneck Analysis through Process Mapping, and Root Cause Analysis of encountered problems using 5 Whys technique. All of them have been possible to implement thanks to the study of times and methods in first hand at Gemba.

Different countermeasures have been suggested, also making use of key lean concepts and means, such as Kanban, Kaikaku, Visual Control, Barriers-to-flow reduction, lean training and complete exploitation of resources. Some of the gains that would be achieved through their implementation have been foreseen, and finally some future work has been suggested.
Keywords: Lean Manufacturing, 5S, Bottleneck Analysis, 5 Whys, Visual Control, Kanban

1. Introduction

In the current market, with a high level of competitiveness, maintaining leadership in the aeronautical sector involves revaluing, optimizing and in some cases redesigning business processes. For many companies, this means moving towards Lean Manufacturing principles and methodology.

Lean is a people based operational excellence strategy focused on creating customer value with fewer resources through the persistent pursuit and elimination of waste [1].

The implementation of lean techniques usually leads to a reduction of waiting times and operating costs, an increase in quality and safeness in the process and an improvement of employee engagement and morale, thus they are beneficial for any process or organization and everyone involved in it.

The main motivation for the development of this thesis is the change for the better that would bring the implementation of lean strategies at OGMA enterprise.

OGMA is a Portuguese aerospace company that has been providing services of maintenance and manufacture of aircraft and engines in their facilities in Alverca since 1918 [2]. The thesis has been developed in collaboration with the Components area, particularly in the propellers specialized shop.

2. Origings and background

The techniques of organization of production arose at the beginning of the 20th century with the works carried out by F.W. Taylor and Henry Ford who formalized and methodized the concepts of mass production that had begun to be applied at the end of the 19th century. The first one, established the first bases of the organization of production through the application of the scientific method to processes, times, equipment, people and movements. The latter, created the first assembly line revolutionizing the automobile industry. These were sets of actions and techniques that arose and evolved at a time when rigid mass production of large quantities of product was possible. [3]

The rupture with mass production techniques, and thus the first germ of lean thinking, appears in Japan.

In 1902, the basics of Jidoka System ("automation with a human touch") were set through the invention of the automatic loom by Sakichi Toyoda.

Later, after WWII, facing the challenge of rebuilding a competitive industry in the precariousness of a post-war scenario and seeking for new practical alternatives Eiji Toyoda and Taiichi Ohno, from Toyota Company, visited American automobile companies in search of inspiration. From their travels, they concluded that the American system was no applicable to Japan since it advocated reducing costs by manufacturing vehicles in large quantities and limiting the number of models, they also envisioned that the future was going to ask to build small cars and varied models at low cost and thought that this would only be possible by suppressing stocks and the different types of waste [4]. From these reflections, Ohno laid the foundations for a new management system: Just in Time (JIT). The system formulated a very simple principle: "Produce only what is demanded and when the client requests it".

The contributions of Ohno were complemented by the work of Shigeo Shingo who understood the need to transform productive operations into continuous flows, without interruptions, in order to provide the customer only what he required, focusing his interest on reducing preparation times and creating this way the basics of the Single Minute Exchange of Dies (SMED) system. Under the umbrella of the JIT philosophy, different techniques were developed such as: Kanban, Jidoka and Poka-Joke, which were enriching and structuring Toyota Production System (TPS) as known nowadays [5].

The JIT / TPS system gained notoriety with the 1973 oil crisis and the loss-making of many Japanese companies, Toyota then stood out above the other companies and the Japanese government encouraged the extension of the model to other companies [5]. But it is not until the early 90's, when suddenly the Japanese model has a great echo in the West and does so through the publication of "The machine that changed the world" of Womack, Jones and Roos [3]. The book analyses and compares in detail the performance of the production system of major car manufacturers worldwide with the Japanese Toyota system, highlighting and demonstrating the reasons for the clear superiority of the latter compared to all its competitors. Here the term Lean Manufacturing appears for the first time making reference to a new production system capable of combining efficiency, flexibility and quality that could be used anywhere in the world, although, in the end, it was still a way of labeling with a new westernized word a set of techniques that had been employed for decades in Japan. Taking into account all this background, Lean Manufacturing can therefore be understood, roughly speaking, as an extension and diffusion into the Western manufacturing system of the Toyota production methods. Precisely, according to Suzuki (2004), Jidoka and JIT techniques, together with the Japanese work organization system (JWO) are the foundations that make up Lean Manufacturing [6].

3. Lean structure system and tools

Traditionally, the "House of the Toyota Production System" has been used to quickly explain the philosophy contained in Lean.

There, the roof of the house is constituted by the goals pursued that are identified with: the best quality, the lowest cost and the shortest delivery time or maturation time (Lead Time). Holding this roof are the two columns that support the system: JIT and Jidoka. The basis of the house consists of the standardization and stability of processes: Heijunka or leveling of production and the systematic application of continuous improvement (Kaizen). Also the human factor should be added to these traditional foundations as a key aspect in the implementation of Lean. All the elements of this house are built through the application of multiple techniques: in the diagnosis, at an operational level or as follow-up techniques.

From all the diverse tools and techniques provided by Lean Manufacturing, the following ones are somehow the most related to the thesis content:

- **Genchi Genbutsu**

  Japanese term that refers to seeing for yourself. It is the act of going to the Gemba: the actual place where work is performed.

- **5S**

  Lean 5S is a systematic and sustainable method to organize the workplace not just tidying. Because its simplicity and effectiveness should be the first tool to be implemented in any company that deals with Lean Manufacturing. Its implementation aims to prevent the occurrence of the following dysfunctional symptoms in the company which affect, decisively, the efficiency of it: dirty appearance of the workplace, clutter, broken elements, lack of simple operating instructions, frequently breakdowns, employees disinterest in their job, unnecessarily transportation and movement (materials, tools and people), lack of space, etc.

The 5s method implies five steps which can be summarized as [7]:

- *Seiri - Sort*: To free up space and remove cluttering by sorting out what is needed and what is not and then keeping only the necessary items.
- *Seiton - Set in order*: To arrange items to promote efficient workflow. Each thing in its place, each place for one thing.
- *Seiso - Shine*: To clean the work area so it is neat and tidy.
- *Seiketsu - Standardize*: To set standards for a consistently organized workspace. This will sustain improvements.
- *Shitsuke - Sustain*: To create the habit: maintenance and costant revision of standards.

- **Process Mapping Tools**

  Techniques for streamlining work. A process map visually depicts the sequence of events to build a product or produce an outcome. It may include additional information such as cycle time, inventory, and equipment information. Some of the benefits are: Spotlights on waste, streamlines work processes, defines and standardizes, promotes deep understanding and builds consensus. One of the most common and useful Process Mapping type is the Value Stream Mapping (VSM).

- **Bottleneck Analysis**

  A bottleneck (or constraint) in a supply chain refers to the resource that takes the longest time in operations. The goal of Bottleneck Analysis is to determine the slowest parts of the manufacturing process and then figure out how to speed them up.

- **5 Whys**

  Analysis tool that helps to easily identify the root cause of a problem as well to determine the relationship between different root causes of a problem. It starts by writing down the specific problem that is trying to be solved and subsequent to this, asking why the problem happens. Once an answer has been given has to be written down and check if that answer identifies the root cause of the problem, if it does not, Why should be ask again and the answer should be written down, proceeding in this way until the team agrees that the root cause of the problem has been identified.

- **Kanban**

  Kanban is the Japanese word for "card". Kanban can be defined as a visual method for controlling production or materials as part of Just in Time (JIT), this is carried out through a signaling device, usually a card, that gives authorization and minimal instructions for either:

  - A supplying process to know what to produce (Production Kanban). In this case, Kanban instructs the previous activities to start. For example, in a three column production Kanban board, the cards are initially placed in the "to do" column, then when work begins on a project, the card moves to the first Work in Progress column ("doing"), and finally when the activity is completely finished the card is placed in the "done" column. Therefore work is always pulled through the Kanban board rather than pushed. This pull happens according to each column Work in Progress (WIP) limits. If, for example, there is a limit of two items in the WIP column, nothing can be added to that column until there is one item or no items left.
  - A material handler to know which items to replenish and withdrawing from the supermarket only what it is needed when it is needed (Withdrawal Kanban).

    For example, here, colored bins or reorder cards can be used as methods that signal the time to repurchase materials or parts, when a worker reaches the end of a bin or reorder card, he orders stock internally or passes the information to the department in charge of stock purchase, but no material is ordered if the bins remain full or a reorder card has not been reached.

- **Visual Control**

  Visual Control can be any device or symbol that effectively places information at the point of use with few words or none at all. A visual control helps Lean companies make a quick, pre-planned decision without guesswork. There are three major types of visual controls:

  - Information (What is this? Where am I? Who works in this area?)
  - Instruction (What should I do? How do I do it?)

– Status of a process, a machine, a department, etc. (What is happening? What should be happening?)

4. Case of study

The main and more characteristic process carried out inside the propellers area is the Overhaul process. This process can be divided in two easily distinguishable phases, being the the first one the expertise and the second one the blades repair.

When a propeller arrives to the propellers hangar in order to carry out the overhaul process, it is disassembled in its constituent parts, thence the different parts go through diverse operations until expertise is carried out. The most important components of a propeller are the blades, and therefore these activities can be split in blades processes and other components processes. After expertise, if the client gives the go-ahead, the overhaul process continues commonly with the repair of the blades, and culminates with the final assembly of all components.

Being the overhaul process such a large one and the blades their most crucial components, among all operations involved in the overhaul process the thesis will be exclusively focused on the blades processes and specifically on the ones executed inside the propellers hangar.

So the case of study will be comprised for the following processes: Dissassembly and Bushing Inspection, Lead Wood Removal, Cleaning, Plastic Foam Fairing Removal, Borescope Inspection, Dimensional Control, Preliminary Balance, Blades Surface Repair, Polishing Re-Work, Plastic Foam Fairing, Fairing Finishing, Bonding (I and II), Bushings Installation and Balancing.

5. Diagnosis

Genchi Genbutsu technique was employed allowing the gathering of reliable information, the talks with the workers involved in the project and the witnessing of problems as they arose.

The diagnosis can be divided into two main parts: Characterization of the current 5S status and Bottleneck Analysis of the case-of-study processes. In both of them root cause analysis of the problems have been performed making use of the 5 Whys technique.

5.1. 5S status

In order to portrait the current situation of the 5S a questionnaire addressing different questions and concepts related to each of the five categories has been completed by eight of the workers. There, they had to evaluate each question with a number from one to five meaning them: 1-Too bad, 2-Bad, 3-Average, 4-Good, 5-Too Good. They could also add any comments.

From this questionnaire the following results where obtained (Figure 1): Seiri (sorted environment) and Seiton (organized place) where the worst rated categories. The different questions or concepts which in average were rated bellow three allowed us to detect the following improvement opportunities: There are objects out of place preventing material movement or job development, there are materials out of date and usually more quantity of them than needed and at the same time right now no standard procedure is being used in order to carry out the stock control, as for the tools it has been found that neither them nor its place are visually marked making difficult to recognize the place of each thing, sometimes they are not positioned back in their place and as some of them are shared with the landing gears team occasionally they are not even in the propellers area and workers spend some unnecessary time looking for them. Other aspect poorly rated was keeping the tools and equipment clean.

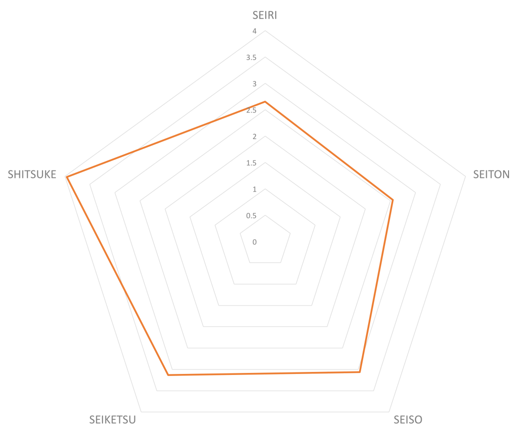

Figure 1: Results obtained from 5S questionnaire

From the obtained results in the 5S Audit in conjunction with in-first-hand observations at Gemba of some specific stoppage events in the process, the following problems have been analyzed in order to find its root cause:

- Time spent looking for tools

  Workers discomfort and a lot of no added value time invested in searching the tools throughout the entire Overhaul process are consequences for this problem.

  Its root cause analysis has resulted in the discovery of three foundational causes: Lack of tools, deficient tool cabinet organization and not enough employees training about 5S.

- Stoppages because of the lack of materials and materials out of date

  5 Whys technique has been used to perform the root cause analysis of these problems from which it has been concluded that the lack of a control system to manage the materials supply is their source.

5.2. Bottleneck Analysis

The different processes which constitute the case of study were observed in first hand and timed, with the purpose of obtaining real information about the flow, as well as the methodology, equipment and required time for each activity of the involved processes. Patience, time and asking a lot of questions were essential ingredients for the succesful completion of this task. An outcome of this has been the construction of two different flowcharts representing visually the Overhaul process which collect the essential information related to each subprocess.

From these flowcharts the processes that are part of the case of study have been isolated and presented together with their respective Lead Times at (Figure 2), thus allowing the easy identification of the critical ones or bottlenecks which appear underlined in red. Not in all critical processes were detected faults, only in those marked with a thunder observable improvements were identified. The results from the root cause analysis performed to these identified faults will be summarized in the following subsections.

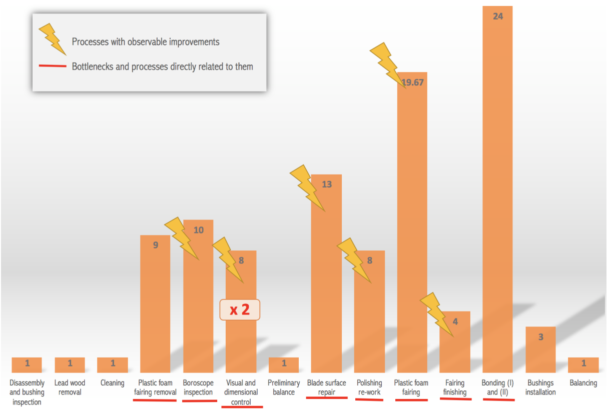

Figure 2: Current Lead Times (Case-of-study processes)

- Borescope inspection

  This process presents a Process Time per blade of 2.5(H) and a Process Lead Time of 10(H), with this it can easily be inferred that the four propeller blades are being inspected in series. The required Man-hours for this process is 10(H), coinciding with its Lead Time, what means that this process is performed just by one employee. Both deductions are not common features among the other processes where the blades are usually processed in parallel, or if they are not, it is because more than one employee are working simultaneously on the same blade, always trying to make the most of the available workforce, this is why it was expected for this process to have a shorter Lead Time.

  After consulting the manual ([8]) and talking to the workers, it turns out that in order to carry out this inspection a special qualification is required but only one worker has this qualification, and so that, only one blade can be inspected at a time making the total process to last at least 10(H).

  After the application of the 5 Whys technique for performing the root cause analysis of this bottleneck it has been concluded that there are not enough employees with the required qualification to perform this task in order to meet the desirable workflow.

- Dimensional control

  Currently the process takes 2(H) per blade and it is carried out between two or three workers manually, summing up at least 16 Man-hours. The tools employed to perform the different measures are heavily archaic, measurements have to be converted to inch, also thickness measurement presents a critical fault: To perform this measurement it is used a caliper gage and instead of picking the measure directly from this instrument due to its lack of precision, a vernier caliper is employed for measuring again the thickness from it. It also should be highlighted that this process must be carried out again after re-work process, making the importance of this process and the magnitude of its faults double

  Trough the root cause analysis of this bottleneck the current procedure of dimensional control process has been identified as being obsolete.

- Blade Surface Repair, Polishing re-work and Fairing Finishing

  - Blade Surface Repair

    At each Overhaul, the blades should be grinded in order to remove the different damaged areas that they present. This process takes at least 6.5(H) per blade.

The space where the activity is performed has four independent posts to position the blades and their respective four extractors, but in the way they are placed only two of them can be used (marked with a red cross at Figure 3), since all workers are right-handed and the grinding movement must be performed from the end of the blade to its beginning; this means that neither the complete infrastructure nor all workforce available are fully exploited. This unuseful layout creates the current situation where only two blades can be worked at a time and thus grinding the complete four blades batch takes at least 13(H).

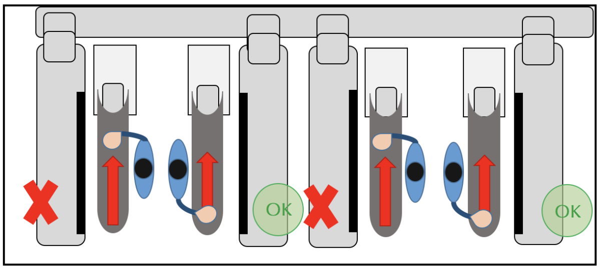

Figure 3: Polishing and grinding problem illustration

– Polishing Re-work and Fairing Finishing
Blades must be polished before the final dimensional control, this takes 8(H) for the complete batch. Ensuing the fairings manufacturing they should also be polished lasting this process 4(H).
Here in these processes the problem remains the same as in Blade Surface Repair process, the incorrect layout does not allow a complete parallel work, therefore also two extractors and blade's placement posts remain unused, but in these two cases we have an additional resource not exploited: there are three polishing machines, so one of them also remains unused.

From the analysis of these three processes the root cause problem for these bottlenecks has been identified as an incorrect layout.

- Plastic Foam Fairing

It has been observed the development of the process and timed each activity that constitutes it. With the current procedure the expected Lead Time is 15.75(H), however, it takes 25(H) for the entire process to be completed. This is because even though the oven has the capacity to work on the four blades simultaneously, nowadays the fairings are treated in the oven in two turns of 8(H) due to the rupture of a mold, first three blades and then just only one blade another day. This affects also to the waiting times (drying and cooling down times) which are also duplicated.

A root cause analysis using the 5 Whys technique has made possible to determine that this bottleneck is caused by the lacking of one fairing mold, thus making impossible to use the oven for treating the four blades simultaneously, furthermore it has been deducted the root cause after the mold rupture: unawareness about cooling down waiting times before taking the blades out of the molds.

5.3. Summary of diagnosis phase

The different tools and results obtained from the root cause analysis that have been exposed through this section can be seen summarized in the following diagrams (Figure 4 and Figure 5).

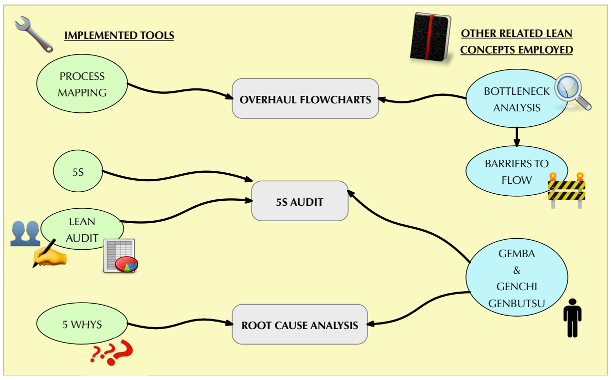

Figure 4: Diagnostic tools summary

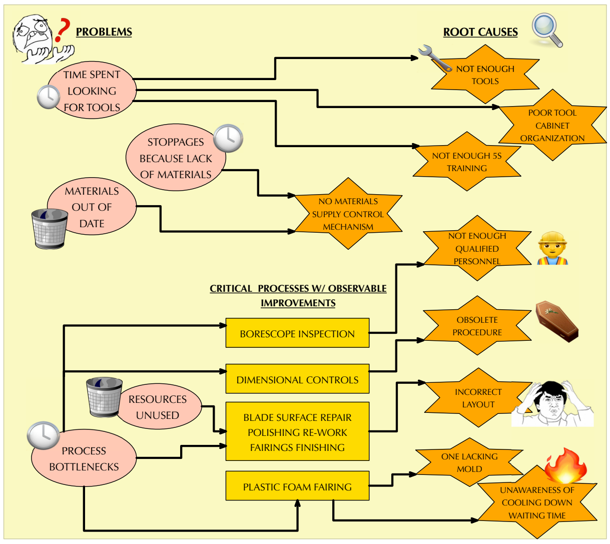

Figure 5: Root cause analysis results summary

6. Proposed Solutions

In this section will be presented the diverse countermeasures to the problems that have been detected during the diagnosis phase.

6.1. Solutions proposed from in 5S questionnaire and overall witnessing of all processes

- Problem: Time spent looking for tools

  - Two more tool trolleys

    It is a fact that there are not enough tools in the propellers area considering they have to share them with landing gears team, so it has been proposed to buy two new tool trolleys that could be exclusively used in the propellers area. From this action would be solved the problems related the unavailability of tools and their placement outside of propellers area.

  - New way of organizing tools

    It is not only needed more tools but also a better organization of them, so another proposition has been the design of a better way to arrange the tools: to mark each tool place with labels and to have each place the shape of the corresponding tool in order to facilitate that each one is placed in the right position and with colored backgrounds in order to identify more easily a possible missing tool. Currently each tool does not have a well defined place, they are not labeled and they do not have the tools shape or if they have, all foam is in the same color so they are not well distinguishable.

  - Lean training over the 5S topic

    It has also been suggested that workers receive specialized training about 5S topic, since a prerequisite to this problem is that the previous worker did not bring the tool back to its original place, a greater concern about the importance of 5S and collaboration to maintain the workspace in good conditions is therefore required.

    5S is considered a "foundational" lean concept, as it establishes the operational stability required for making and sustaining continuous improvements, the aim is to increase workers consciousness about 5S and embed the lean thinking in the own employees philosophy. It is foreseen that this measure would also affect to another detected faults and low rated categories by workers in the 5S Audit as cleanliness and other objects out of place. All that will contribute to a better work environment resulting in a happier, easier and more comfortable and productive time-work.

- Stoppages because of the lack of materials and materials out of date

  In the diagnosis phase it has been determined that those problems have their root cause in the absence of a control system for materials supply, the proposed solution in order to fix them should therefore aim towards the development of a system to control materials supply at POU, a Kanban System has been proposed for this purpose. The goal will be to have only the sufficient quantity of each material so that it could cover the demand successfully, but no more. Excess inventory requires extra handling, extra space, extra interest charges, extra people, extra paperwork, and so on [6]. In order to develop the Kanban System three steps have been carried out:

  - Study of the demand

    The only information available that could help in the quantification of the demand were the records of propellers finished projects. In the analysis it has been considered the quantity of propellers that entered during a day or month as the demand for that specific time-period of study and then, later on, the results have been adapted to each material multiplying it by the quantity of the material that is used in an Overhaul per propeller.

    Firstly, monthly daily demands with their standard deviations and variances have been computed. In those cases where more than one data set were known for the same month, the variance and average daily demand have been calculated as the average of each distribution values, with regards to standard deviations, they have been calculated as the squared root of the average variance of both data sets.

    From the monthly results that have been obtained, the daily demand characterization for one year of work has been computed proceeding in the same way: Average daily demand and variance as the average between the twelve months results, with regards to the standard deviation: as the square root of the variances average. As a result it has been obtained an annual daily demand characterization of 0.195 propellers with a standard deviation of 0.501.

  - Number of Kanban cards

    Once the average daily demand (DD) had been characterized, the number of Kanban cards for each material has been calculated having into account the Lead Time (LT) (average time elapsed between the order of the material in question and its arrival to the point of use) which in this specific case it was four days for all cases since the communication is between the propeller's hangar and the warehouse, and the quantity of containers per Kanban (QTY_{cont}) which for convenience has been set as one material container per Kanban card.

In order to protect the Kanban System against the demand fluctuations it has been added a quantity of safety stock (SS) for each material having into account its standard deviation from daily demand (σ_{DD}). For purposes of setting safety stock, Z score is the appropriate statistic to use, and, in theory, should be applied to the variability of daily demand through lead time (DLT) and not to discreet daily usage values. However, the simplified approach using the square root of Lead Time and daily-usage values provides the same result and is much simpler to calculate and to automate [9]. The safety stock for each material has been calculated therefore as follows (Equation 1). A service level of 95.05% has been imposed in order to provide a highly reliable stock management system, after consulting a correlation table between Z Score and Product Availability, a Z score of 1.65 was found to correspond to this service level.

$$SS = \sigma_{DD} \cdot \sqrt{LT} \cdot Zscore \qquad (1)$$

Finally the number of Kanban cards (# Kanban) for each material has been computed as the least integer greater than or equal to the result obtained through the application of Equation 2.

$$\#Kanban = \frac{(DD \cdot LT + SS)}{QTY_{cont}} \qquad (2)$$

– Proposed design

Lastly, it has been designed a model for the Kanban card that could be used indicating the essential information that should be transmitted. As well as a model for the Kanban board that has been divided in three parts to indicate which materials have to be ordered, which ones have already been ordered and finally the orders that must be collected.

6.2. Solutions proposed within each specific process

- Borescope Inspection

  If the goal is to optimize the overhaul process, each subprocess Lead Time must be lowered as much as possible. In order to achieve this, continuous flow (which is the most efficient way to produce [10]) should be developed wherever possible. The fact that there is only one worker capable of performing this activity turns this process into a bottleneck inside the overhaul flux, a barrier to flow, the solution proposed aims to transform this entirely serial process in at least fifty percent parallel one by introducing one more qualified worker (Figure 6).

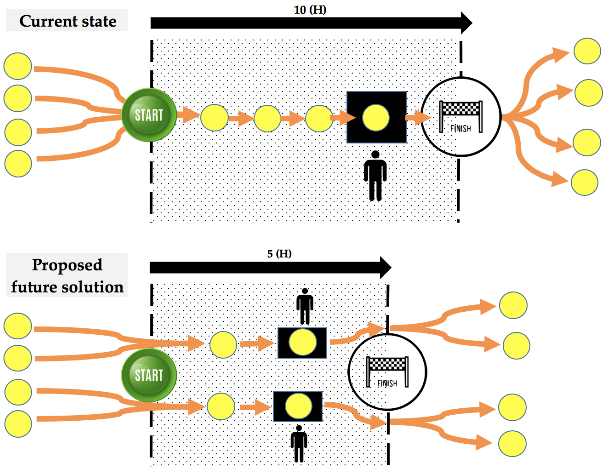

Figure 6: Graphical illustration of the proposed solution for Borescope Inspection

- Dimensional Control

  Since the current procedure was qualified as obsolete, the optimal solution that could be proposed for its optimization had to be linked to a utterly transformation of the process: *Kaikaku*. This radical transformation implies a previous research of the latest technologies for this purpose in the aeronautical sector, this investigation has lead us to Aeroscan M5 - Precision Blade Measurement System, an automatic measuring machine that uses laser technology. The machine, is capable to perform all required measures in less than 5(min), meanwhile using traditional measurement it takes 2(H) to OGMA 2(H).

  With the huge change expected in Man-hours has been considered of interest the calculation of the labor savings or Freed Capacity (FC) that would be obtained, this is to say, the change in number of Full Time Equivalent (FTE) employees needed for the dimensional control processes. As a result, it has been obtained that 1.421 FTE's (almost one and a half full time employees) that could be reassigned to other tasks and positions as consequence of the efficiency improvement in the process.

- Blade Surface Repair, Polishing Re-work and Fairing Finishing

  Since in the diagnose of these processes was stated that the current layout is wrongly designed for a full exploitation of existent resources, the countermeasure that has been proposed is the conception of a new layout for the grinding and polishing activities area. The new layout would consist in placing the incorrect posts in opposite direction to the way they are currently placed, resulting in the following combination (Figure 7). In order to be able to perform this change in the layout some adjustments must be done: Blade's location posts would move to their counter direction, extractors corners which are useless and vent pipe's horizontal parts must be cut off. Everything was measured and two dimensional maps of current and future states have been designed.

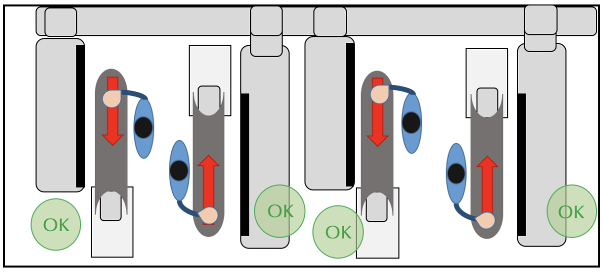

Figure 7: Polishing and grinding problem solution illustration

- Plastic Foam Fairing

  The solution to this problem starts by ordering one new fairing mold in order to treat in the oven the complete batch simultaneously, and therefore, making use of all available resources.

  Additionally, it has been considered of interest from a lean perspective to think about a preventive measure that could keep fairings mold rupture for happening again. It has been found that the blade's repair manual ([8]) states that one hour cooling period at room temperature must precede molds removal. Since currently employees are unaware of this mandatory cooling time, a visual alert to place over the molds and a procedure to locate at the oven area have been created.

6.3. Solutions summary diagram

The following diagram (Figure 8) recaps the different exposed countermeasures.

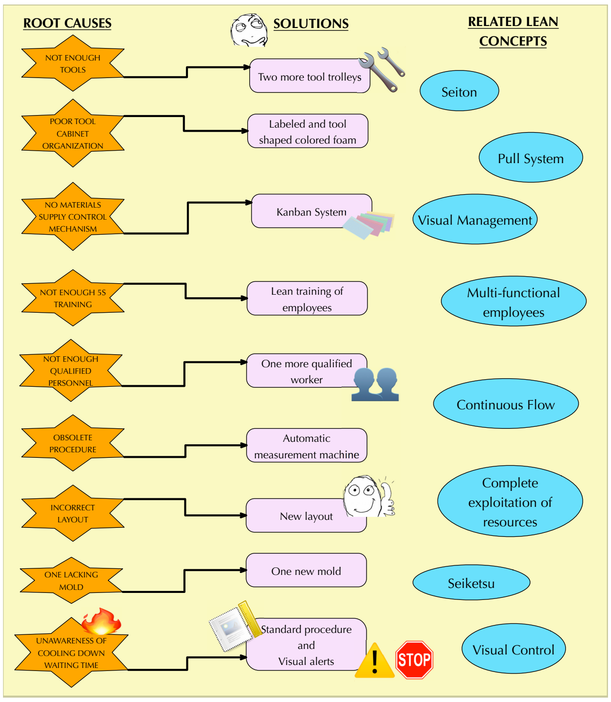

Figure 8: Countermeasures summary diagram

7. Conclusions

7.1. Envisioned gains

In the following table (Table 1) appear all processes that constituted the case of study and their current and future Lead Times that would be attained through the implementation of the different proposed solutions within processes.

Table 1: Lead Time gains

	Current State (H)	Future State (H)
DISASSEMBLY + BUSHING INSPECTION	1	1
LEAD WOOD REMOVAL	1	1
CLEANING	1	1
PLASTIC FOAM FAIRING REMOVAL	9	9
BOROSCOPE INSPECTION	10	5
DIMENSIONAL CONTROL	16	0.67
PRELIMINARY BALANCE	1	1
BLADE SURFACE REPAIR	13	6.5
POLISHING RE-WORK (TREME)	8	4
PLASTIC FOAM FAIRING	25	16.5
FAIRING FINISHING	4	2
BONDING	24	24
BUSHINGS INSTALLATION	3	3
BALANCING	1	1
TOTAL	**117**	**75.67**

The Process Lead Times of those activities in their current state sum up a total Lead Time of 117 (H), after the implementation of the diverse solutions that have been proposed a total Lead Time of 75.67 (H) is expected, resulting in a **35**% of overall optimization.

Difficult to quantify their impact are the suggested solutions related with the acquisition of new tool trolleys and the better organization of the tools in a more visual way, as well as the Kanban System that will prevent situations of lacking materials and the excess of materials inventory, also the evolution towards a more lean environment and pull ordering relationship with the warehouse.

7.2. Furure work

The most critical Lead Times inside the Overhaul process correspond to those processes carried out outside propeller's area which were not the object of study of this thesis, the Activity Ratio of those processes is really small in comparison with all the other ones, indicating that transporting and waiting times are really important there, this is because in those processes the resources available must be shared with other OGMA products. A more significant improvement in the Overhaul process would imply the study of these external processes and a better planning and coordination between those external areas and the propellers department.

Regarding to the proposed solutions, following the Deming Wheel philosophy of "Plan, Do, Check and Act", they must now be implemented and the obtained results quantified, that will dictate the future actions to take. This quantification and control could be performed through the implementation of well known lean tracking tools, such as Visual Management or Key Performance Indicators.

If the Kanban solution were finally implemented it would be important the Kanban maintenance. The factors that impact the Kanban must be reviewed periodically, and the number of Kanban cards must be recalculated if these factors happened to change and ensure that inventory matches demand. Also a person in charge of dropping the Kanban cards and the replenishment of materials would be necessary to its proper functioning: a "Water Spider". It is important to highlight that even though a high service level of 95.05% has been imposed in the calculations of the safety stock for each material in order to guarantee the proper functioning of the system through the demand fluctuations, a Kanban System works better if the demand is stable, so a more stable demand would provide better results and allow to have less safety stock. Also, as inventory levels are being reduced through the implementation of the Kanban System it may be found more problems that need to be addressed before the inventory level can be reduced further, such as poor scheduling, line imbalance, communication problems, lack of house-keeping, vendor delivery problems, etc.

In the creation of a continuous improvement culture that could sustain the proposed changes, the development of standardized procedures and internalizing the new changes through routine until they become habits (Kata) are essential steps. Also, employees job satisfaction will be fundamental to guarantee the success of the Lean implementation.

Finally, it must be recalled that Lean is a philosophy of continuous improvement (Kaizen), and thus it promotes the belief that what is good enough today is not good enough for tomorrow and that there is always opportunities for improvement, so it will be always future work.

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