Application of Lean Manufacturing in the maintenance of propellers

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Thesis to obtain the Master of Science Degree in

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Resumo

O mercado global actual, com a sua elevada competitividade, força as empresas do sector aeronáutico a uma reavaliação constante dos seus processos internos, com o objectivo de optimizá-los ao máximo numa tentativa de manter uma posição de relevância. Os princípios e as metodologias de produção *Lean* têm em vista a redução ou eliminação de qualquer tipo de desperdício nos processos de uma empresa, maximizando a capacidade produtiva, reduzindo tempos de espera e custos de operação. Aumentos na qualidade do produto, na segurança e na pro-actividade de membros da força de trabalho também são consequências típicas desta implementação. O trabalho desenvolvido durante a elaboração desta tese visou melhorar o processo de ”Overhaul” de hélices na empresa OGMA, recorrendo à implementação de diferentes técnicas e conceitos de produção Lean.

Uma análise da situação actual e respectivo diagnóstico foram realizados. Nestes, foram usadas as ferramentas de: auditoria Lean para determinar o status atual das “5S”, “Bottleneck Analysis” através do “Process Mapping” e “Root Cause Analysis” dos problemas encontrados empregando a técnica dos “5 Whys”. Previamente, e como requerimento para a aplicação de todas estas ferramentas, os tempos e métodos utilizados foram registados, presencialmente, no “Gemba”.

Diferentes medidas foram consideradas, todas baseadas em conceitos chave de Lean como: Kanban, Kaikaku, Controlo Visual, redução das ”Barriers to Flow, treino Lean e um aproveitamento pleno dos recursos disponíveis. Os ganhos resultantes da implementação de cada medida foram previstos e algumas medidas adicionais e possível trabalho futuro foram sugeridos.

Palavras-chave: Lean, 5S, Análise de Gargalos, 5 Whys, Controlo Visual, Kanban

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; increases in quality, safeness and employee engagement are also 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

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Nomenclature

Acronyms

5S	Five Ss
ACO	Aircraft Certification Office
FAA	Federal Aviation Administration
FTE	Full Time Equivalent
JIT	Just in Time
JWO	Japanese Work Organization
NDI	Nondestructive Inspection
NVAT	Non Value Adding Time
PDCA	Plan-Do-Check-Act
POU	Point-of-Use
SMED	Single Minute Exchange of Dies
TPS	Toyota Production System
VAT	Value Adding Time
VSM	Visual Stream Mapping
WIP	Work In Progress

Abbreviations

Apr	April
avg	Average
BSR	Blade Surface Repair process
FF	Fairings Finishing process
GL	US Liquid Gallon

H	Hours
Jan	January
Kg	Kilogram
L	Litre
M-H	Man-Hours
mg	Milligram
min	Minutes
mL	Milliliter
MT	Machine Time
PLT	Process Lead Time
PRW	Polishing Re-work process
PT	Process Time
QTY	Quantity
UM	Unit Measure

Latin variables

AR	Activity Ratio
DD	Daily Demand
DLT	Demand through Lead Time
FC	Freed Capacity
FTE	Full Time Equivalent
LT	Lead Time
PLT	Process Lead Time
PT	Process Time
QTY	Quantity
SS	Safety Stock
V	Variance
VA%	Value Percent of Time
Zscore	Z Score

Greek variables

σ	Standard Deviation

Subscripts

cont	Container
CS	Current State
DD	Daily Demand
FS	Future State
i	Enumerates each sample of a data set
j	Enumerates different data sets
m	Number of a data sets
mat	Material
N	Number of samples of a data set
prop	Propeller

Symbols

#	Number

Chapter 1

Introduction

In this first chapter the thesis main motivation, topic and major objectives will be exposed, as well as the outline that the document will follow.

1.1 Motivation

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.

It is a fact that the implementation of lean techniques are beneficial for any process or organization and everyone involved in it, from workers to customers. They reduce the waiting time and operating costs, they also lead to an increase in quality, safeness and improvement of employee engagement and morale.

Having said that, 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 company, and particularly in the area of propellers maintenance.

1.2 Topic overview

Different techniques and strategies of Lean Manufacturing are going to be studied and applied with the purpose of ameliorate the processes involved in the expertise and blades repair of aircraft propellers at OGMA enterprise.

First of all, a general overview of Lean Manufacturing is going to be presented: its origins, the main principles of Lean, its most commonly used techniques and other useful concepts. Then, the case of study is going to be portrayed and analyzed, the critical processes or bottlenecks are going to be

detected and other general deficiencies which affect the overall process will be spotted, their root causes will be identified and several solutions to them will be proposed, the different improvements associated with the implementation of those solutions will be envisioned and finally, some conclusions and further future suggestions will be presented.

1.3 Objectives

The main objectives of this thesis can be summarized in the following points:

- Observation, measurement of times and identification of improvements in a lean optic of the blades processes of the propellers Overhaul, specifically those carried out inside the propellers area.
- Development of solutions to the spotted problems and validation of them with the production team.
- Forecast of future gains that would be attained through the implementation of the proposed solutions.

1.4 Thesis outline

The present document will follow the following structure:

- **Chapter 1: Introduction**

  In the present chapter it is exhibited the thesis main motivation, a brief synopsis of the topic, the leading objectives and the thesis outline.

- **Chapter 2: General concepts and techniques of Lean Manufacturing**

  This chapter contains an introduction to Lean Manufacturing: Its history, its most common techniques and tools and some useful concepts.

- **Chapter 3: Case of study**

  Along this chapter, an brief introduction to the company is presented and the case of study is portrayed: The workplace area and the flowcharts which characterize the Overhaul process are exhibited, furthermore it is clarified which subprocesses are within our field of analysis.

- **Chapter 4: Diagnosis and root cause analysis**

  Through this chapter the diagnosis of the current situation is presented, the critical processes are identified, the different spotted problems are analyzed and their root causes found.

- **Chapter 5: Proposed solutions**

  This chapter includes the various proposed solutions to the problems encountered during the diagnosis phase and in order to indicate the gains that would be attained through their implementation, the foreseen changes in times and other useful performance metrics are exhibited.

- **Chapter 6: Conclusions**

  Finally, this chapter includes a recapitulation of the various lean techniques that have been employed and the different solutions proposals, also the overall time savings that would be achieved and some further suggestions for future work are presented.

Chapter 2

General concepts and techniques of Lean Manufacturing

This chapter aims to give an introduction to Lean Manufacturing and its most commonly used techniques.

2.1 Definition. What is Lean?

Lean is an operational excellence strategy that enables people and organizations to change for the better. It is a people based system focused on creating customer value, this means, any action or process that a customer would be willing to pay for, while minimizing waste (everything else that is not adding customer value: processes or activities that use more resources than strictly necessary). In a nutshell, Lean means creating more value for customers with fewer resources through the persistent pursuit and elimination of waste. [1]

2.2 Origins 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. Taylor established the first bases of the organization of production through the application of the scientific method to processes, times, equipment, people and movements. Later on, Henry Ford created the first assembly line revolutionizing the automobile industry, wherein he made an intensive use of the standardization of products, machines for elementary tasks, the simplification and sequencing of tasks and routes, the synchronization between processes, specialized training and the specialization of work. In both cases they were sets of actions and techniques that sought a new form of organization and that arose and evolved at a time when rigid mass production of large quantities of product was possible. [2]

The breakup with these mass production techniques occurs in Japan, where the first germ of lean thinking emerges. Already in 1902, Sakichi Toyoda, who later founded with his son, Kiichiro, the Toyota Motor Company Corporation, invented a device that stopped the loom when the thread broke and indicated with a visual signal to the operator that the machine needed attention. This system of “automation with a human touch” allowed man to be separated from the machine. With this simple and effective measure a single operator could control several machines, which meant a tremendous improvement in productivity that gave way to a permanent concern to improve working methods.

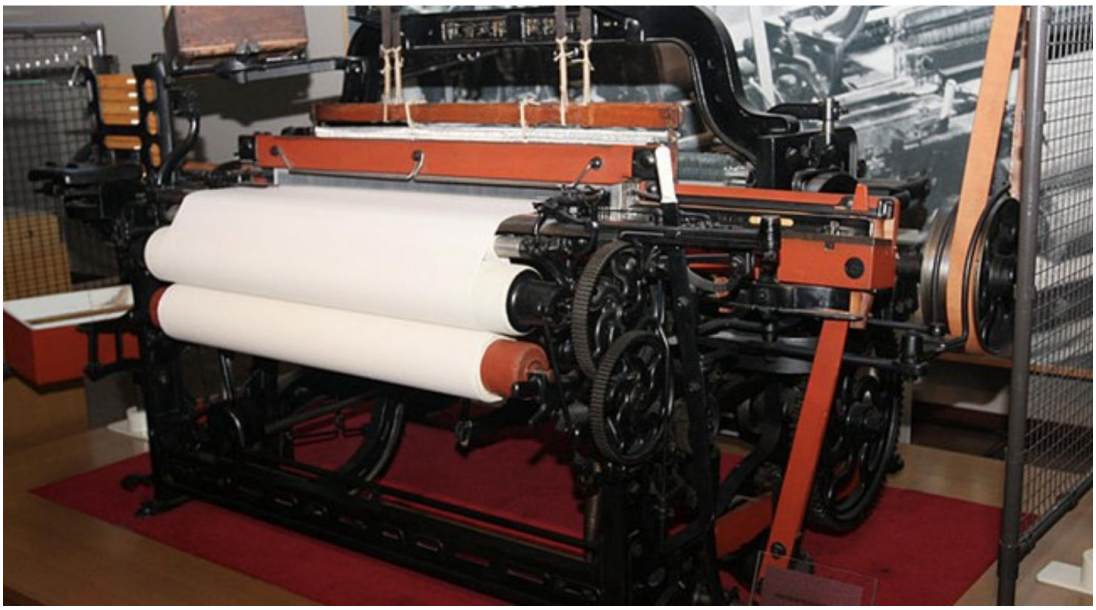

Figure 2.1: Type-G Toyoda Automatic Loom, the origin of Jidoka [3]

For his contributions to the industrial development of Japan, Sakichi Toyoda is known as the “King of Japanese inventors”. In 1929, Toyoda sells the rights to his patents (looms) to the British company Platt Brothers [4] and orders his son Kiichiro to invest in the automotive industry, thus creating the Toyota company. This firm, like the rest of the Japanese companies faced after the Second World War the challenge of rebuilding a competitive industry in a post-war scenario. The Japanese became aware of the precariousness of their position in the global economic scenario, lacking raw materials, they could only count on themselves to survive and develop.

The challenge for the Japanese was to achieve productivity benefits without resorting to economies of scale. They began to study the production methods of the United States, with special attention to the productive practices of Ford, the statistical process control developed by W. Shewhart and the quality techniques of Edwards Deming and Joseph Moses Juran, as well as the developed in Japan itself by Kaoru Ishikawa. [5]

In this environment of “survival” the Toyota company searched intensely for new practical alternatives. At the end of 1949, a collapse in sales forced Toyota to fire a large part of its workforce after a

long strike [6]. At that time, two young engineers from the company, Eiji Toyoda (Kiichiro's nephew) and Taiichi Ohno, who is considered the father of Lean Manufacturing, visited American automobile companies. At that time, the American system advocated reducing costs by manufacturing vehicles in large quantities but limiting the number of models. They observed that the rigid American system was not applicable to Japan and that the future was going to ask to build small cars and varied models at low cost. They concluded that this would only be possible by suppressing stocks and the different types of waste. So they detected several drawbacks in the American model, saw them as a opportunities for improvement and built a new system which sought to eliminate all possible wastes in production and focused on value-add functions. [7]

From these reflections, Ohno laid the foundations for the 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, also an industrial engineer from Toyota, who studied in detail Taylor's scientific management and Gilbreth's time and motion theories. He 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. His first applications focused on the radical reduction of tool change times, creating 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. [8]

The JIT / TPS system gained notoriety with the 1973 oil crisis and the loss-making of many Japanese companies. Toyota stood out above the other companies and the Japanese government encouraged the extension of the model to other companies. [8]

However, 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 [2]. This book summarizes the International Motor Vehicle Program (IMVP) that was carried out at the MIT (Massachusetts Institute of Technology) in order to contrast, in a systematic way, the production systems of Japan, Europe and the United States; highlighting and demonstrating the clear superiority of the Japanese Toyota system compared to all its competitors since its techniques used less human effort, capital investment, floor space, materials, and time in all aspects of operation than western methods. In this publication, 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 of the Toyota production methods into the Western manufac-

turing system. Precisely, according to Suzuki (2004), the foundations that make up Lean Manufacturing are Jidoka and JIT techniques, together with the Japanese Work Organization system (JWO) (which consists in devising and establishing a way to organize the work oriented to the exhaustive practical application of the skills of the workers, that is, to the full utilization of the capabilities of the workforce). [9]

2.3 Structure of the Lean System

Traditionally, the scheme of the “House of the Toyota Production System” (Figure 2.2) has been used to quickly visualize the philosophy contained in Lean and the techniques available for its application.

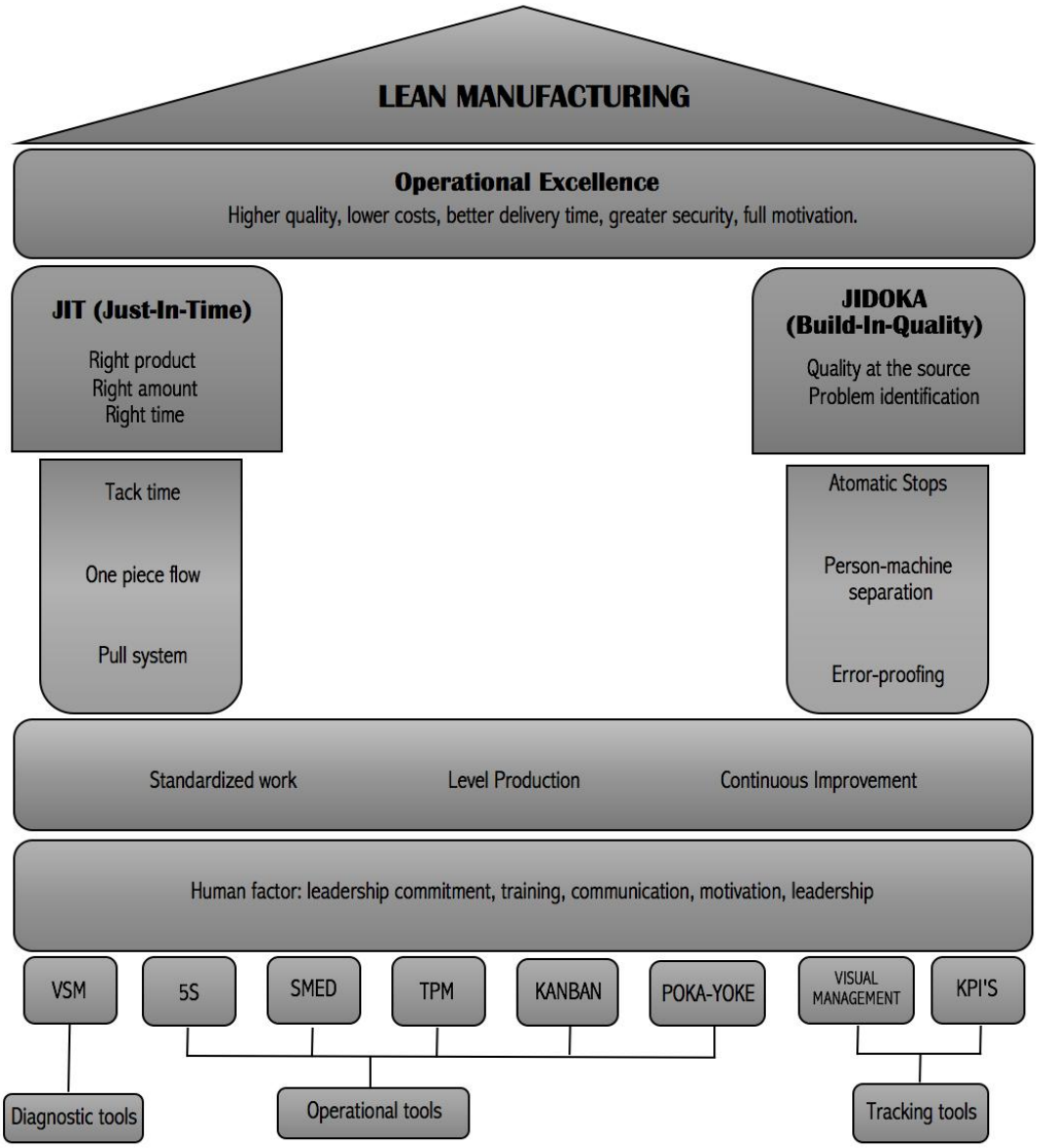

Figure 2.2: Toyota House

The Toyota Production System was established based on two pillars [7] [8]:

- **Jidoka — Manufacturing high-quality products.** This concept is based in the notion that quality must be built in during the manufacturing process, ceasing dependence on inspection to achieve it.

  The term Jidoka used in the TPS can be defined as "automation with a human touch" and traces its roots to the invention of the automatic loom (Figure 2.1): since the loom stopped when a problem arose, no defective products were produced and a single operator could be put in charge of numerous looms. In order to implement Jidoka successfully Visual Control (section 2.6.2) is commonly employed, allowing operators to identify problems in the production line with only a glance.

- **Just-in-Time — Philosophy of complete elimination of waste, productivity improvement.** This concept is based in the notion of making only what is needed, when it is needed, and in the amount needed.

  One of the main challenges that the JIT system presents is to achieve a balance in the production, allowing an harmonic operation depending on the customer's demand. Here the concept of Pull System appears, where opposed to the traditional Push System where lots of products are manufactured regardless of external demand, the client "pulls" from its endpoint to indicate the need for delivery, thus making the system produce only what the customer requests. In order to carry this out, the processes and the effects that the variations of the demand have on them must be perfectly known. The Heijunka method, whose literal translation is "leveling", seeks to intelligently understand the client's demand and adapt the processes to be able to comply with it while avoiding excess inventory of raw materials, products in process and finished products. The common tool employed to implement JIT is the Kanban System (section 2.6.2).

So to sum up, the main focus of TPS is in the elimination of waste and the minimization of batch sizes, ideally only one piece at a time: Single-piece-flow. The achievement of both of these main objectives requires stable and regularized processes, situation which can be attained through workplace organization, standard operating procedures, and fail-safe processes (Jidoka). Lean also requires creating a self-learning and continuously improving organization (Kaizen), several aspects in the organization can contribute to this purpose, such as: more transparency thus facilitating immediate faults identification (usually through Visual Management (section 2.6.3)) and the conduction of rigorous Root Cause problem solving; additionally must be stressed out that it is utterly important to make this continuous improvement thinking part of the daily working routine and team philosophy to guarantee its success. [10] [7]

2.4 Unwanted attributes: The 3Ms of Lean

The 3Ms of Lean is a concept which underpins some of the nuclear principles in Lean Manufacturing.

The 3Ms are derived from three Japanese words. Each of which describes an undesirable property in our processes or work environment.

- **Mura**: Roughly translated as inconsistent, erratic, irregular or uneven. This is, fluctuating production or workload due to poor planning, staffing, inoperative equipment, missing supplies or irregular demand.
- **Muri**: Mura inside a process leads to Muri or overburden, also translated as unreasonable, impossible or excessive. Results in safety and quality problems.
- **Muda**: Finally, Mura and Muri lead to Muda, which means futile, useless or pointless, this is to say, non value-added: waste.

In Lean people use to talk about waste elimination and they refer to Muda, but it is important to understand that Mura and Muri can be progenitors of Muda. From this it can be deducted that variability is the main enemy of Lean approach, for this produces overburden which triggers activities that do not produce value [11]. Mura is a root cause Muda is an outcome.

2.4.1 Seven Muda: The 7 wastes of Lean

In order to eliminate waste, no value adding activities must be identified in order to lessen as much as possible the time spent there. The seven forms of waste also known as Ohno's seven muda have been identified as [12]:

- **Transportation.** Unnecessary movement of people or parts between process. Every time a product is touched or moved unnecessarily there is a risk that it could be damaged, lost, delayed, etc. as well as being a cost for no added value.
- **Inventory.** Excess of stock. Raw material, work in progress (WIP) or a finished good which is not having value added to it.
- **Motion.** Unnecessary movement of people, parts or machines within a process. Excessive travel between work stations, excessive machine movements, etc.
- **Waiting.** People or parts that wait for a work cycle to be completed. Waiting is not something that the customer will be willing to pay for, the cost of the time spent waiting will come directly from the company's profit.
- **Over Processing.** Processing beyond the standard required by the customer. Putting more into the product than is valued by the customer. Clear standardized instructions avoid over-processing.
- **Over Production.** To produce sooner, faster, or in greater quantities than the customer demand. The aim should be to make only what is required by the customer when it is required, the philosophy of JIT.

- **Defects.** Repetition or correction of a process. Implementation of poka-yoke systems and autonomation can help to prevent defects from occurring.

Apart from the Ohno's seven muda that have already been presented, Womack identified an eighth source of waste related to the design of products or services that do not meet client's necessities. [13]

2.5 PDCA Cycle

PDCA stands for Plan-Do-Check-Act and is an iterative four-step management method used in business for the control and continual improvement of processes and products [14]. It is also known as the Deming Cycle or Deming Wheel after W. Edwards Deming, who introduced the concept in Japan in the 1950s [15]. It is one of the key elements in Lean Manufacturing, or for that matter in any kind of improvement process.

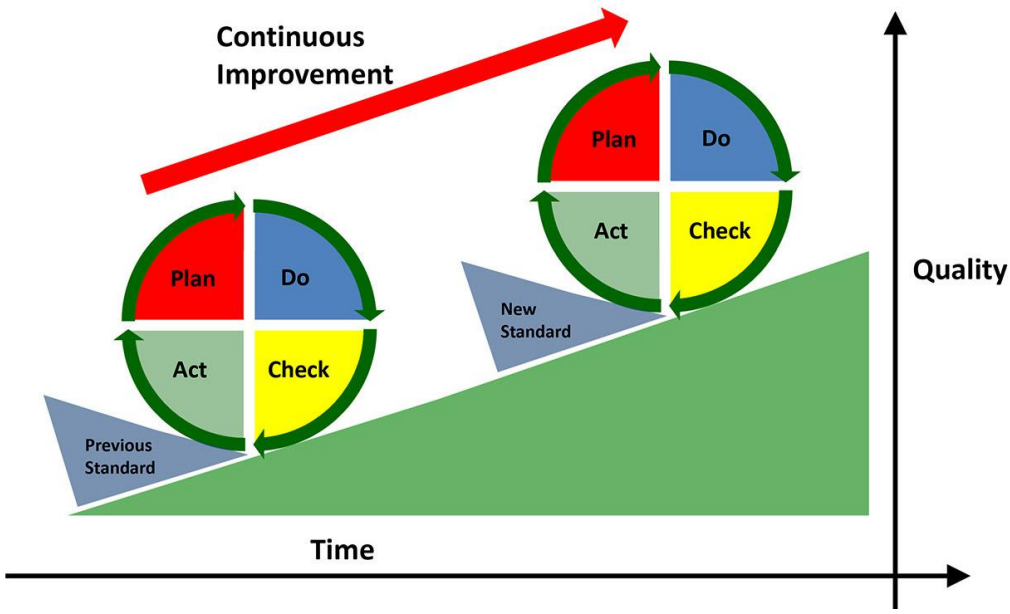

Figure 2.3: PDCA Cycle and its relationship with Kaizen philosophy [16]

The PDCA cycle has four stages:

- **Plan**: Determine goals for a process and needed changes to achieve them.
- **Do**: Implement the changes.
- **Check**: Evaluate the results in terms of performance.
- **Act**: Standardize and stabilize the change or begin the cycle again, depending on the results.

2.6 Some of the main tools of Lean Manufacturing

In this section a further exploration of the tools that are somehow more related to the thesis development will take place.

2.6.1 Diagnostic tools

Process Mapping Tools

Process Mapping also known as Flow Charting. It is one of simplest and most valuable 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 of Process Mapping 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 types is the Value Stream Mapping.

- **Value Stream Mapping (VSM)**
  VSM is a very useful panoramic view of the entire value chain, showing both the flow of materials and the flow of information from the supplier to the customer. The VSM also shows stock levels, manning, process times and other useful pieces of information that can be used to analyze your overall process flow. A key aspect is that VSM collects a timeline with Value Adding Times (VAT) and the rest Non Value Adding Times (NVAT). The comparison between these two is enlightening and can be an excellent indicator of potential for improvement.

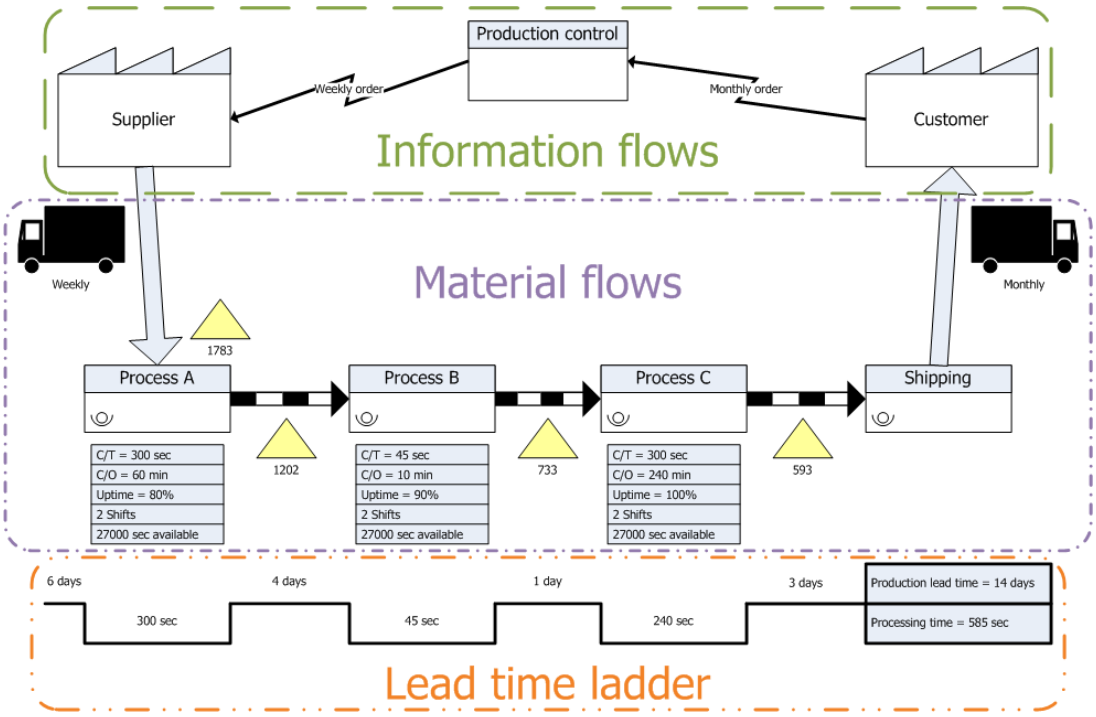

Figure 2.4: Typical VSM [17]

5 Whys

The 5 Whys is one of the simplest analysis tools the easy identification of the root cause of a problem as well to determine the relationship between different root causes.

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.

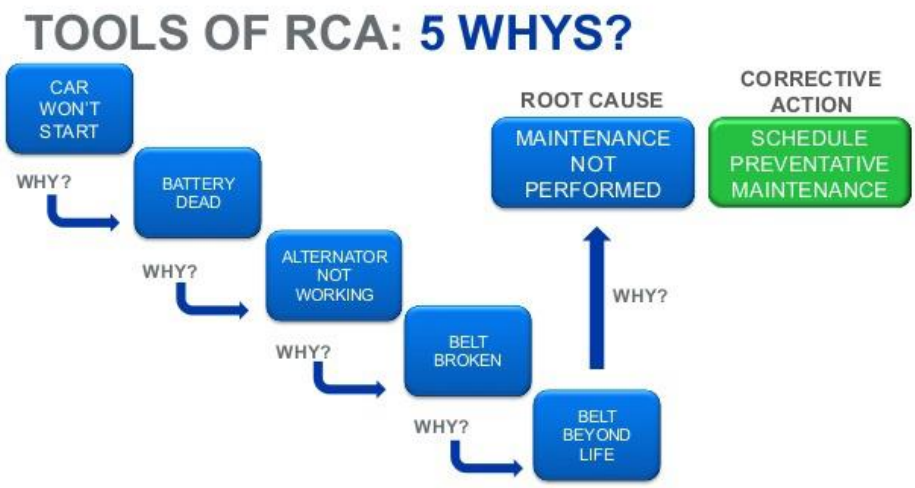

Figure 2.5: Example of 5 Whys implementation [18]

2.6.2 Operational Tools

Lean 5S

Lean 5S is a systematic and sustainable method to organize the workplace not just tidying. This method encourages ownership and self-discipline for sustainability. It is a technique that is applied worldwide with excellent results due to its simplicity and effectiveness, and because of that, it 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 (machines, facilities, tools, etc.), clutter (busy corridors, loose tools, etc.), 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.

Figure 2.6: Lean 5S [19]

The 5s method implies five steps which can be summarized as [20]:

- **SEIRI - SORT.** To free up space and remove cluttering by sorting out what is needed and not needed and then keeping only the necessary items in the workspace.
- **SEITON - SET IN ORDER.** To arrange items to promote efficient workflow. By marking the limits of work, storage and corridor areas and having an adequate place for each thing, avoiding duplicities. Each thing in its place, each place for one thing.
- **SEISO - SHINE.** To clean the work area so it is neat and tidy. A better and cleaner environment will make easier the identification of faults and will create a good first impression among workers.
- **SEIKETSU - STANDARDIZE.** To set standards for a consistently organized workspace. This will sustain improvements, make 5S a routine and ensure that there is not a fall back into the old ways (as can be glimpsed in Figure 2.3).
- **SHITSUKE - SUSTAIN.** To create the habit, this is to say, maintenance and costant revision of standards. This is maybe the most difficult part, 5S is a culture that needs to be developed and cultivated in the organization, this needs training and stimulation of employees awareness, everyone has to share the same values and employees have to support the method. The idea is to make the 5S an embodied philosophy among workers in order to avoid breaking the already established procedures.

Kanban

Kanban is the Japanese word for “card”. Kanban can be defined then as visual method for controlling production or materials as part of JIT and thus Lean Manufacturing, 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 (WIP) 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’s WIP limits. If, for example, if 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.

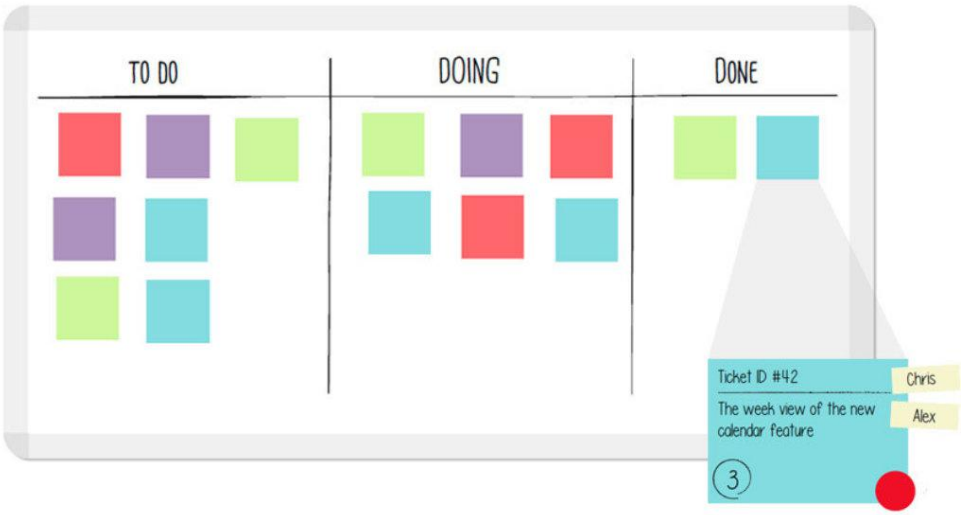

Figure 2.7: A physical Kanban board with a basic three-step workflow [21]

- 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.

  The ordering, though, is not necessarily from an external supplier. It may also be from some other department within the company or an order from a warehouse.

From this method different benefits can be achieved:

- To enable lean pull systems (to produce exactly what a customer needs and when it is needed and to order new materials just when needed).
- To enable lean flow, which is the over arching first priority for a lean transformation.
- To identify opportunities to improve efficiency.

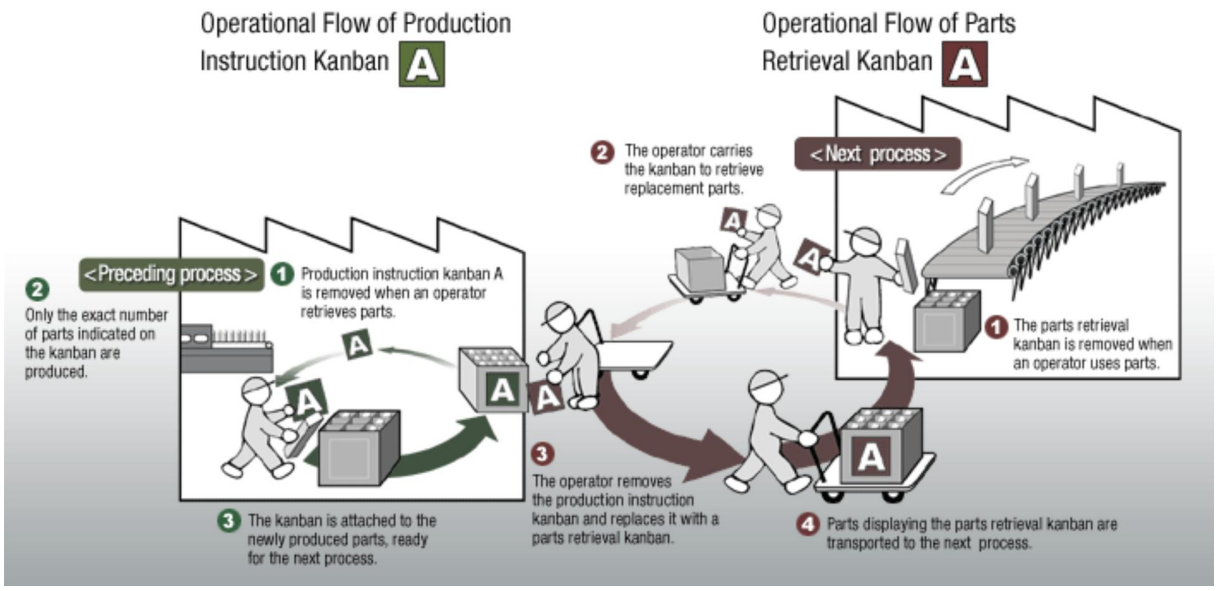

Figure 2.8: Coceptual diagram of the Kanban System. Two kinds of Kanban: Production and withdrawal [8]

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?

Figure 2.9: Examples of Visual Control implementation [22] [23]

2.6.3 Tracking tools

Visual Management

Visual Management means the use of visual aids to manage the operation, including schedules, performance tracking, stock controls and project status displays standard versus actual. The objectives of Visual Management are: Clarify waste, display problems in a simpler way, clearly indicate your efficiency goals and increase effective communication.

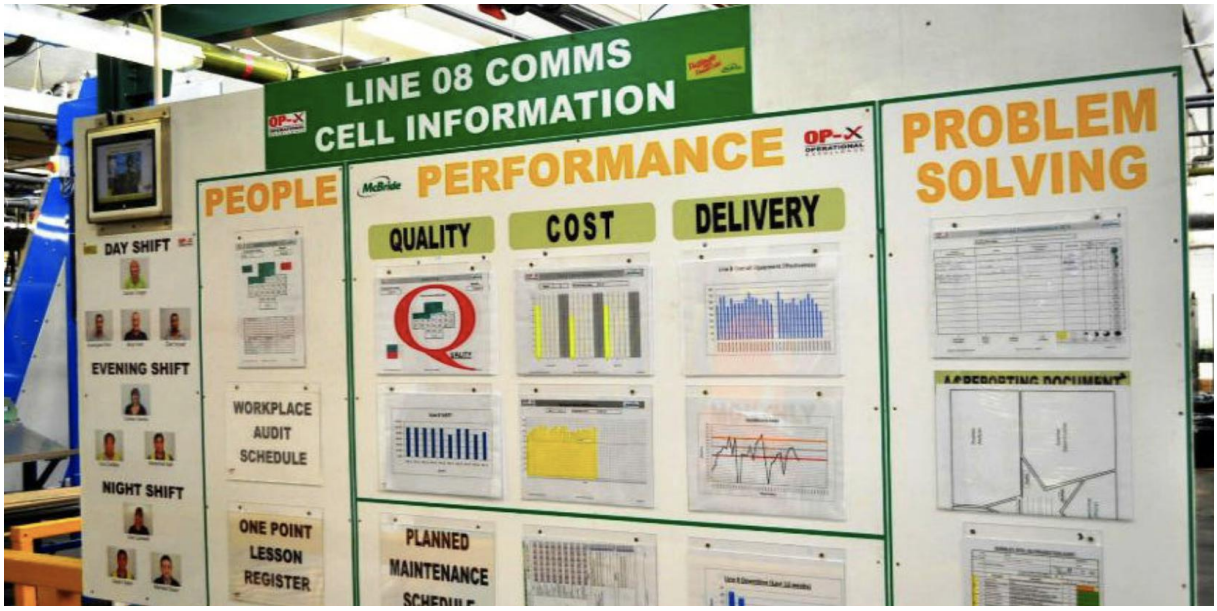

Figure 2.10: Example of Visual Management implementation [24]

Key Performance Indicators (KPIs)

KPIs are metrics that allow the monitoring of the continuous improvement of the companies.

It is convenient to define an accessible and reliable indicator system to capture, measure, analyze and evaluate the results and deviations from the objective in a methodical and reliable way. Indicators such as labor performance, hours dedicated to urgent work, repair costs or availability are valid for this purpose. A good and widely used numerical indicator is the Overall Equipment Effectiveness (OEE) because in a single indicator all the fundamental parameters of industrial production are evaluated.

- **Overall Equipment Effectiveness (OEE)**

  The OEE is a measure of system productivity. It relates the availability rate (which is a measure of the equipment stoppages), the performance rate (which measures the speed of the process) and the quality rate (which quantifies quality losses). It is calculated as shown in Figure 2.11.

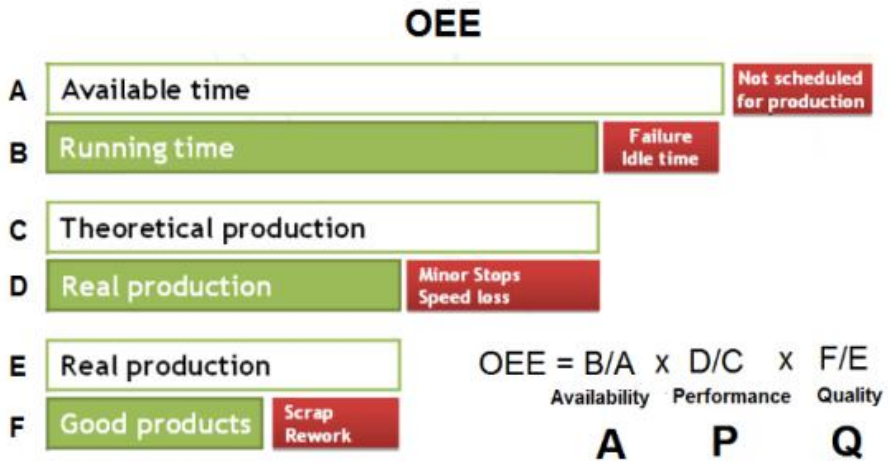

Figure 2.11: Overall Equipment Effectiveness (OEE) [25]

2.7 Additional definitions

This theoretical chapter is going to be concluded with some other essential lean concepts and tools that will be useful later on.

- **Flowchart**: A flowchart is a visual representation of the progression of an entity (product, person, information, etc...) through a process.

  Flowcharts have two main uses:

  - Process flowcharts are used for documenting the steps of an operation. The visual nature of the flow chart makes is useful for learning a process, for quickly checking the next step as a memory tool, or when reviewing the work of others.
  - Flowcharts are a problem solving tool. They are useful as an analysis tool in nearly every process improvement effort.

- **Flow**: The smooth, uninterrupted movement of a product or service through a series of process steps. In true flow, the work product (information, paperwork, material, etc.) passing through the series of steps never stops.

- **Barriers to Flow**: Any barrier, physical or not, that prevents the passing of one unit of work directly to the next process without the work stopping.

- **Continuous Flow**: A work process management system wherein workers only work on one unit at a time, and only one unit of work moves from process to process. Implementation of continuous flow can have significant impact on reducing throughput time, minimizing waste, and improving value-adding activity. This concept is also referred to as Single Piece Flow or One Piece Flow.

- **Batch and Queue**: A processing method where multiple pieces of work (often referred to as a “batch” or “lot”) are processed and/or passed together from one operation to the next. Upon arrival

at the next process, some or all of these pieces of work may wait in a “queue” to be worked on.

- **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. The process can be costly, but will usually lead to increased efficiency and profits. Ignoring a bottleneck issue can be very costly down the line.

- **Waiting in Process Time**: Time that a product (in our case it would be one blade) spends without being worked inside an specific process. It could be understood as a type of Queue Time but inside an specific process, the product is in line behind another one and waiting for the same resource.

- **Process Time or Processing Time**: Process time is a measure of the time a product is actually being worked on in a machine or by an employee in a work area, this is to say, the time that activities are being performed on WIP. Process time may consist of VAT and NVAT activities.

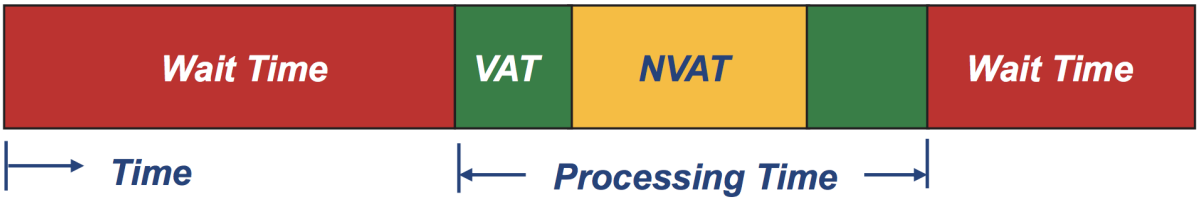

Figure 2.12: Process Time visual definition [26]

- **Lead Time**: Lead Time is the amount of time that passes between the commencement and the end of a process, it is measured by elapsed time (minutes, hours, etc...). Along the present document we will distinguish between the individual Process Lead Time of each Overhaul sub-process and the Total Lead Time or Overhaul Lead Time, which would be therefore all the sub-processes times added up to each other, plus all the waiting times between the sub-processes steps (Queue Times).

- **Man-Hours**: The sum of the working hours spent in a specific process by all the operators involved in it.

- **Machine Time**: The time that a machine is working on the product.

- **Activity Ratio**: An indicator of process efficiency, equal to the sum of the Process Times for the individual steps divided by Total Lead Time. The Activity Ratio is a good gauge of how much time work is sitting idle in a value stream. It is a solid measure of how quickly work moves through a process, a measure of flow, the higher the ratio the better the flow.

$$AR = \frac{(PT)}{(PLT)} \tag{2.1}$$

The drawbacks to using the activity ratio as an indicator is that there is no measure of value and might be a lot of waste in the process (for instance a specific process step may not be adding any value to the finished product).

- **Value Percent of Time**: VAT in the product along the process divided by the Lead Time of that specific process, expressed as a percentage.

$$VA(\%) = \frac{(VAT)}{(PLT)} \cdot 100 \tag{2.2}$$

  For each analyzed process it will be computed the Value Percent of Time per blade and per batch, on one side the first one will give us a notion of how much of the time that a blade spends inside the process is translated in actual value added to it (the rest will be idle work or waiting in process time). On the other side the second one will indicate complete idle time inside the process, this is to say, time that is not invested in adding any value to a blade neither to the other three of the batch.

- **Gemba**: The actual place where work is performed. This is a basic tenet of lean thinking: go to the place where work is being done and observe first hand the process in action because relying on data and observations produced by others does not give a complete understanding. So as Honda Company claims in its *Three Actuals* [27]:

  ”Go to the actual place - Talk to the actual people - Doing the actual work”.

- **Genchi Genbutsu**: Japanese term that refers to seeing for yourself. Genchi genbutsu is the act of going to the gemba.

- **POU**: POU stands for Point-of-Use. This term will be used to talk about the stock that is stored at the location where it will be employed. Since space is typically limited at the point-of-use it is important to have an adequate system to handle this material.

- **Kata**: Kata is the practice of routines. Kata are structured routines to practice deliberately a pattern that becomes a habit.

- **Water spider**: Also called water strider or ‘mizusumashi‘ in Japanese, is a person who has a prescribed set of tasks to keep materials in stock at the point of use in production areas. They take finished goods from the work area, drop Kanban cards, refill bins from central locations and remove waste materials so that the production personnel can focus on the value-added tasks that create products. A water spider has a standardized process, they should make their rounds the same way, and perform replenishment tasks identically each and every time.

- **Kaikaku**: Radical process improvement over a short period of time — innovation. Kaikaku is concerned with making fundamental and radical changes to a production system, unlike Kaizen which is focused on incremental minor changes.

- **Full Time Equivalent (FTE)**: Number of resources (usually people) required to run a process or series of processes if they were employed full time on that activity. [28]

$$FTE = \frac{\sum Processing\,Times\,(H) \cdot Occurrences/year}{Available\,work\,hours\,man/year} \tag{2.3}$$

- **Freed Capacity**: The amount of capacity created as a result of process improvements, typically expressed in number of FTEs. It is computed by subtracting for that specific process the FTEs needed in the future state from the FTEs required in the current state. [28]

$$FC = FTE_{CS} – FTE_{FS} \tag{2.4}$$

- **Countermeasure**: A tool applied to improve a process or work area by reducing or eliminating the root cause of an undesired effect.
- **Lean Audit**: A Lean Audit is a tool used to determine how well Lean Manufacturing principles are working in a factory or company.

Chapter 3

Case of study

Along this chapter a brief introduction to the company will be presented, the case of study will be define and, in order to help the reader in its understanding and envisioning, the industrial context and the different flowcharts indicating the diverse subprocesses involved in it will be exhibited.

3.1 Introduction to the company

OGMA – Indústria Aeronáutica de Portugal S.A. is an aerospace company providing maintenance services and manufacture of aerostructures. Since 1918 aircraft and engines have been produced and maintained at their facilities in Alverca.

A new era in the company's history started in 2003, when the government of Portugal took a decision to privatize almost the entire company. At that time, a major drive was initiated to make the company efficient on a world scale to expand into new unexplored markets. [29]

The company shares continued to vary until 2005 when they arrived to the current situation: Retaining the government of Portugal 35% of the shares and private ownership and Embraer owning the remaining 65% of the company share capital. [30]

OGMA is a fully qualified company in both civil and military aviation, with certification as a FAR 145 and EASA 145 repair station, AQAP 2110 and ISO 9001-2008 Quality Management. The company is an established and authorized maintenance center for several Original Equipment Manufacturers, including Lockheed Martin, Embraer, Rolls-Royce among others. [29]

MRO services provided by OGMA are divided into six areas: Commercial Aviation, Defence Aviation, Executive Aviation, Engines, Components, and finally, Engineering. The thesis has been developed in collaboration with the Components area, which is comprised of five different specialized shops: Electrical, Hydraulic & Fuel Systems, Avionics, Dynamic & Mechanical and Propellers. Of these, the latter was

the object of study of the present work. [29]

Figure 3.1: OGMA - Industria Aeronautica de Portugal S.A. [29]

3.2 Presentation of the case 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. The blades treated are solid aluminum alloy A711D-2, A7111E-2 propeller blades manufactured by Hamilton Standard Division. In a complete Overhaul process they pass through all processes as it is determined by the Overhaul Instructions manual.

OGMA usually performs around 73 overhauls per year, with fewer propeller inductions during summer season. A further study of the demand is exhibited in chapter 5 as it has been required for the development of one of the proposed solutions.

That will be the case of study and the present work will try to improve these processes through the implementation of some of the various tools provided by Lean Manufacturing.

3.3 Workplace

The main processes analyzed are carried out inside the propellers area and its layout is represented in the following map (Figure 3.2). Only a portion of the fairings manufacturing process is accomplished outside this area in a very close place, the landing gears room, wherein the oven is placed.

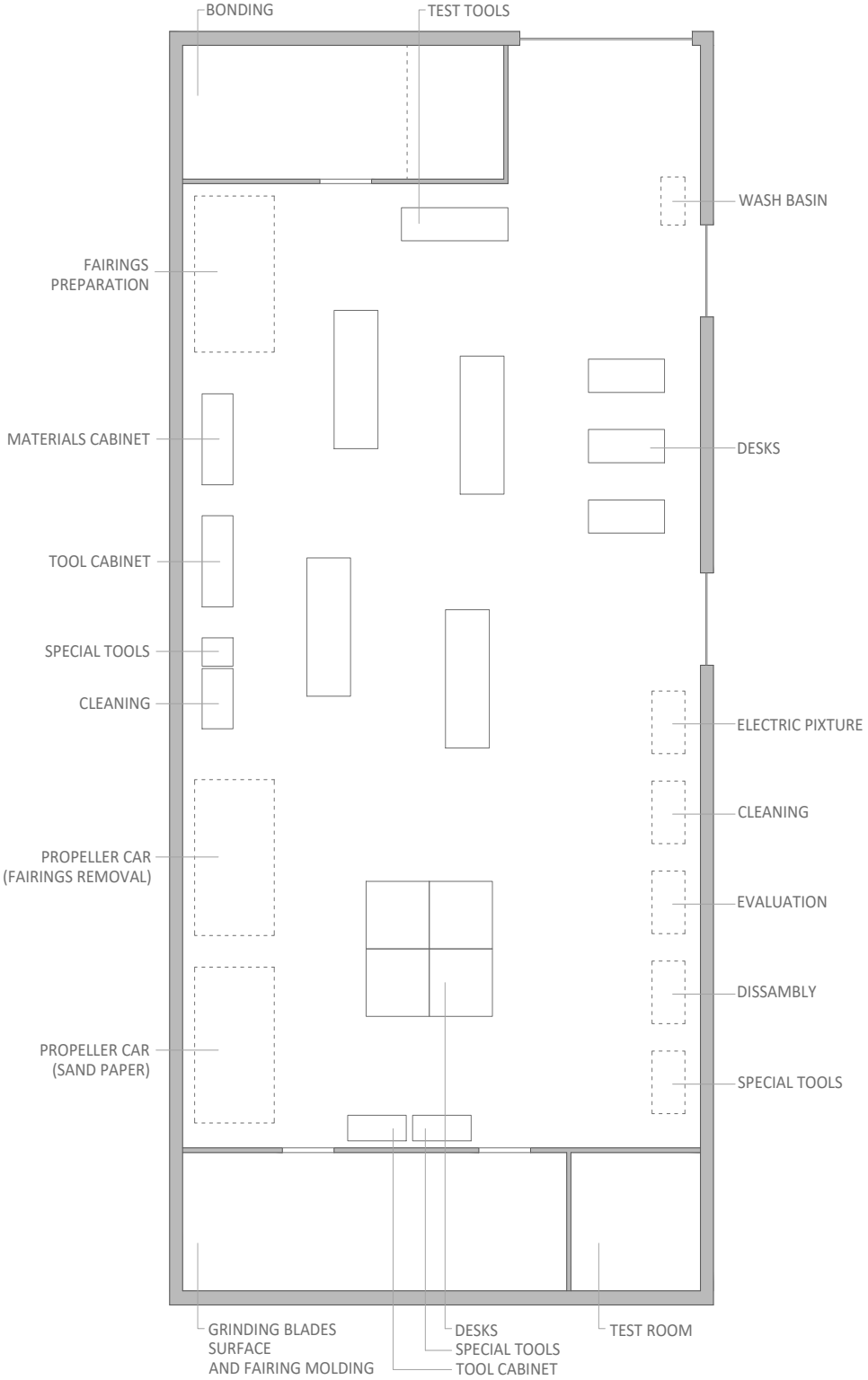

Figure 3.2: Propellers area map

Figure 3.3: Workplace view

3.4 Overhaul flowcharts

The Overhaul process is visually illustrated in the following flowcharts (Figure 3.4 and Figure 3.5). There, the different subprocesses through which the blades go through and other useful information about times and number of workers for each one are exhibited.

The first flowchart presents all blades related processes carried out from the propeller induction until expertise. The blue processes refer to processes that include all components and therefore they are not part of the case of study, likewise yellow ones which are also excluded since they are carried out outside propellers hangar in other OGMA facilities. All white and red processes comprise the case of study, being the red ones the most critical ones or bottlenecks since they have the biggest lead times.

In the second flowchart appear the activities executed after expertise. The operations prior to the pre-assembly are blades repair processes. After pre-assembly, the totality of the components continue all together to go through the last operations until the propellers expedition. The color codes and their implications remain the same.

The processes which comprise the case of study are therefore: 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. All of them were observed and timed at Gemba, and notes about the different abnormalities encountered and other relevant data where taken.

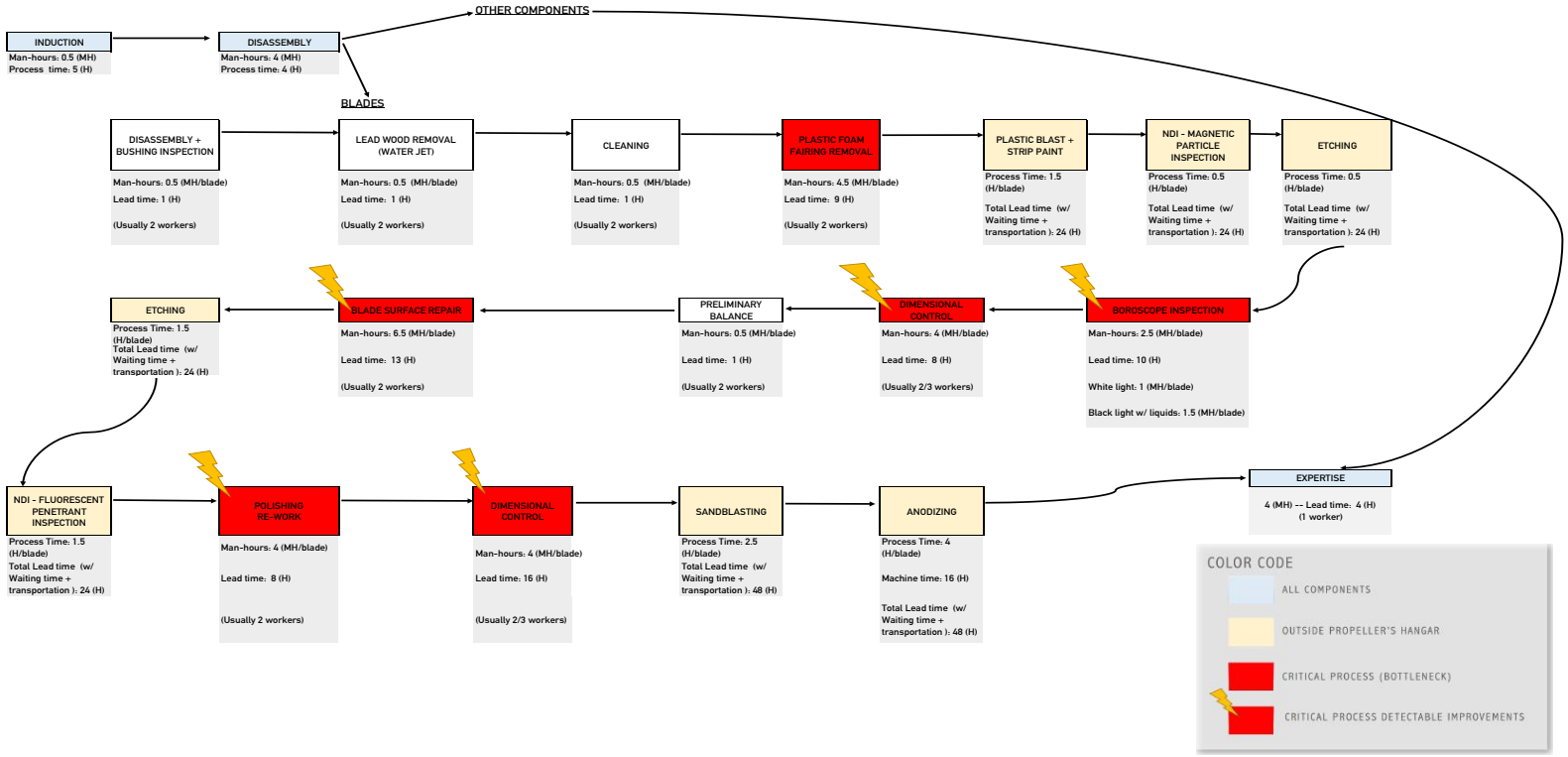

Figure 3.4: Expertise flowchart

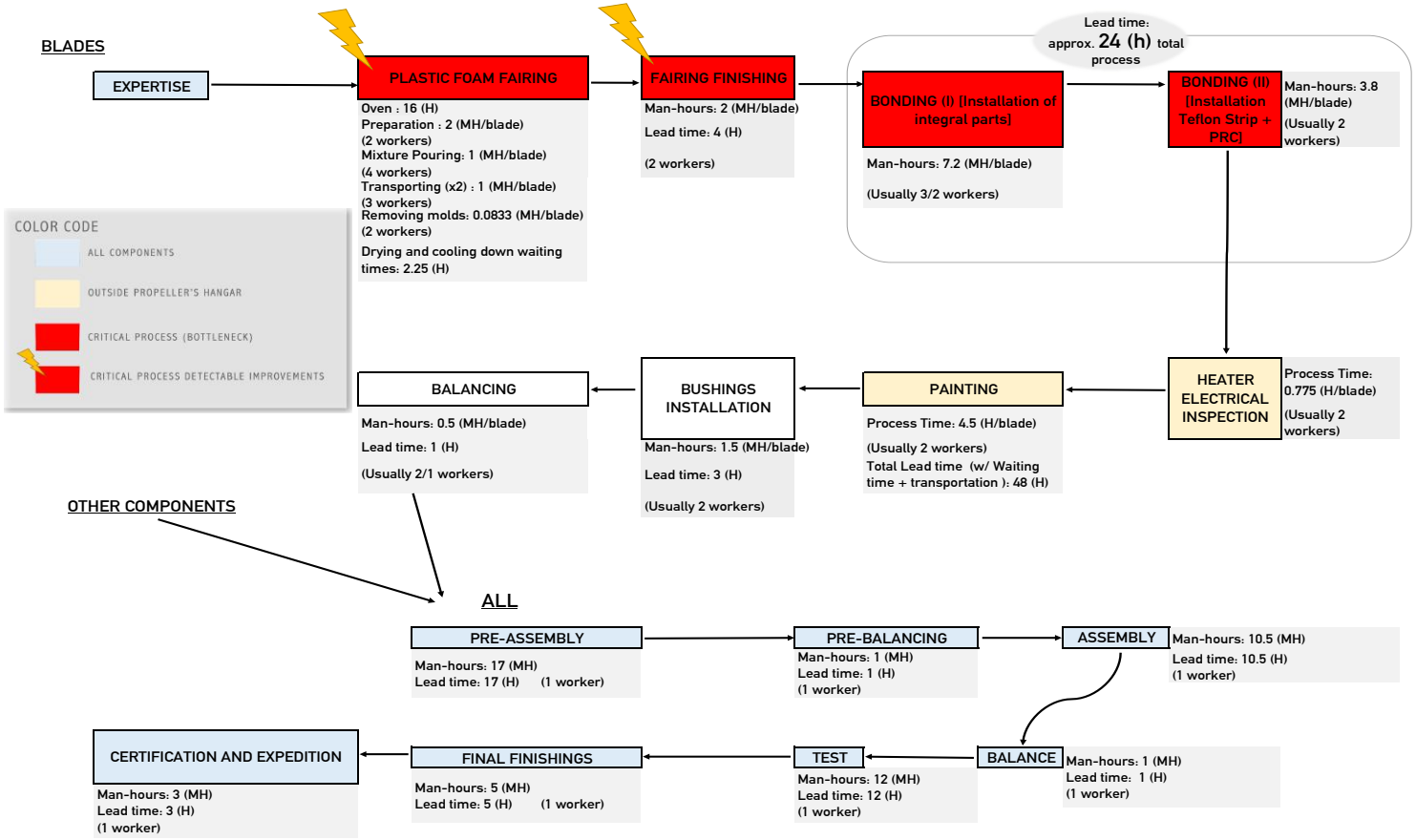

Figure 3.5: Blades repair flowchart

Chapter 4

Diagnosis and root cause analysis

In this chapter the case of study current situation will be analyzed. In the first part of the diagnosis the current 5S situation will be portrayed, as well as the root cause analysis of those problems encountered in relation with that situation. The second part of the diagnosis is focused on the analysis of the bottlenecks found inside our case of study, just digging deeper in the ones where some faults where detected: critical processes with observable improvements.

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.

4.1 Characterization of 5S status

In order to portrait the current situation of the 5S, since they constitute one of the main bases of Lean Manufacturing, diverse informal talks with the workers took place, during these talks a questionnaire addressing different questions and concepts related to each of the five categories was 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 (Figure 4.1) the following results where obtained (Figure 4.2): Seiri (sorted environment) and Seiton (organized place) where the worst rated categories from the subjective point of view of the employees. The different questions or concepts which in average were rated bellow three allowed the identification the following improvement opportunities: There are objects out of place preventing material movement or job development (as can be seen at Figure 4.3), 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 (Figure 4.4), 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.

5S' AUDIT QUESTIONNAIRE

1	Too bad
2	Bad
3	Average
4	Good
5	Too good

CATEGORIA		QUESTIONS	1	2	3	4	5	COMMENTS
Seiri (Sort)	1	Are there any unnecessary elements in workspace?						
	2	Are there any objects preventing material movement or job development?						
	3	Are there materials out of date or more materials than needed?						
	4	Are the corridors and work areas large enough and well marked?						
		TOTAL SCORE						
Seiton (Set in order)	1	Is there a specific location for the tools?						
	2	Are the tools visually marked?						
	3	Is the tool stand close to the work place?						
	4	Is it easy to recognize the place of each thing?						
	5	Are things repositioned in their place after being used?						
	6	Time spent looking for things						
	7	File arrangement						
		TOTAL SCORE						
Seiso (Shine)	1	Are the working areas clean?						
	2	Is the equipment kept in good condition and clean?						
	3	Are cleaning materials easy to locate?						
	4	Are cleaning measures and cleaning hours easily visible?						
		TOTAL SCORE						
Seiketsu (Standardize)	1	Do workers have all the necessary documentation for the development of their work, such as regulations and procedures?						
	2	Are all rules and procedures always respected?						
	3	Is there any standard procedure to carry out the stock control?						
		TOTAL SCORE						
Shitsuke (Sustain)	1	Do workers respect safety measures?						
	2	Are the organization, the order and the cleanliness being regularly checked?						
	3	Are the non-eating and non-smoking areas respected?						
	4	Team work						
	5	Self-discipline						
	6	Awareness of the 5s						
		TOTAL SCORE						

Figure 4.1: 5S questionnaire

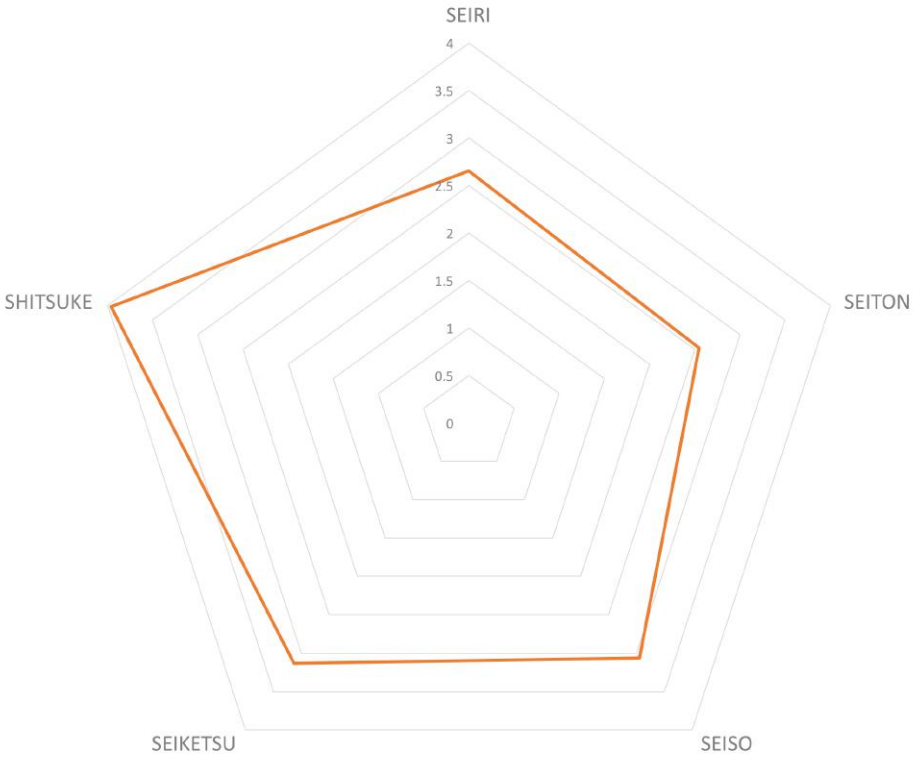

Figure 4.2: Results obtained from 5S questionnaire

Figure 4.3: Unwanted situations found in the workplace

Figure 4.4: Current situation of the tools cabinet

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

1. Time spent looking for tools

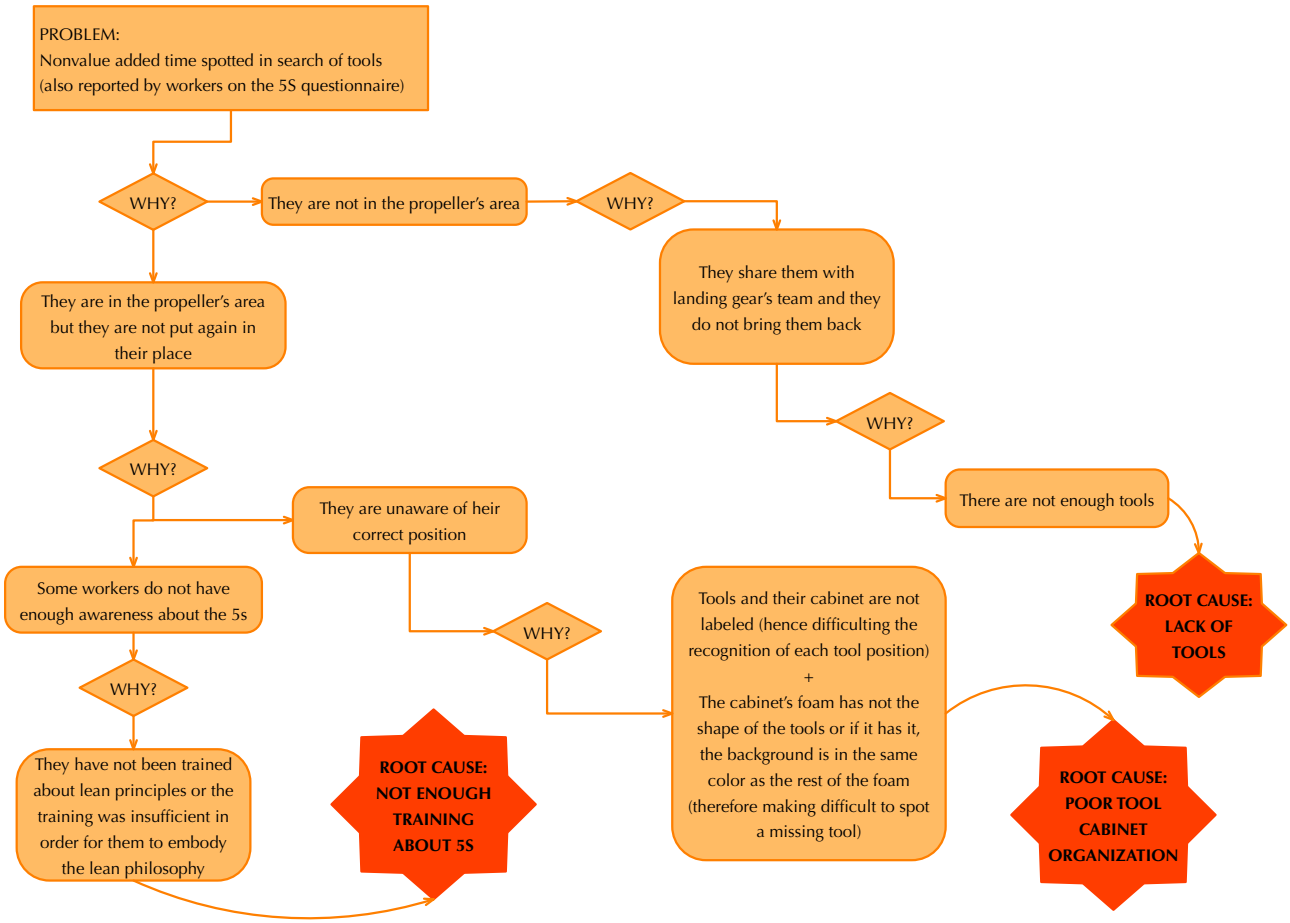

Figure 4.5: Root cause analysis for the tools problem

Workers spend constantly a lot of time looking for tools, resulting in feelings of discomfort among employees and a lot of no adding value time throughout the entire Overhaul process. The root-cause analysis for this problem can been seen at Figure 4.5, through it, there have been reached three foundational causes: Lack of tools, deficient tool cabinet organization and not enough employees training about 5S.

2. Stoppages because of the lack of materials and materials out of date

   There have been noticed some stoppages due to the lack of materials, as well as lots of materials out of date at the POU. The materials storage cabinet is also disorganized making difficult the detection of expired materials or lacking ones. Through a root cause analysis it has been concluded that the lack of a control system to manage the materials supply is the source of these problems (Figure 4.6).

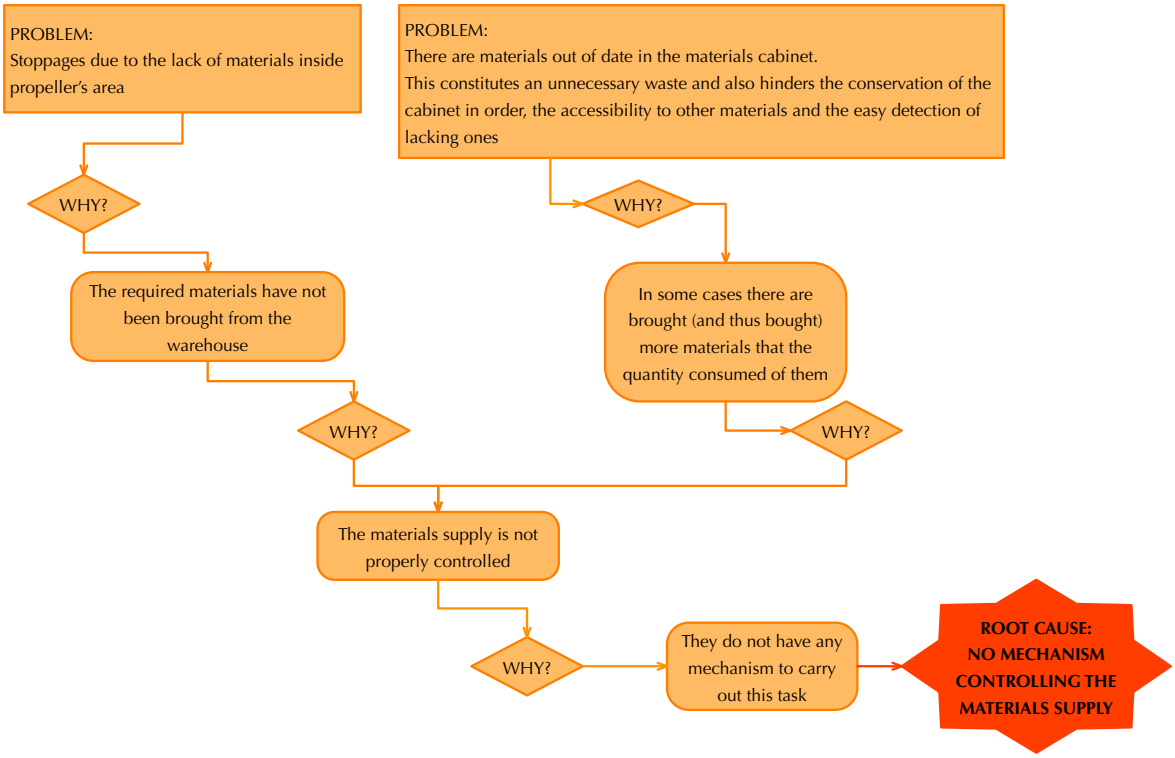

Figure 4.6: Root cause analysis of the materials management problems

4.2 Critical processes with observable improvements

The different processes which constitute the case of study were observed in first hand and timed at Gemba. The purpose of this has been to obtain real information about the flow, as well as the methodology, equipment and time required for each specific activity, also to be present at the exact moment when problems appeared. The flowcharts presented at Figure 3.4 and Figure 3.5 are an outcome of these observations and provide a quick and reliable visualization of the current Overhaul process state.

From these flowcharts the processes that are part of the case of study have been isolated and presented all together with their respectives Lead Times at Figure 4.7, thus allowing the easy identification of the most critical ones or bottlenecks which appear underlined in red. These bottlenecks are relative bottlenecks, processes which cause blockages in the flow, since the principal bottleneck would correspond to bonding activities which have the biggest Lead Time but it is completely justified by the procedure that must be followed according to the blades manual repair and therefore any fault that could be optimized has been encountered there. Only in those processes marked with a thunder observable improvements were identified, a deeper insight about them will be provided in the following subsections.

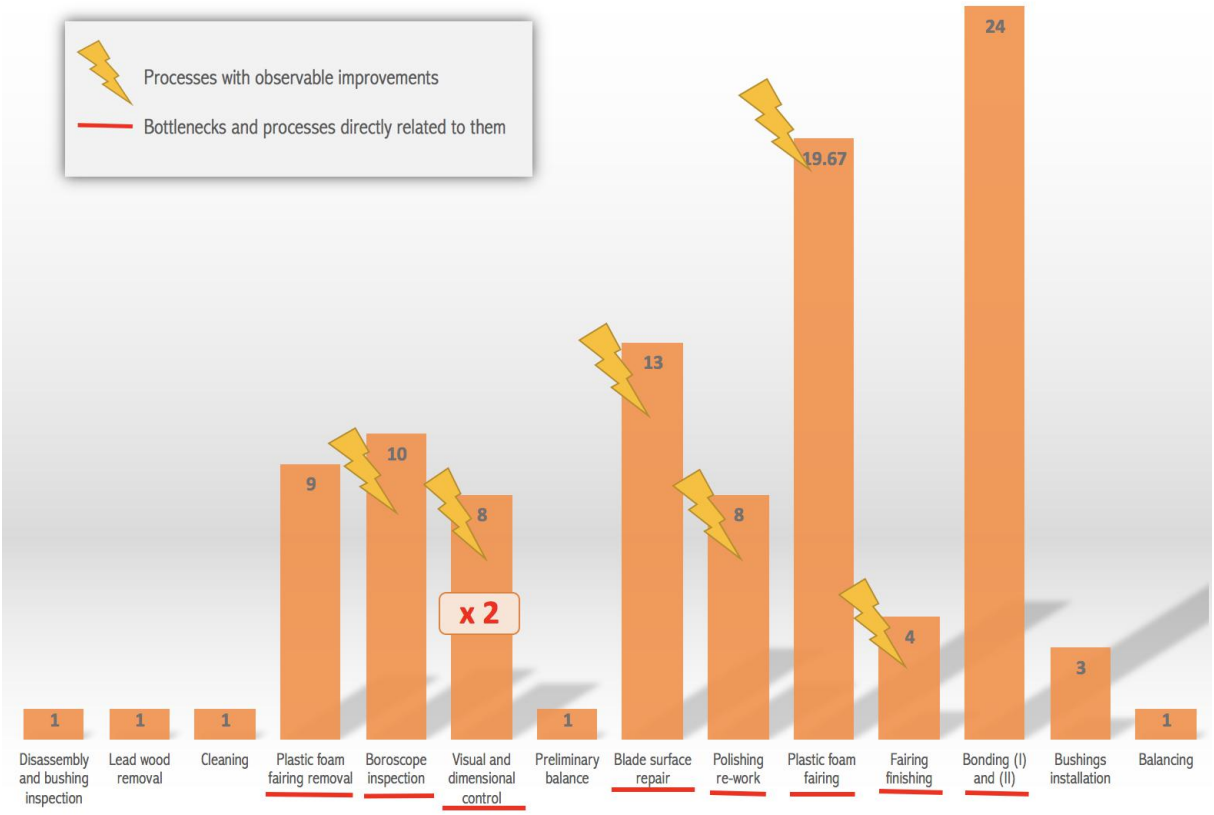

Figure 4.7: Case-of-study processes initial Lead Times in hours

BORESCOPE INSPECTION

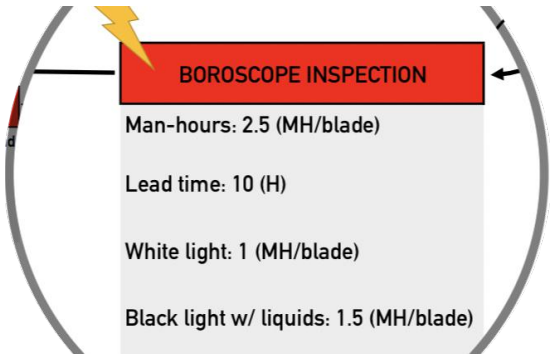

Figure 4.8: Borescope Inspection process (flowchart zoom)

Currently the process takes 2.5 (H) per blade, and it consists in two distinguishable phases: White light phase (1 H/blade) and black light with liquids phase which takes a little more time (1.5 H/blade). The times that characterize this process are collected in Table 4.1. Looking at the Process Time per blade and comparing it with the Process Lead Time, it can easily be inferred that the four propeller blades are being inspected in series.

Also the fact that the required Man-hours coincides with the Lead Time of the process makes clear that this process is performed just by one employee. Both features are not common 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.

Table 4.1: Times for Borescope Inspection process

BORESCOPE INSPECTION	
Process time (H/blade)	2.5
Process Lead time (H)	10
Man-hours (H)	10
Machine time (H)	0

After consulting the manual ([31]) 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). It has been concluded that there are not enough employees with the required qualification to perform this task to meet the desirable workflow. The line of thought that has been followed in the diagnosis of this specific process can be summarized in the following diagram (Figure 4.9).

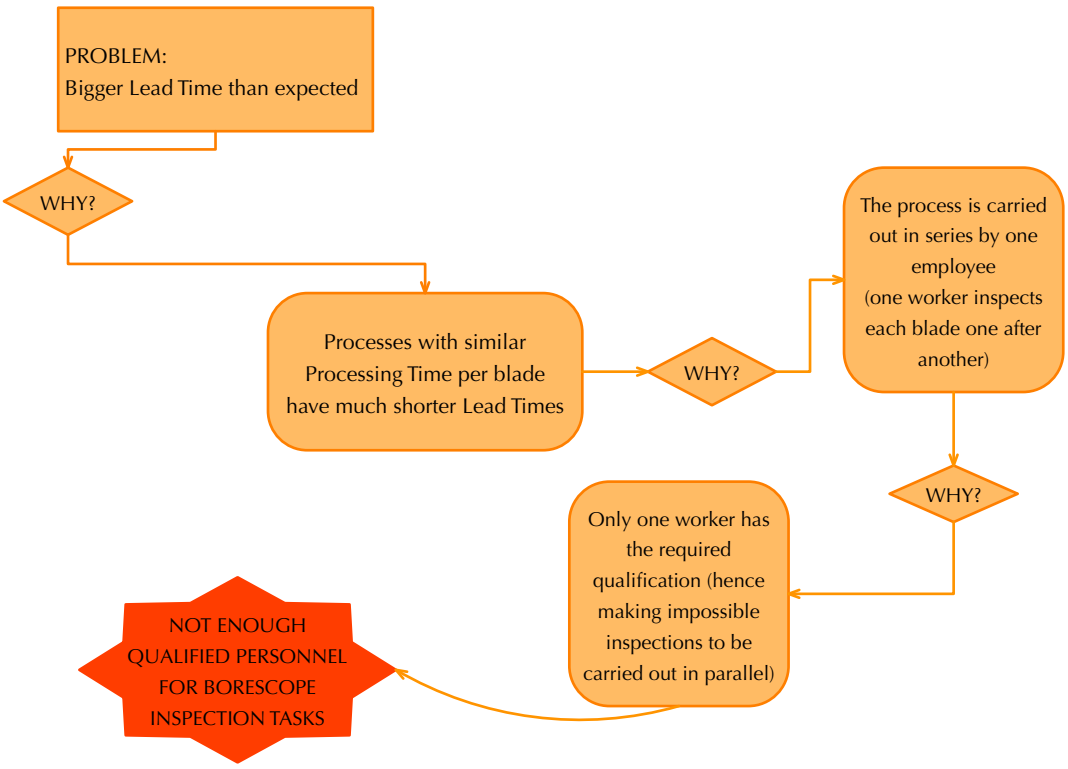

Figure 4.9: Root cause analysis for the Borescope Inspection process

DIMENSIONAL CONTROL

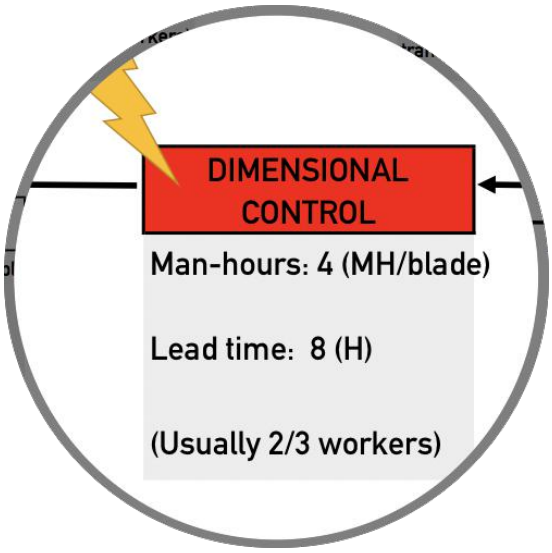

Figure 4.10: Dimensional Control process (flowchart zoom)

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 process consists in five measures: thickness, edge alignment, face alignment, angle, and finally, width. Their characteristic times are collected in Table 4.2.

The tools employed to perform the different measures are heavily archaic as can be seen in the images presented in the following subsections. It must be also pointed out that the measurements have to be converted to inch constituting this task in a perfectly dispensable non-value adding activity.

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.

Table 4.2: Dimensional Control process

DIMENSIONAL CONTROL		
	The process	In the complete overhaul process
Process time (H/blade)	2	4
Process Lead time (H)	8	16
Man-hours (H)	16	32
Machine time (H)	0	0

In order to help the reader in the understanding of how the process is currently carried out and try to portray the situation in the best possible way, the tools employed in the different measurements are going to be showed in the following-up figures:

1. **Thickness**

   When thickness is measured a critical fault is found in its procedure. To perform this measurement it is used a caliper gage (Figure 4.11) and instead of picking up the measure directly from this instrument due to its lack of precision, a vernier caliper (Figure 4.12) is employed for measuring again the thickness from it. The measure therefore is computed two times duplicating the required time, losing professionalism, increasing the chances of making mistakes and losing accuracy.

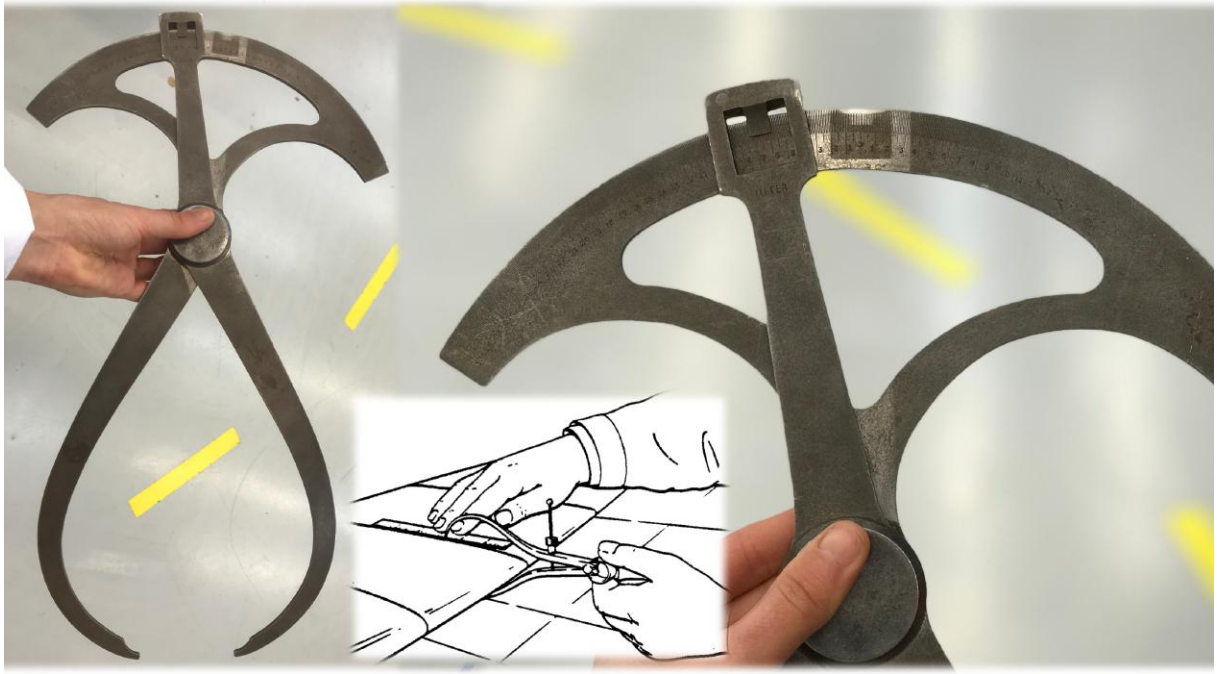

Figure 4.11: Caliper gage employed for the measurement of thickness [31]

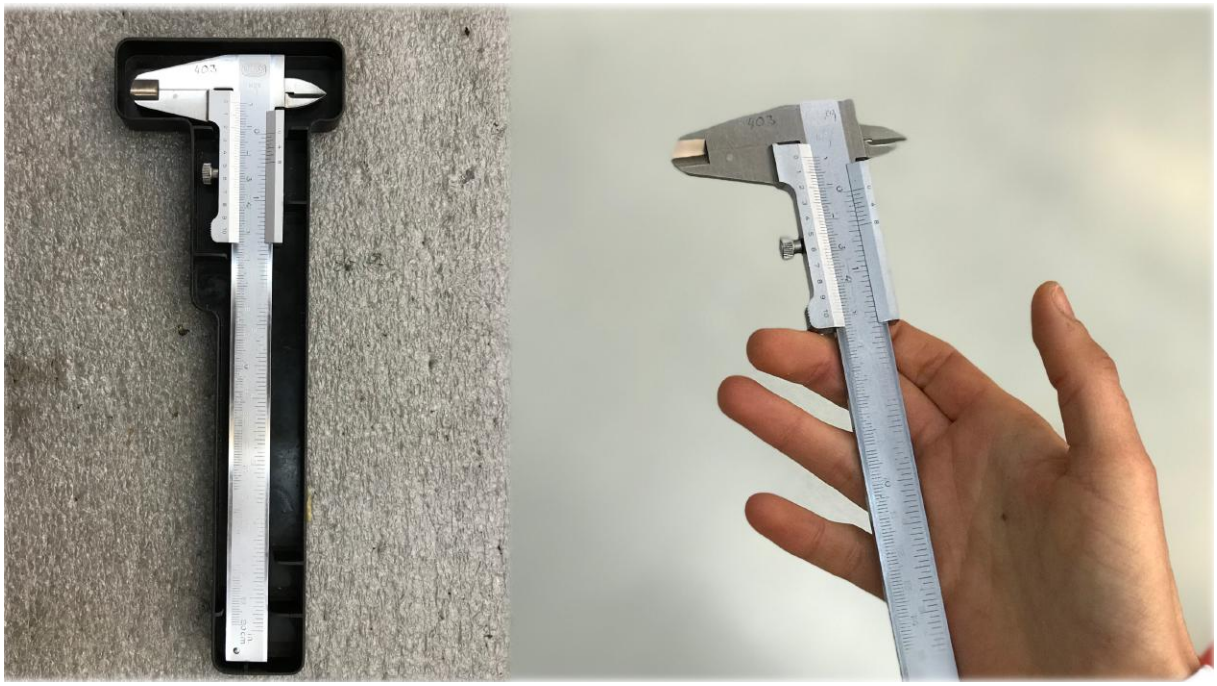

Figure 4.12: Vernier caliper employed for the measurement of thickness from the caliper gage

2. **Edge and face alignments**

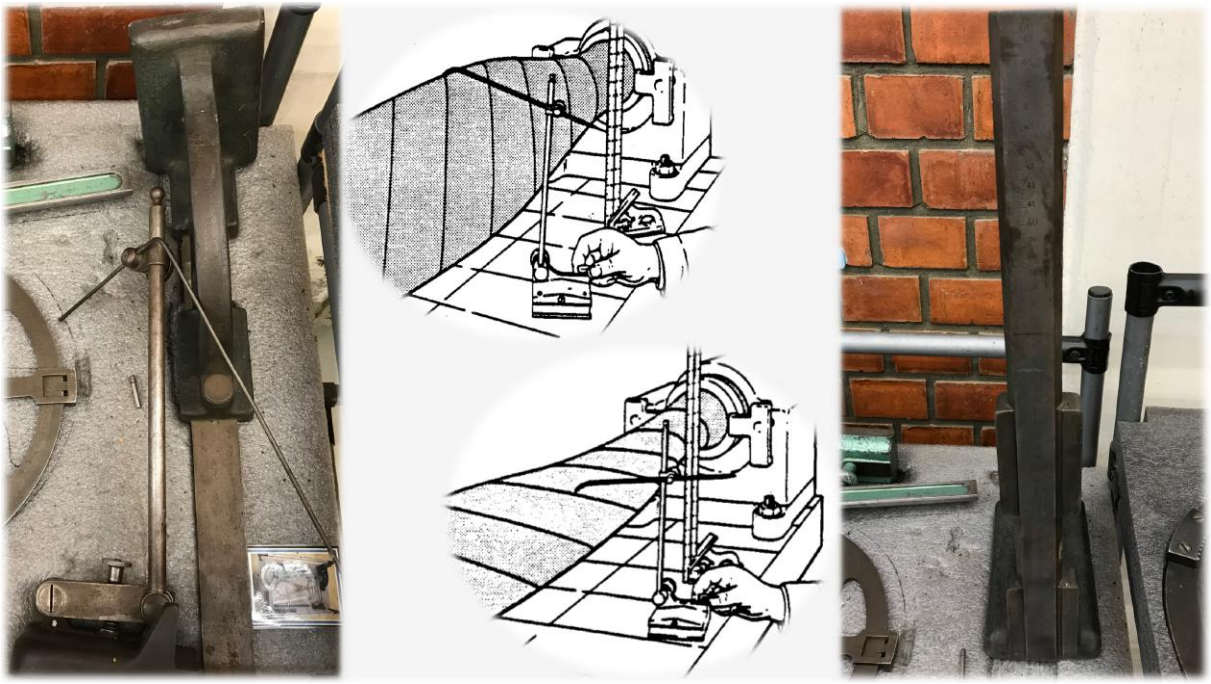

Figure 4.13: Surface gage scriber used for the measurement of edge and face alignments [31]

3. **Angle**

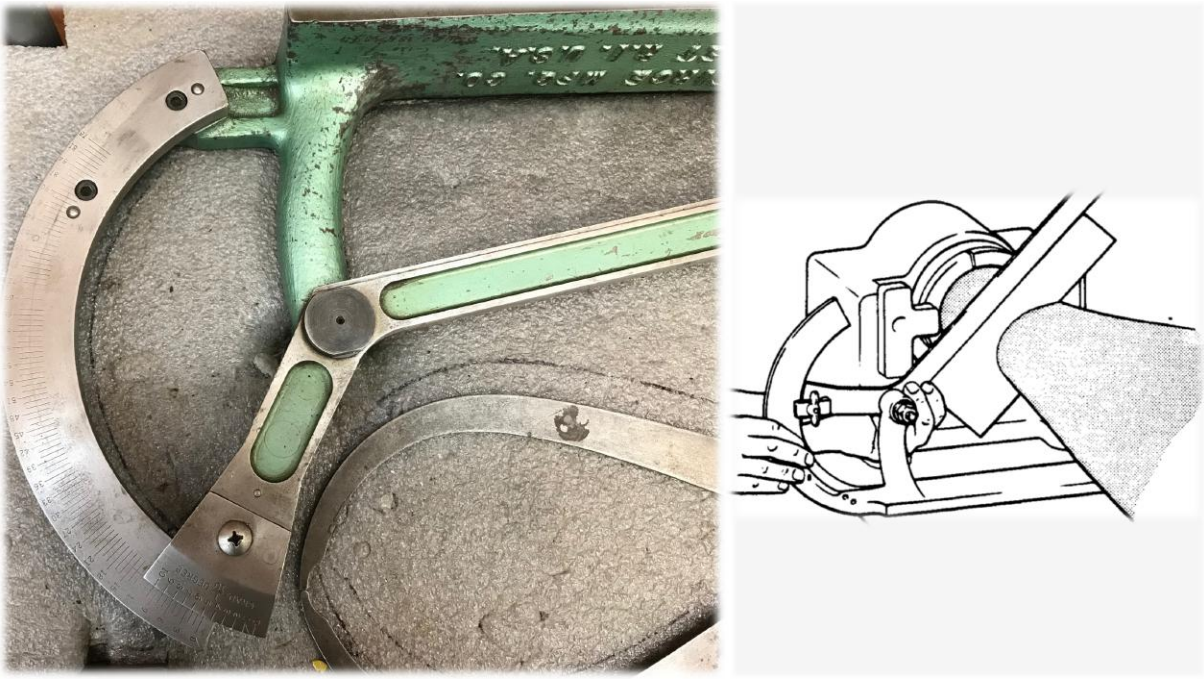

Figure 4.14: Protractor used the measurement of the angle [31]

4. **Width**

Figure 4.15: Vernier caliper used for the measurement of width

In the diagnosis of this process its procedure has been identified as being obsolete. The following diagram (Figure 4.16) sums up the diagnosis of this critical process in order to find its root cause.

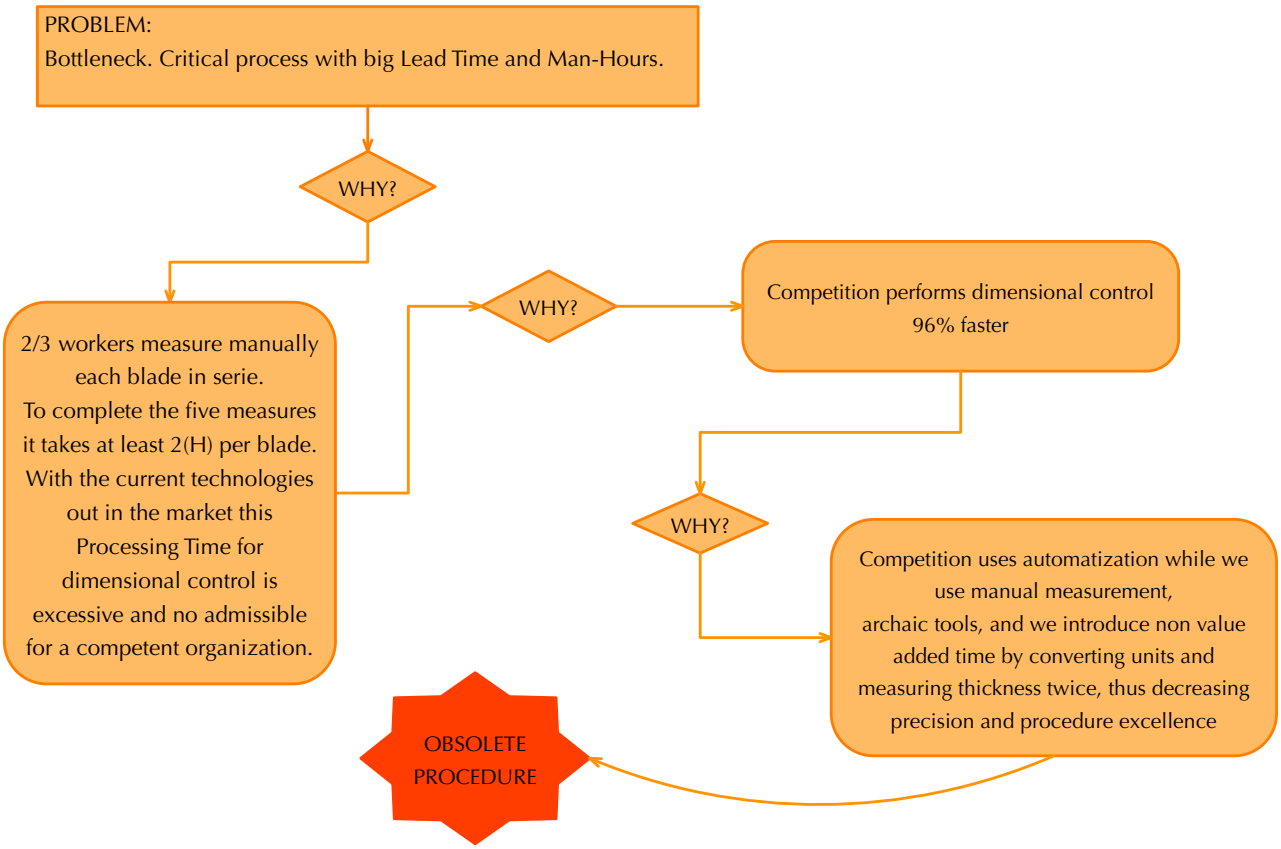

Figure 4.16: Root cause analysis for the Dimensional Control process

Blade Surface Repair, Polishing re-work and Fairing Finishing

Figure 4.17: Blade Surface Repair, Polishing re-work and Fairing Finishing processes (flowchart zooms)

- **Blade Surface Repair**

  Its Lead Time makes it the most critical process from the three ones presented in this subsection.

  At each Overhaul, the blades should be refinished by removing sufficient material through grinding 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 its respective four extractors (Figure 4.18), but in the way they are placed only two of them can be used, 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 (incorrect ones are marked with a red cross at Figure 4.19).

  This unuseful layout creates the current situation where only two blades can be worked at a time and grinding the complete batch takes at least 13 (H). The measured times which characterize this process can be observed at Table 4.3.

Table 4.3: Times for Blade Surface Repair process

BLADE SURFACE REPAIR	
Process time (H/blade)	6.5
Process Lead time (H)	13
Man-hours (H)	26
Machine time (H)	0

Figure 4.18: Grinding / polishing area.

- **Polishing Re-work and Fairing Finishing**

  After etching and NDI processes blades must be polished before the final dimensional control. And later on, after the fairings are made they should also be polished. The representative times for both processes can be seen at Table 4.4.

  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 blades placement posts remain unused, but in these two cases we have an additional resource unexploited: there are three polishing machines, so one of them also remains unused.

Table 4.4: Times for Polishing Re-work and Fairings Finishing

	POLISHING RE-WORK	FAIRING FINISHING
Process Time (H/blade)	4	2
Process Lead Time (H)	8	4
Man-hours (H)	16	8
Machine Time (H)	0	0

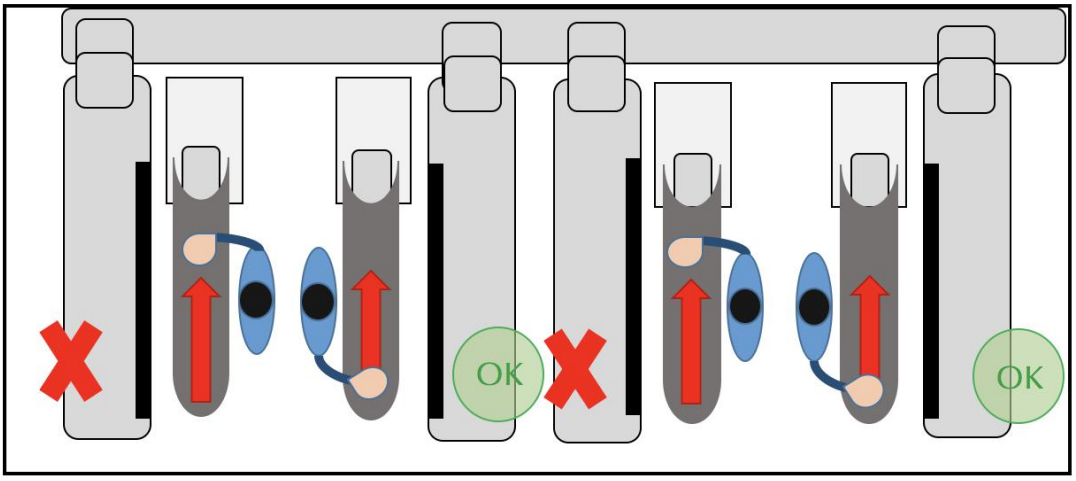

Figure 4.19: Polishing and grinding problem illustration

After analyzing these processes the root cause problem has been diagnosed as incorrect layout, the line of thought that has been taken is shown at the following diagram (Figure 4.20).

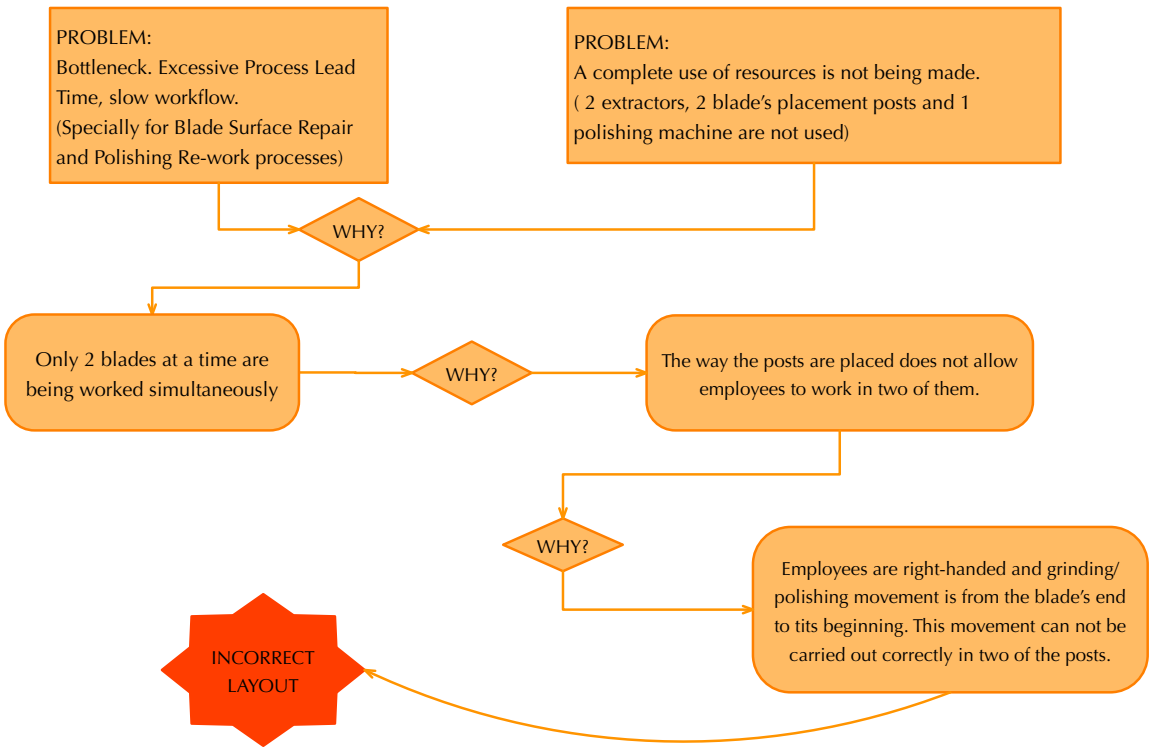

Figure 4.20: Root cause analysis for Blade Surface Repair, Polishing Re-work and Fairing Finishing processes

Plastic Foam Fairing

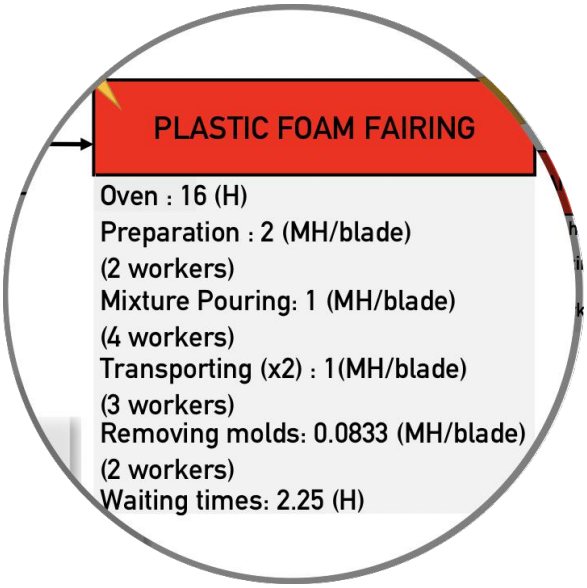

Figure 4.21: Plastic Foam Fairing process (flowchart zoom)

This process consists on many steps. The initial phase takes place the day before the fairings are made, this is the preparation of the fairings; along this preparation the blade firstly is placed in the mold in order to determine the blades area that will receive fairing, then EC766 product is sprout over it and 1 (H) should be waited in order to allow the product to dry, afterwards the mold is cleaned and mold release is sprout.

All this preparation excluding the waiting time lasts 1 (H) per blade and it is done usually by two employees.

The blades and molds ensembles now need to be transported to the oven, which is located in the landing gears area, this takes 10 (min) per blade and is carried out between three workers. The blades and molds are now prepared to be treated in the oven the day after.

Early in the morning the ensembles (blades plus molds) are placed in the oven to preheat phase. After this initial preheating phase, the ensembles are taken out of the oven and suspended with the tip of the blade down for the pouring operation, the products are then mixed and poured into the fairing mold, after this, the ensemble is placed back into the oven where after 30 (min) of waiting they are heated for another 3.5-4.5 (H). Altogether the oven process (pre-heat and heat) takes 8 (H) to be completed, the pouring of the mixture takes 1 (H) for the four blades and it is performed by at least four employees.

Finally after the oven process is concluded, the ensembles are transported back into propellers area (this takes another 10 (min) per blade between three workers), and ultimately the blades are removed from the molds between two workers and taking around 10 (min) for the complete batch. Before the removal of the molds workers do not have the habit of waiting for a fixed time in order to allow the ensemble to cool down but they usually wait around 15 (min).

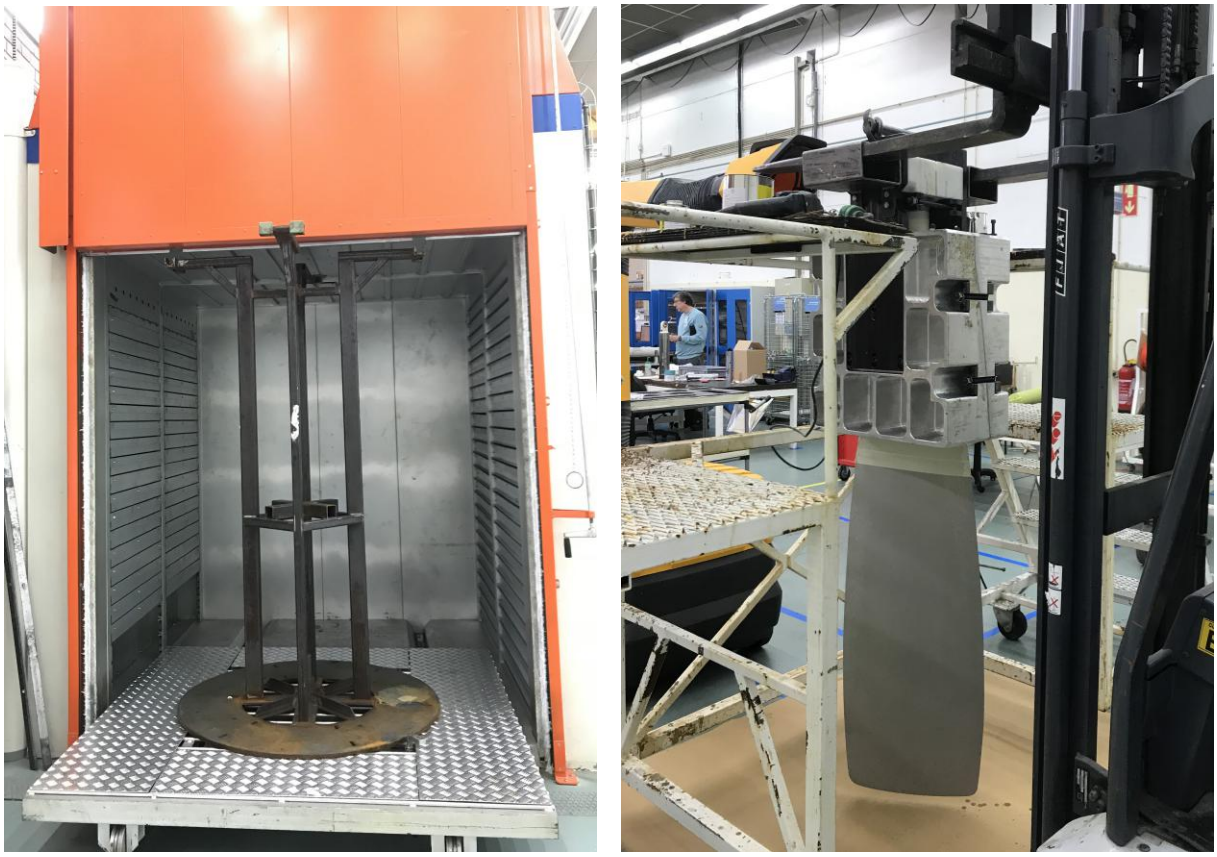

Figure 4.22: Oven and blade and mold ensemble just before pouring operation

In the following table (Table 4.5) are showed the expected times with the current procedure that has been described versus the actual times.

Table 4.5: Ideal vs Actual times with the current procedure for Plastic Foam Fairing process

	How ideally should be with the current procedure	**How it is with the current procedure**
Process time (H/blade)	10.88	10.88
Process Lead Time (H)	15.75	25
Fairings' preparation	4	4
Drying waiting time	1	2
Transporting (x2)	1.33	1.33
Time in oven	8	16
Mixture pouring	1	1
Waiting time for the molds to cool down	0.25	0.5
Removing molds	0.17	0.17
Man-hours (H)	16.33	16.33
Machine time (H)	8	16

The Process Time per blade it is fixed for this specific procedure as can be seen in Table 4.5; we should then question why the Lead Time does not match the expected one, a simple overlook to the table reveals the answer, the Machine Time (which coincides with the time in oven in this case) is doubled. This is because even though the oven has the capacity to work on the four blades simultaneously, nowadays the four fairings are made in two turns due to the rupture of one mold, first three blades and

then just only one blade another day. This affects also to the waiting times which are also duplicated. Altogether sums up approximately 10 (H) extra to the expected Process Lead Time.

In Figure 4.23 can be seen how the diagnosis of the process has proceeded, where it has been concluded that the 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.

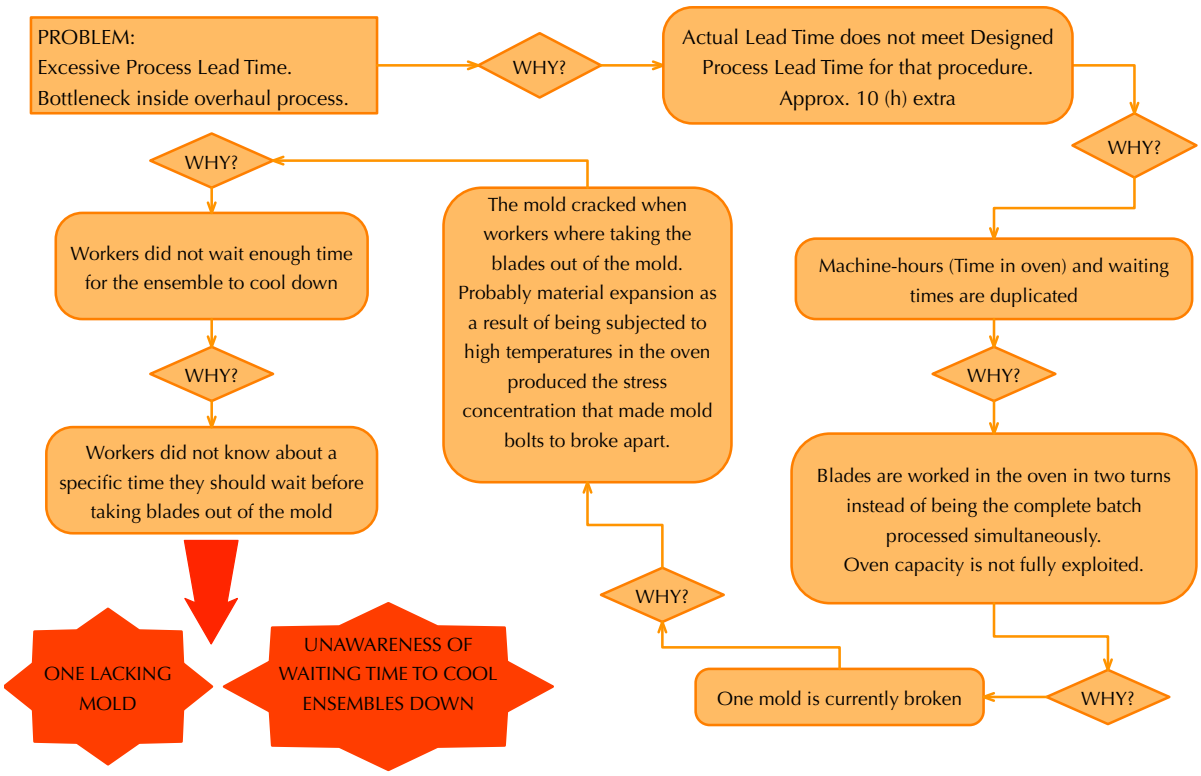

Figure 4.23: Root cause analysis for Plastic Foam Fairing process

4.3 Diagnosis summary diagrams

Finally the different tools used in the diagnosis and the results obtained from the root cause analysis of the problems are summarized in the following diagrams (Figure 4.24 and Figure 4.25).

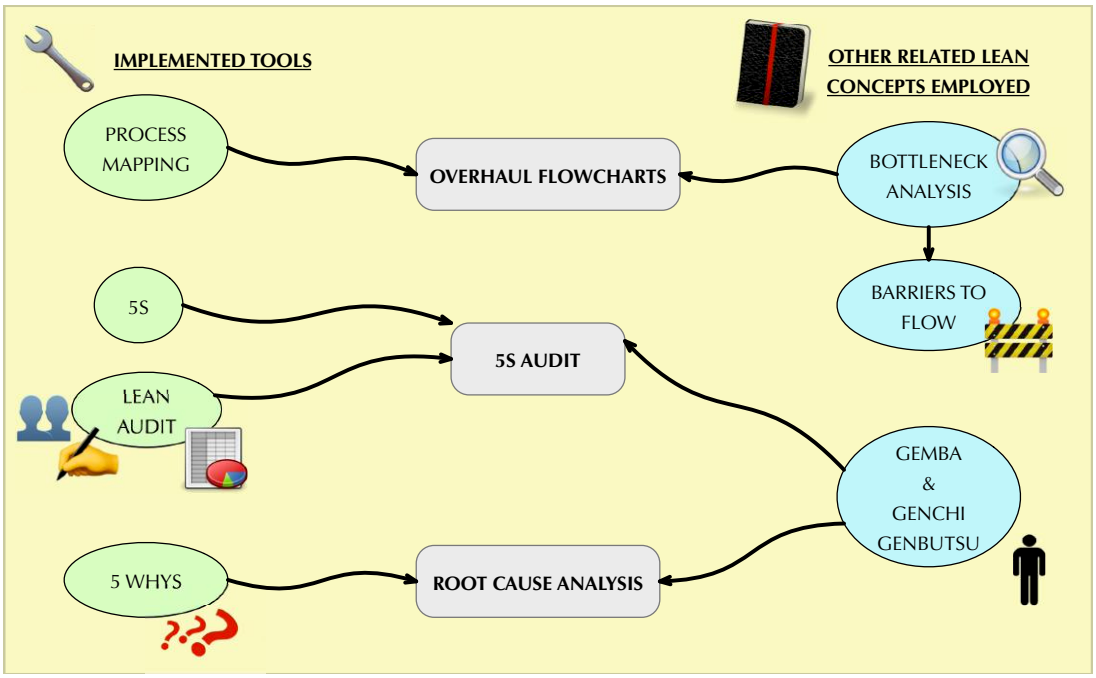

Figure 4.24: Diagnostic tools summary

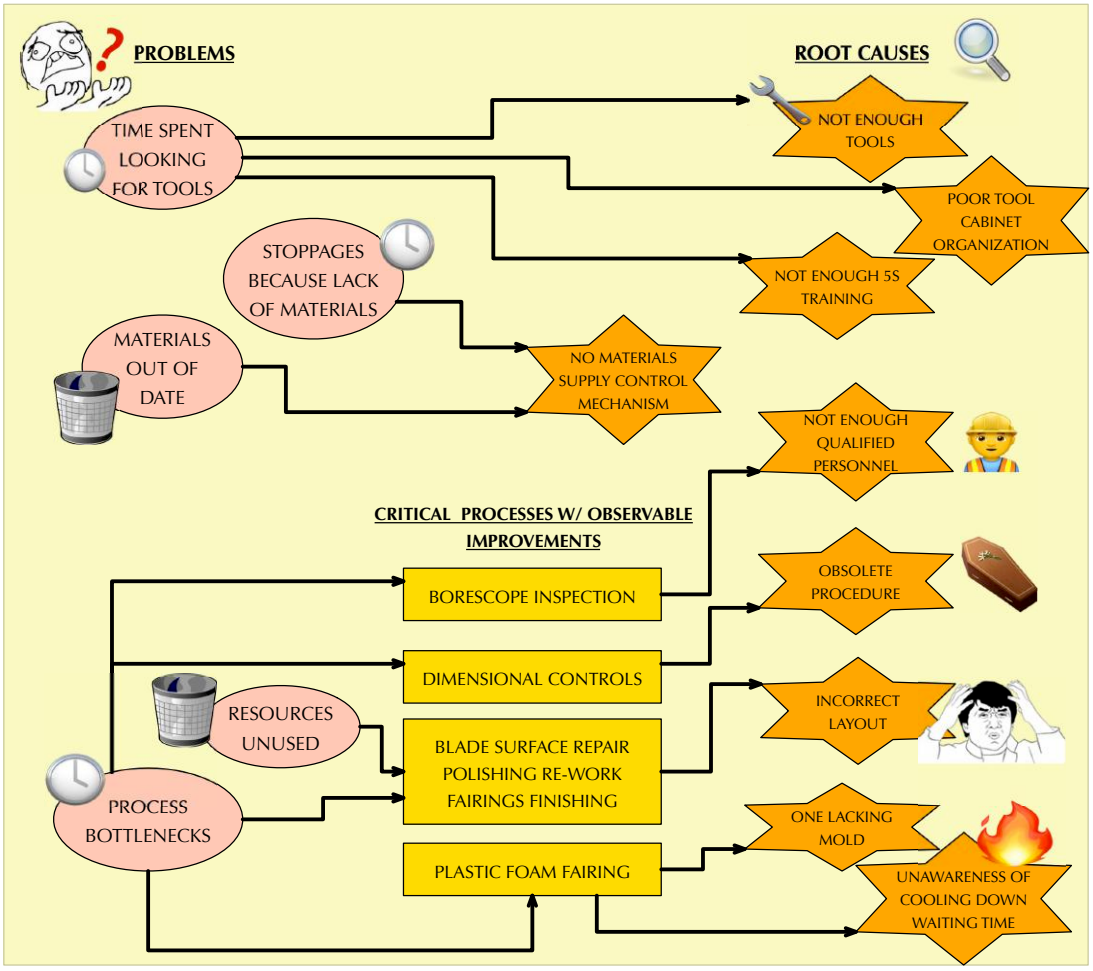

Figure 4.25: Root cause analysis results summary

Chapter 5

Proposed solutions

In this chapter will be presented the diverse countermeasures to the problems that have been detected during the diagnosis phase (chapter 4).

5.1 Solutions proposed from 5S questionnaire and overall witnessing of all processes

5.1.1 Problem: Time spent looking for tools

Two more tool trolleys

One of the suggestions to deal with this problem is the acquisition of more tools, from this action would be solved the problems related the unavailability of tools and their placement outside of propellers area.

It is a fact that there are not enough tools in the propellers area since they have to share them with landing gears team. The unnecessary time spent looking for them has been witnessed and reported by workers on the 5S questionnaire.

Thus it is proposed to buy two new tool trolleys that could be exclusively used in the propellers area.

New way of organizing tools

It is not only needed more tools but also a better organization of them, so another proposition will be 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, with this new way of organizing them we will promote the correct placement of each tool and the quick appreciation of misplaced ones.

The proposed solution pretends to have a similar aspect to Figure 5.1.

Figure 5.1: Labeled and tool shaped colored foam [32]

Lean training over the 5S topic

It will be suggested also that workers would 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 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, this proposition looks forward to increase workers consciousness about 5S and it is foreseen that this measure would also affect to another detected faults and low rated categories by workers as cleanliness and other objects out of place. The aim is to embed the lean thinking in the own employees’ philosophy, because as it is well known, people are the heart of Lean, and to participate conscientiously in the compliance of 5s principles means also to contribute to a better work environment which will result in a happier, easier and more comfortable and productive time-work.

5.1.2 Problems: 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 proper countermeasure should therefore aim towards the development of a system to control the 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. Any given inventory should ideally only hold the quantity of raw materials that would keep production flowing and orders for new materials should only be issued when these materials are actually needed; otherwise, we would have the current situation of chaos within the materials cabinet and a multitude of expired materials which constitutes a big waste. Excess inventory requires extra handling, extra space, extra interest charges, extra people, extra paperwork, and so on [33].

In order to develop the Kanban System three steps have been carried out: Firstly, a study of the demand with the available data has been done. Secondly, based on the results obtained in the daily demand characterization the number of Kanban cards needed for each material have been calculated. Finally, it has been designed a model for the Kanban card and the Kanban board.

Study of the demand

The only information available that could help in the quantification of the demand were the records of propellers finished projects. These documents contained information related to the diverse projects which were finished along 2017 and 2018 (until April). From each project it has been feasible to obtain the propellers entering date, 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 having into account the quantity of that material used in an Overhaul per propeller. In the following images (Figure 5.2 and Figure 5.3) the collected information appears visually represented.

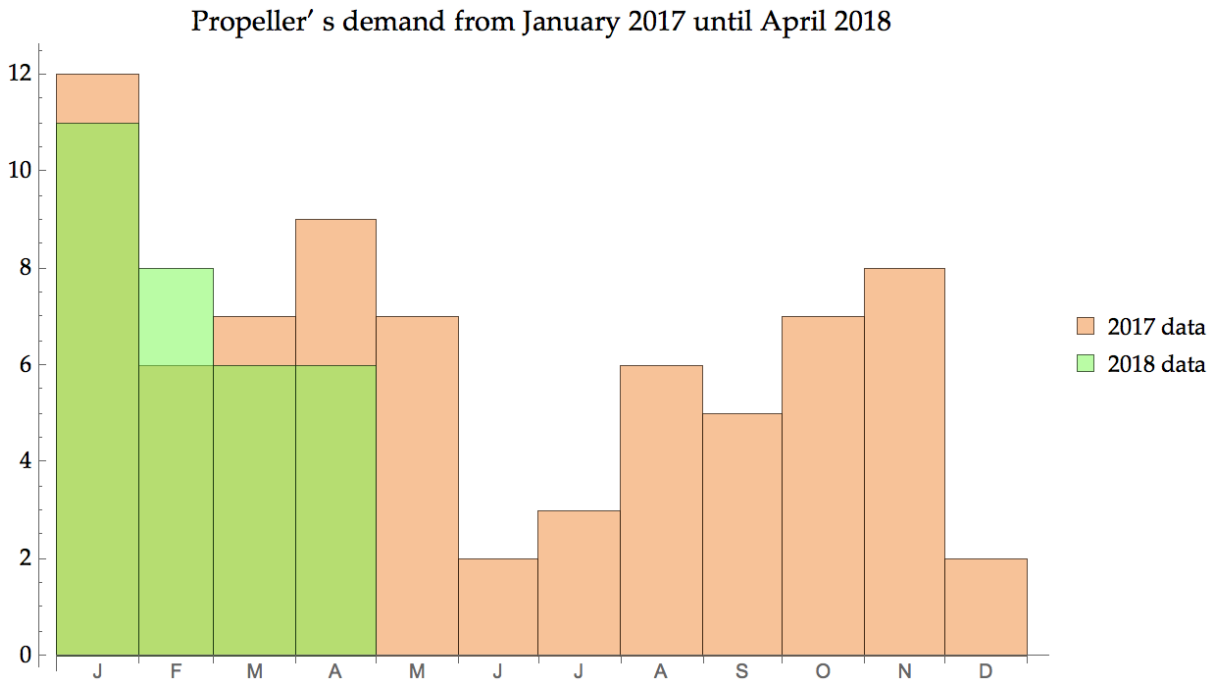

Figure 5.2: Monthly histogram of propellers demand along Jan-2017 and Apr-2018

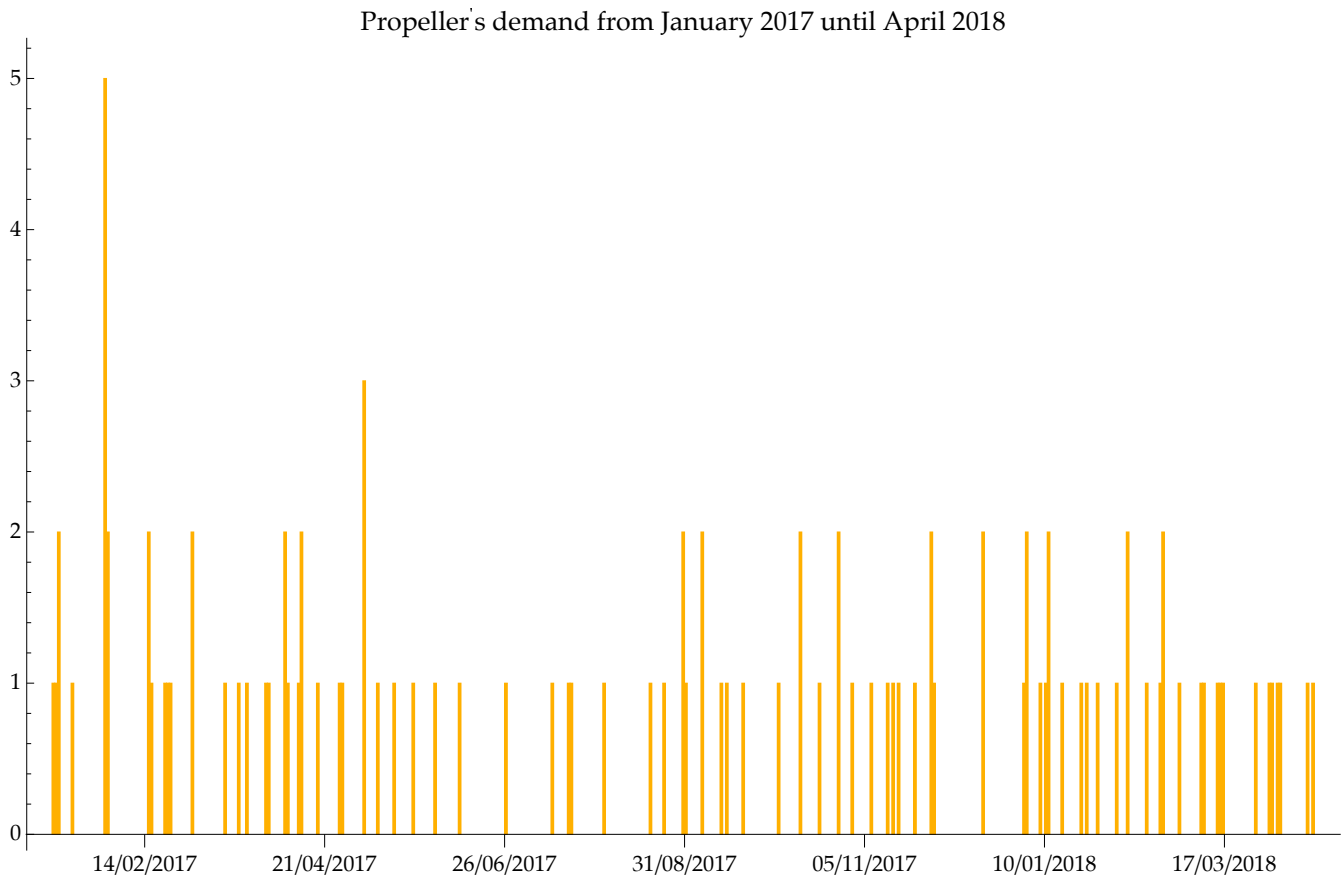

Figure 5.3: Daily histogram of propellers demand along Jan-2017 and Apr-2018

Once the projects records have been analyzed and extracted from them each propeller entering date, the next step has been the definition of a daily demand of propellers that could be used in the calculation of the required number of Kanban cards, which had to be done in a consistent way with the collected data: it had to represent reality.

Firstly, monthly daily demands and their standard deviations have been computed in order to quantify the dispersion around the average daily demand of each monthly data set, this calculation has been made following Equation 5.1 where σ stands for standard deviation, N for the number of data collected and x for each data; their variances (V) (Equation 5.2) have also been computed since they have been used later for the calculation of the average standard deviations (σ_{avg}) in those cases where more than one data set were known, as happened to be from January to April where 2017 and 2018 distributions were known for one same month; in these cases, the variance and the average daily demand have been calculated as the average between both years distributions, but with regards to the standard deviation, it can not be calculated as the average between standard deviations, it must be calculated as the squared root of the variance average of both data sets as shown in Equation 5.3, where m refers to the number of data sets or distributions.

The obtained results have been presented in Table 5.1. These results stand out seasonal differences

in the demand, the demand heavily drops during June, July and December months.

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2} \tag{5.1}$$

$$V = \sigma^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2 \tag{5.2}$$

$$\sigma_{avg} = \sqrt{\bar{V}} = \sqrt{\frac{1}{m-1}\sum_{j=1}^{m}\sigma_j^2} \tag{5.3}$$

Table 5.1: Total demand, daily demand average, standard deviation and variance for each month

Month	# Propellers 2017	# Propellers 2018	Daily demand (avg.)	Standard deviation	Variance
January	12	11	0.371	0.841	0.708
February	5	10	0.268	0.519	0.269
March	7	6	0.21	0.452	0.204
April	9	6	0.25	0.5102	0.26
May	7	[X]	0.226	0.617	0.381
June	2	[X]	0.0667	0.254	0.0644
July	3	[X]	0.0968	0.301	0.0903
August	6	[X]	0.194	0.477	0.228
September	3	[X]	0.1	0.305	0.0931
October	7	[X]	0.226	0.56	0.314
November	8	[X]	0.267	0.521	0.271
December	2	[X]	0.0645	0.359	0.129

Once it has been studied each month separately (Table 5.1), the daily demand during one year of work has been computed from these twelve different samples. Proceeding in the same way as for monthly results when we had more than one data set, the average daily demand and variance for the entire year have been calculated as the average between the twelve months results, regarding to the standard deviation, it has been computed again as the square root of the variances average (Equation 5.3).

The attained results are shown in Table 5.2, this will be the daily demand characterization that will be employed in the calculus of the number of Kanban cards required for each material, even though a more stable demand would result in a more precise and reliable Kanban System. In order to mitigate the effects that this variability could have on the proper functioning of the Kanban System the quantity of safety stock required for a high level service have been also calculated.

Table 5.2: Characterization of the demand through an entire year

Average daily demand	Standard deviation	Variance
0.195	0.501	0.251

Number of kanban cards

Once the average daily demand was characterized, the calculus of the number of Kanban cards required for each material could be effectuated.

For this computation had to be taken into account the Lead Time (average time elapsed between the order of the material in question and its arrival to the point of use), which in this specific case is always four days since the communication is between the propellers hangar and the warehouse and not directly with each material supplier. Also, it had to be defined the quantity of containers per Kanban, which for convenience has been set as one material container per Kanban card. This implies that each material recipient will have one Kanban card and that when this card is reached (when a recipient is opened), another recipient should be ordered.

Also it was necessary to convert the average daily demand of propellers (DD_{prop}) and its standard deviation (σ_{prop}) presented in Table 5.2 to the average daily demand of each material (DD_{mat}) and its standard deviation (σ_{mat}), this conversion has been easily done by multiplying them by the quantity of material used per propeller in each Overhaul (QTY_{mat}) (Equation 5.4 and Equation 5.5).

$$DD_{mat} = (QTY_{mat}) \cdot (DD_{prop}) \tag{5.4}$$

$$\sigma_{mat} = (QTY_{mat}) \cdot (\sigma_{prop}) \tag{5.5}$$

As has already been stated before, in order to protect the system against the demand fluctuations it has been added a quantity of safety stock for each material having into account its standard deviation from daily demand. 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 [34]. The safety stock for each material has been calculated therefore as follows (Equation 5.6).

$$SS = \sigma_{DD} \cdot \sqrt{LT} \cdot Zscore \tag{5.6}$$

Hence, a required service level had to be defined, which has been set to be 95.05% providing a highly reliable stock management system. For this service level the Z Score it was found to be 1.65 (Table 5.3).

Finally, with the Daily material Demand (DD), the Lead Time (LT) in days, the Safety Stock for that particular material (SS) and the quantity of material per container, the number of Kanban cards for each material has been computed as the least integer greater than or equal to the result obtained through the application of Equation 5.7. The results are shown in Table 5.4.

$$\#Kanban = \frac{(DD \cdot LT + SS)}{QTY_{cont}} \tag{5.7}$$

Table 5.3: Z Score Table (correlation between Z Score and Product Availability (Service Level)) [34]

Z	%	Z	%	Z	%	Z	%
0.00	50.00	1.00	84.13	2.00	97.72	3.00	99.865
0.05	51.99	1.05	85.31	2.05	97.98	3.05	99.886
0.10	53.98	1.10	86.43	2.10	98.21	3.10	99.903
0.15	55.96	1.15	87.49	2.15	98.42	3.15	99.918
0.20	57.93	1.20	88.49	2.20	98.61	3.20	99.931
0.25	59.87	1.25	89.44	2.25	98.78	3.25	99.942
0.30	61.79	1.30	90.32	2.30	98.93	3.30	99.952
0.35	63.68	1.35	91.15	2.35	99.06	3.35	99.960
0.40	65.54	1.40	91.92	2.40	99.18	3.40	99.966
0.45	67.36	1.45	92.65	2.45	99.29	3.45	99.972
0.50	69.15	1.50	93.32	2.50	99.38	3.50	99.977
0.55	70.88	1.55	93.94	2.55	99.46	3.55	99.981
0.60	72.57	1.60	94.52	2.60	99.53	3.60	99.984
0.65	74.22	1.65	95.05	2.65	99.60	3.65	99.987
0.70	75.80	1.70	95.54	2.70	99.65	3.70	99.989

Table 5.4: For each material: Quantity per propeller, Quantity per container and number of Kanbans

Material Name	QTY (UM)/prop.	QTY (UM)/cont	# Kanbans
PLURICOLOR PA-25 * SPRAY VERMELHO	20 (mL)	400 (mL)	1
PLURICOLOR CA-01 * SPRAY BRANCO	20 (mL)	400 (mL)	1
PLURICOLOR CA-06* SPRAY AMARELO	20 (mL)	400 (mL)	1
PLURICOLOR PL-01 * SPRAY PRETO FOSCO	20 (mL)	400 (mL)	1
PZYGLO ZP-9F * DEVELOPER	100 (mL)	400 (mL)	1
SPOTCHECK SKC-S * CLEANER	200 (mL)	400 (mL)	2
ZYGLO ZL-27A * PENETRANT	50 (mL)	400 (mL)	1
LPS3	380 (mL)	380 (mL)	3
EA901NA/L-3 * HYSOL EA901 NA/AB	0.25 (L)	1 (L)	1
AV121N-1KG * ARALDITE AV121N-1	0.25 (L)	1 (L)	1
ADHESIVE, EPOXY, ONE COMPONENT * AY103	0.25 (L)	1 (L)	1
EPON 828	0.25 (L)	1 (L)	1
RENLEASE QZ5111 * DESMOLDANTE	0.25 (L)	1 (L)	1
AEROSHELL GREASE22	0.1 (L)	3.78541 (L)	1
EDGE SEALER 3950 * VERNIZ 3950	10 (mL)	100 (mL)	1
MAGNA-TAC M-688/CH16	0.1 (L)	1 (L)	1
EEC-776	0.1 (L)	1 (L)	1
BOSTIK 1007	0.25 (L)	1 (L)	1
EVASELINA SOLIDA, SOLIDA 1KG	0.01 (Kg)	1 (Kg)	1
VVP-236A * VASELINA	0.01 (Kg)	1 (Kg)	1
LOCTITE GRD AA	5 (mg)	50 (mg)	1
AEROSHELL FLUID 31	4 (GL)	1 (GL)	10
BOSTIK 1096MR 1GL	1 (GL)	1 (GL)	3
EY-4014 A/B	0.25 (L)	1 (L)	1
BOSCODUR 4L	50 (mL)	500 (mL)	1

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 (Figure 5.4), such as its name, position, quantity to be ordered, its Kanban card number, supplier, destiny, quantity per container and Lead Time.

HORA DE REORDENAR MATERIAL !

NOME:	POSIÇÃO POU:	QUANTIDADE:		# CARTÃO KANBAN
AEROSHELL FLUID 31	22	1		1
DO DEPT:	AO DEPT:	QUANTIDADE / RECIPENTE		LEAD TIME (DÍAS)
ARMAZÉM	POU HÉLICES	1	(GL)	4

Figure 5.4: Kanban card model

For the Kanban board the following model has been proposed (Figure 5.5), dividing the board in three parts distinguishing between the materials that have to be ordered (in red), the ones that have already been ordered (in green) and the orders that must be collected (in yellow).

Figure 5.5: Kanban board model [35]

It could also be used a bigger Kanban board, so each material has its own three phases, this option makes clearer the status for each material but also more space would be required (Figure 5.6).

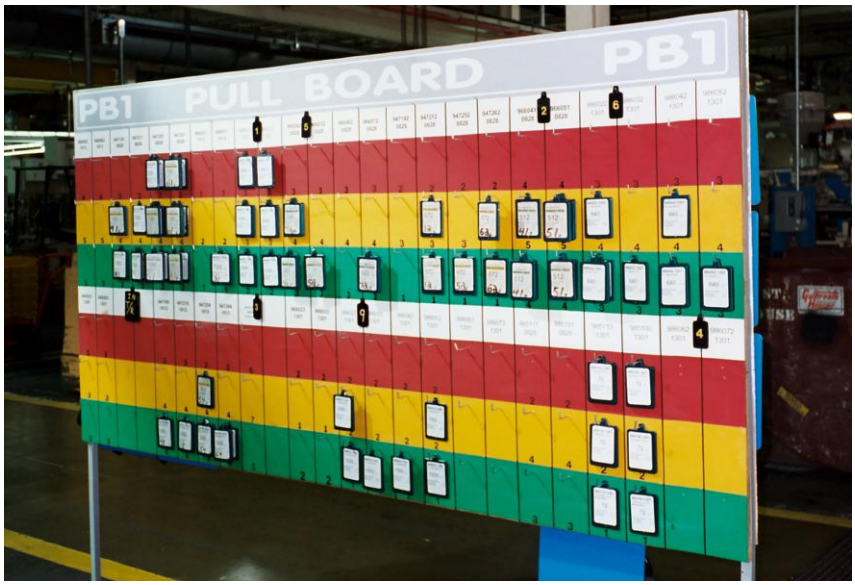

Figure 5.6: Kanban board alternative model [35]

5.2 Solutions proposed within each specific process

In this section different countermeasures to the problems detected in some of the case-of-study bottlenecks will be proposed.

5.2.1 Borescope Inspection

One more worker would be a great added value.

If the goal is to optimize the Overhaul process, each subprocess Lead Time must be lowered as much as possible.

The fact that there is only one worker capable of performing this activity turns the Borescope Inspection into a bottleneck inside the Overhaul process, 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 5.7), improving workflow and decreasing the impact of this particular bottleneck.

Multi-functional workers, this is to say, individuals trained and qualified to perform a variety of tasks, are of great value in lean processes in which workers are typically cross-trained on operations upstream and downstream of their primary work so they can support the value stream in case some problems happened to occur.

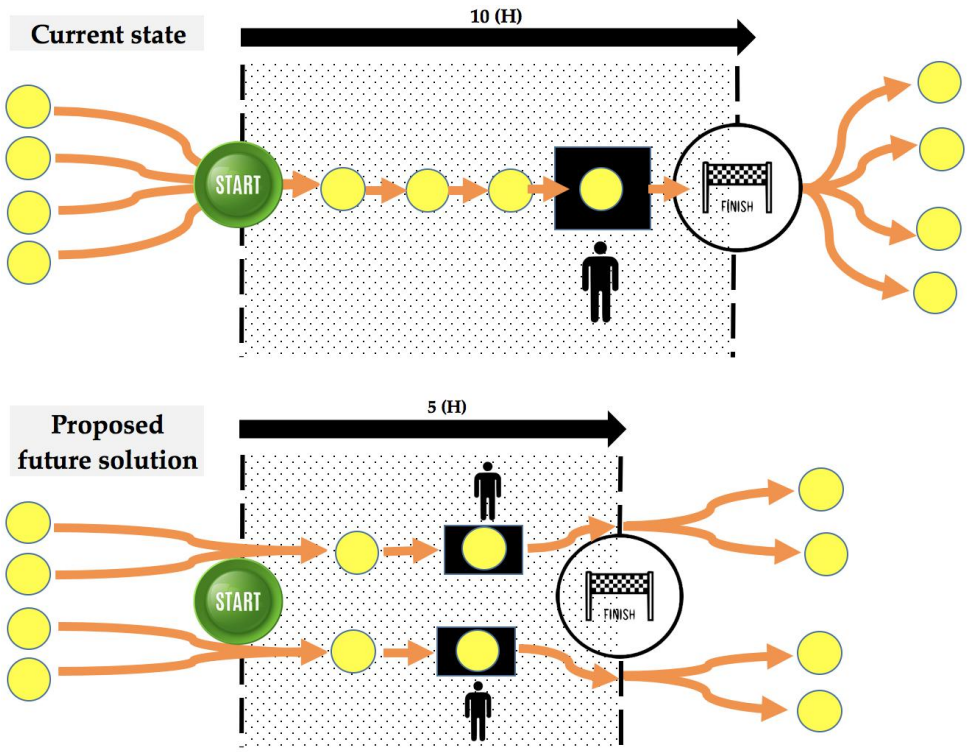

Figure 5.7: Graphical illustration of the proposed solution for Borescope Inspection

This simple shift would reduce the Process Lead Time by half (Figure 5.8). New times and the different percentages of time variance (reduction or increment) respect the current ones are presented at Table 5.5.

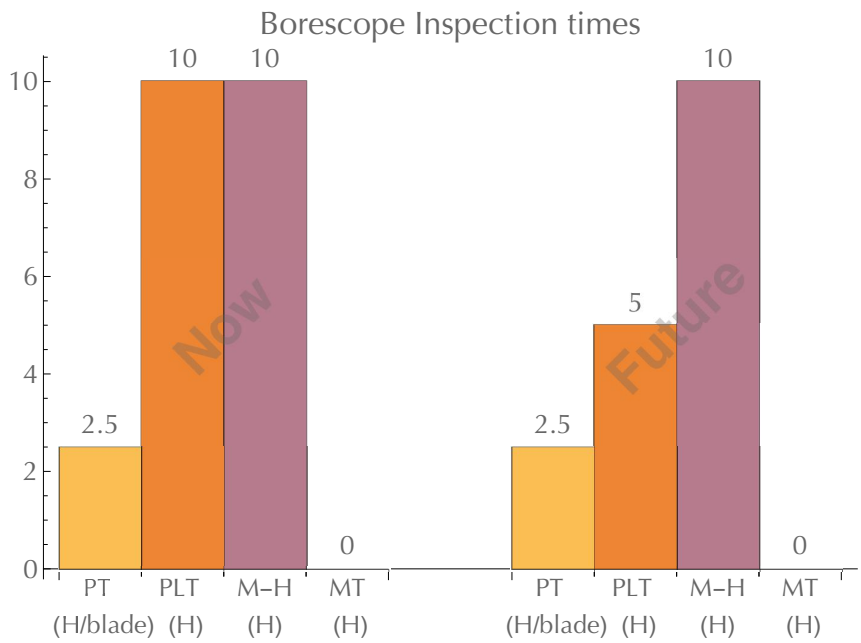

Figure 5.8: Graphical comparison of current and future Borescope Inspection times

Table 5.5: Times for Borescope Inspection process

BORESCOPE INSPECTION			
	Current state	Proposed future state	Percent Variance
Process time (H/blade)	2.5	2.5	0%
Process Lead time (H)	10	5	-50%
Man-hours (H)	10	10	0%
Machine time (H)	0	0	[-]

Based on the results attained at Table 5.5, the following changes in Waiting in Process Time and the Value Percent of Time per blade and per four blade's batch have also been computed (Table 5.6).

Table 5.6: Waiting in Process Time and Value Percent of Times for Borescope Inspection process

	Current state	Proposed future state
Waiting in Process Time (H)	7.5	2.5
Value Percent of Time / blade	25%	50%
Value Percent of Time / batch	100%	100%

5.2.2 Dimensional Control

A more modern procedure to perform the dimensional control is a must in order to be up to the competence.

In the diagnose of this process the current procedure was identified as obsolete, not only the tools were archaic and the duplicated thickness measurement and unit conversions constituted a waste, but the complete procedure manually effectuated is highly antiquated. Therefore, the optimal solution that could be proposed in the optimization of this process had to be linked to an utterly transformation of the process: *Kaikaku*.

This radical transformation in the procedure implies a previous research of the latest technologies for this purpose in the aeronautical sector and the study of the different solutions implemented by the competition. This investigation has lead to *Aeroscan M5 - Precision Blade Measurement System*, an automatic measuring machine that uses laser technology to perform this task. This machine (Figure 5.10) developed by the AeroScan Propeller Metrics company is capable to perform all required measures in less than 5 (min), meanwhile using traditional measurement it takes to OGMA 2 (H) to perform the same task. The time saved can be used for more profitable tasks and the propellers can be returned to service far faster. Also regarding to the precision, technicians can produce accurate results (even though that requires far more time to set up for each station and compute the five measurements) but if however the technicians are rushed and are not very careful then the measurements can be inaccurate or inconsistent, so Aeroscan M5 machine produces more reliable results.

It is necessary also to point out that the proposed solution has been evaluated and approved by the FAA [36]:

"The Aeroscan M5 program is a computer-controlled tool that can be used to accurately measure complex aircraft propeller blade configurations. This measurement can be used to comply with requirements and limits set in the manufacturer's maintenance manual".

'The Chicago ACO witnessed a test of the calibration and operation of the Aeroscan M5 tool in accordance with Revision C to the Aeroscan M5 Operations Manual at Aircraft Propeller Service, Inc. The testing performed was successful and showed the program evaluating a number of blade stations in order to determine that the blade met the dimensional requirements called out in the propeller maintenance manual".

With the implementation of this automatic measurement method through the acquisition of Aeroscan M5 the following time changes are foreseen (Table 5.7). It is important to recall that this process is carried out two times along the overhaul process enlarging the solution's impact, thus the savings in time shown in Table 5.7 would be doubled, the total time invested in dimensional control during an Overhaul would decrease from 16 (H) to 0.67 (H) and total Man-hours from 32 (H) to 0.13 (H).

Table 5.7: Times for Dimensional Control process

DIMENSIONAL CONTROL			
	Current state	Proposed future state	Percent Variance
Process time (H/blade)	2	0.083	-95.84%
Process Lead time (H)	8	0.33	-95.84%
Man-hours (H)	16	0.067	-99.58%
Machine time (H)	0	0.27	[-]

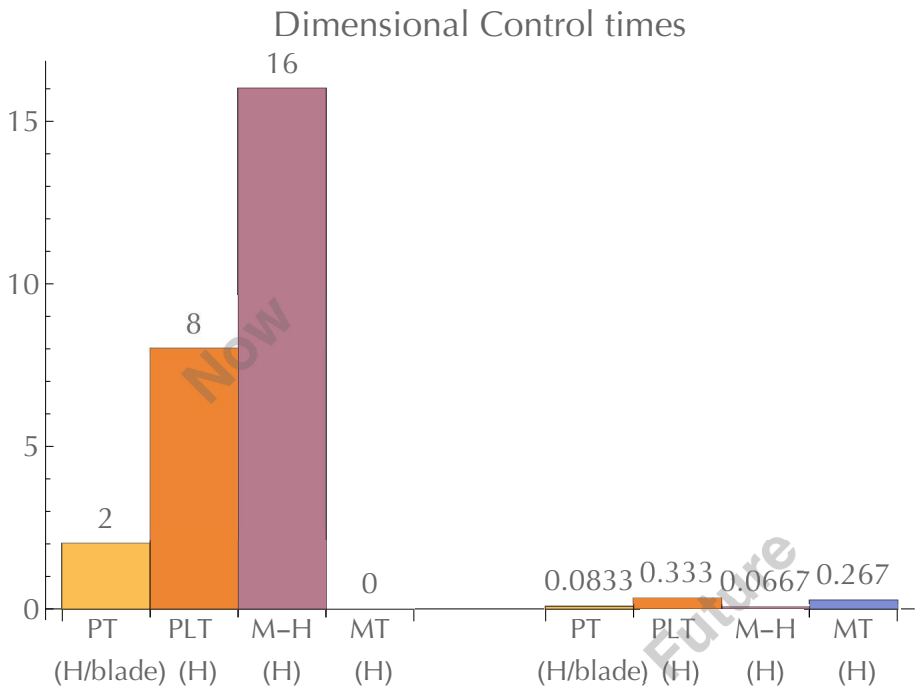

Figure 5.9: Graphical comparison of current and future Dimensional Control times

From Table 5.7 outcomes the following additional changes in Waiting in Process Time and Value Percent of Time have been also calculated (Table 5.8). In this case should be pointed out that not all Process Time is VAT since times spent in set-ups, bringing the measuring tools, converting units to inch and duplicated thickness measurement, which do not add any value to the product, represent 56.44% of the Process Time per blade, resulting in just 0.871 (H) of VAT per blade processed.

Table 5.8: Waiting in Process Time and Value Percent of Time for Dimensional Control process

	Current state	Proposed future state
Waiting in Process Time (H)	6	0.25
Value Percent of Time / blade (%)	10.89%	20%
Value Percent of Time / batch (%)	43.56%	80%

Figure 5.10: Aeroscan M5 - Precision Blade Measurement System [36]

With the huge change in Man-hours foreseen it has been considered of interest the calculation of the labor savings or Freed Capacity (Equation 5.10) that would be obtained, this is to say, the change in number of FTES needed for dimensional control processes along the Overhaul process. For this purpose it has been used the foreseen demand of propellers along 2018 (73 propellers), the OGMA productive calendar for 2018 (where it has been found that excluding holidays a worker will work 238 days) and available working hours per turn (6.88 (H)).

$$FTE_{CS} = \frac{32 \cdot 73}{6.88 \cdot 238} = 1.427 \tag{5.8}$$

$$FTE_{FS} = \frac{0.13 \cdot 73}{6.88 \cdot 238} = 0.0058 \tag{5.9}$$

$$FC = FTE_{CS} - FTE_{FS} = 1.421 \tag{5.10}$$

As a result, it has been obtained that 1.421 FTE's (almost one and a half full time worker) could be reassigned to other tasks and positions as consequence of the efficiency improvement that would be achieved at dimensional control process.

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

Since in the diagnose of these processes it has been stated that the current layout is wrongly designed for a full exploitation of existent resources, the proposed solution is the conception of a new layout for the grinding and polishing activities area.

In order to carry this out the room, the extractors, the blades location posts, the vent pipes parts, and the available spaces in between the extractors and the room walls have been measured. The more relevant measures can be seen in Figure 5.11.

Figure 5.11: Grinding / polishing area essential measures

The new layout would consist in placing the incorrect posts (marked with a red cross in Figure 4.19) in opposite direction to the way they are currently placed, resulting in the following combination (Figure 5.12). In order to be able to perform this change in the layout some adjustments must be done: Blades location posts would move to their counter direction, extractors corners which are useless and horizontal parts of the vent pipes must be cut off (Figure 5.13).

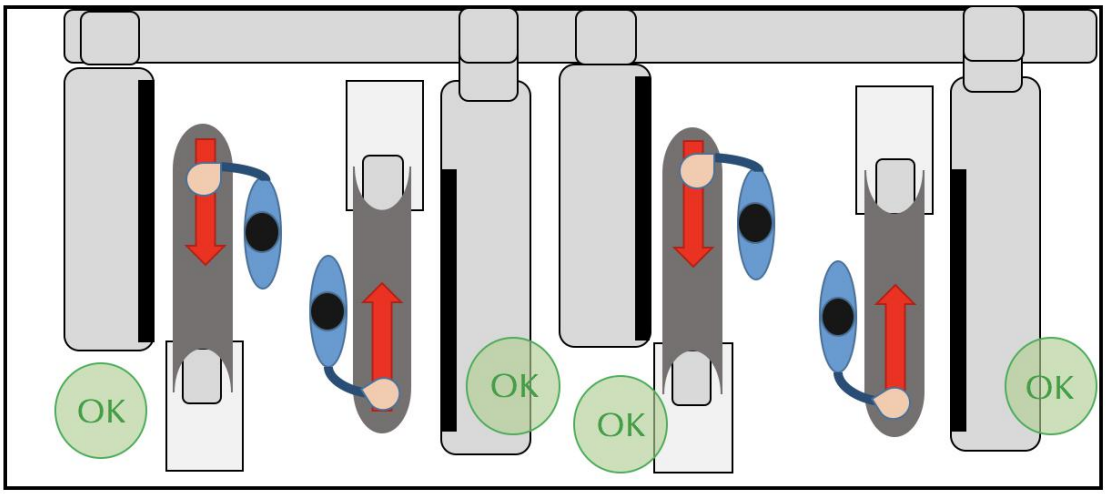

Figure 5.12: Polishing and grinding problem solution illustration

Figure 5.13: Grinding / polishing area layout changes

With the proposed changes in the layout (current and future state dimensional layout maps are found respectively at Figure 5.14 and Figure 5.15), and the acquisition of two grinding machines and one additional polishing machine, the following fluctuations in times for the three processes would be obtained.

Table 5.9: Times for Blade Surface Repair process

BLADE SURFACE REPAIR			
	Current state	Proposed future state	Percent Variance
Process time (H/blade)	6.5	6.5	0%
Process Lead time (H)	13	6.5	-50%
Man-hours (H)	26	26	0%
Machine time (H)	0	0	[-]

Table 5.10: Times for Polishing Re-work process

POLISHING RE-WORK PROCESS			
	Current state	Proposed future state	Percent Variance
Process time (H/blade)	4	4	0%
Process Lead time (H)	8	4	-50%
Man-hours (H)	16	16	0%
Machine time (H)	0	0	[-]

Table 5.11: Times for Fairing Finishing process

Fairing Finishing			
	Current state	Proposed future state	Percent Variance
Process time (H/blade)	2	2	0%
Process Lead time (H)	4	2	-50%
Man-hours (H)	8	8	0%
Machine time (H)	0	0	[-]

From the changes in time that would be achieved in the the three processes the following variations in Waiting in Process Time and Value Percent of Times would also be attained (Table 5.12).

Workers need to rest around 10 (min) each 45 (min) of polishing/grinding work activity, there is also some time invested in putting on and off the required masks and clothes and a bunch of stoppages related to employees breaks and meal times, so in these processes also not all Process Times are VATs, in fact, it has been computed to be value-adding only the 65.8% of them.

Table 5.12: Waiting in Process Time and Value Percent of Time for Blades Surface Repair, Polishing Re-work and Fairings Finishing processes

	Current state	Proposed future state
Waiting in Process Time (H) - BSR	6.5	0
Waiting in Process Time (H) - PRW	4	0
Waiting in Process Time (H) - FF	2	0
Value Percent of Time / blade (%)	32.9%	65.8%
Value Percent of Time / batch (%)	65.8%	65.8%

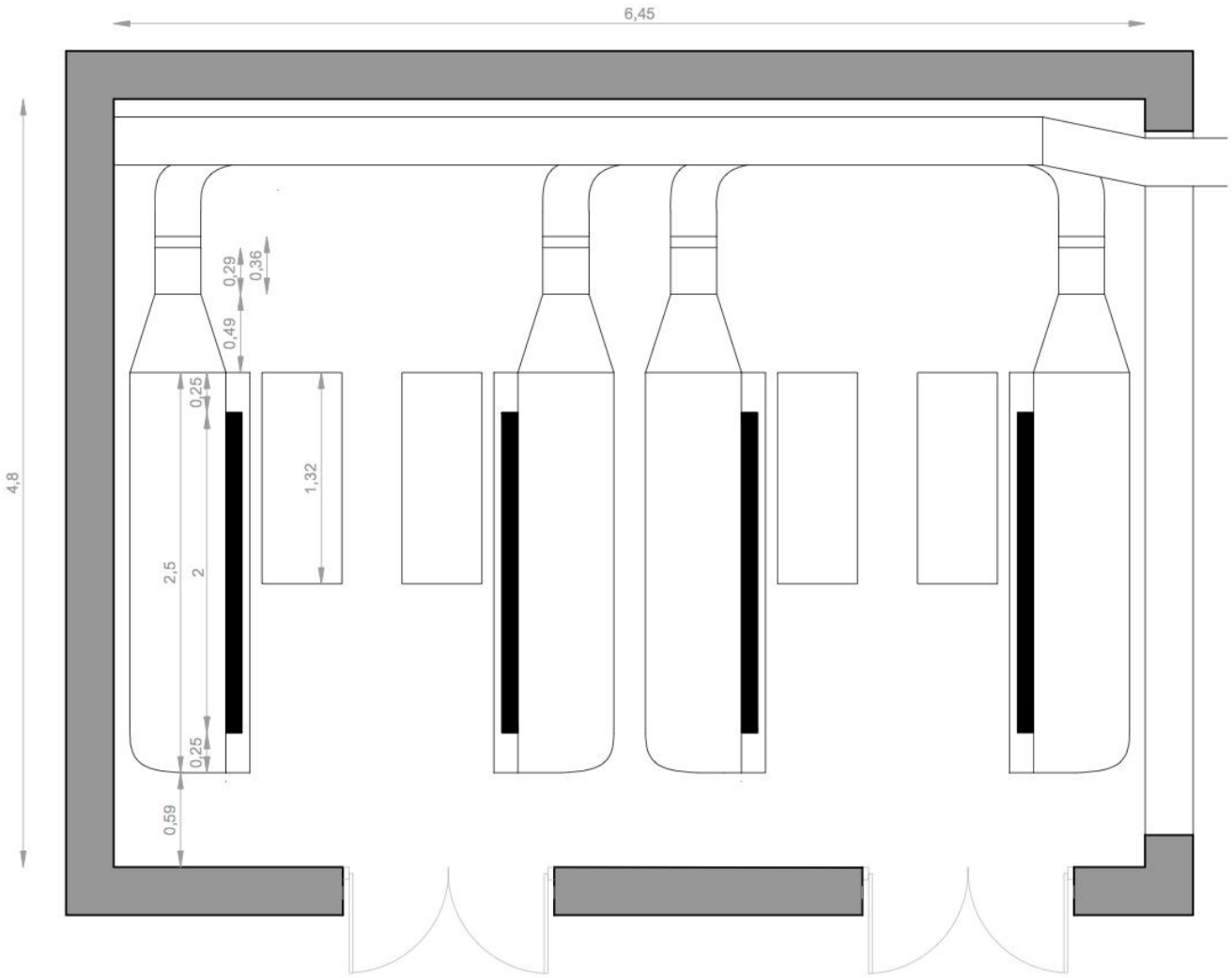

Figure 5.14: Current layout map

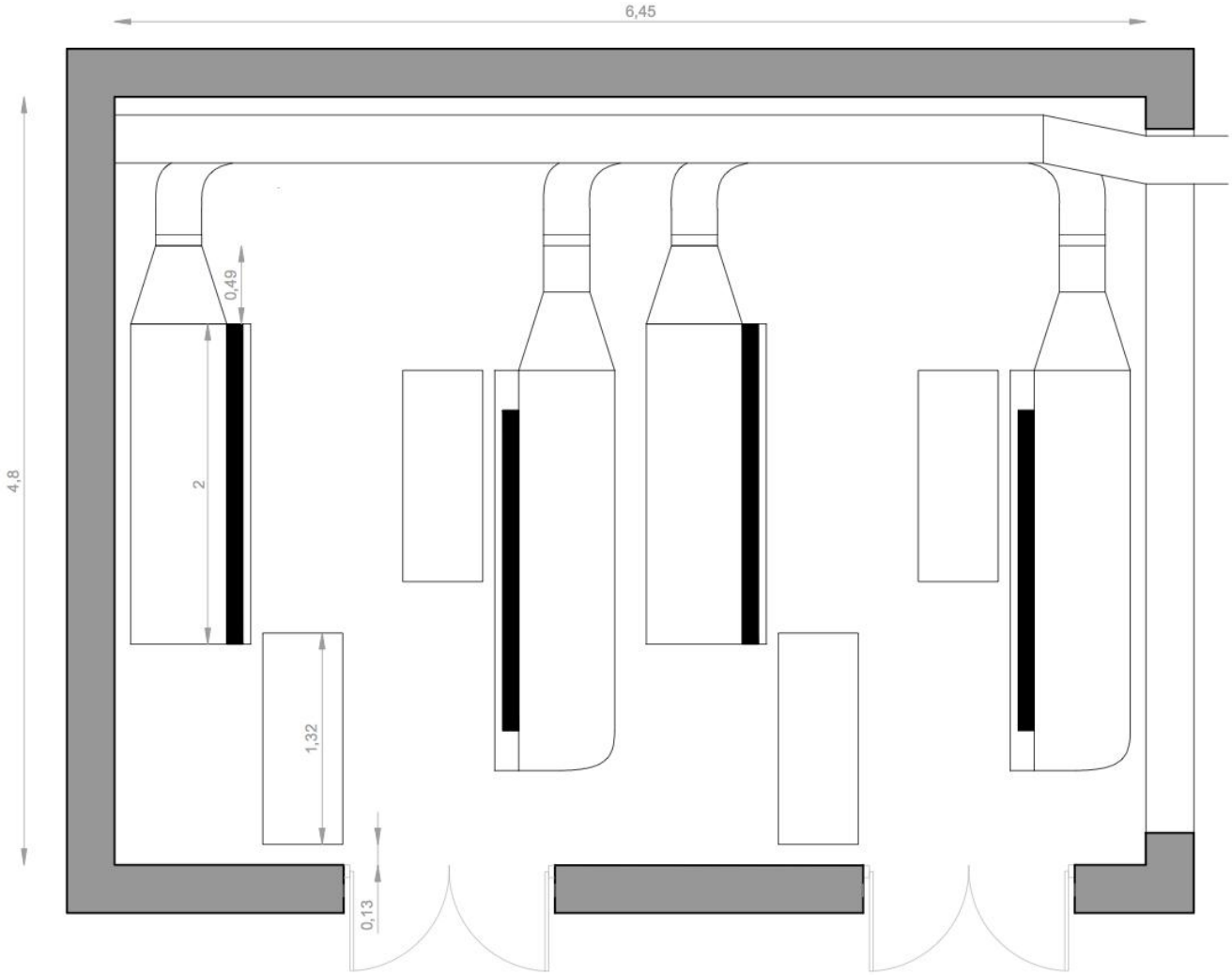

Figure 5.15: Future layout map

5.2.4 Plastic Foam Fairing

One fairing mold must be ordered in order to treat in the oven the complete batch simultaneously, and therefore, making use of all available resources and removing unnecessary duplicated Machine Times and Waiting Times (waiting to dry and cooling down times).

Additionally, it would be interesting 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 blades repair manual ([31]) states that one hour of cooling period at room temperature must precede the molds removal. Since currently the employees are unaware of this mandatory cooling time, two models for a visual alert to place over the molds and a procedure to locate at the oven area have been created, both follow at the end of this subsection (Figure 5.18 and Figure 5.19). Visual Control tools have been chosen for this preventive purpose because they make possible a quick broadcast of information and easy comprehension by employees.

With the arrival of the new fairing mold and the increment of cooling waiting time as preventive measure the following reduction in Process Lead Time and Machine Time will be achieved (Figure 5.16 and Table 5.13).

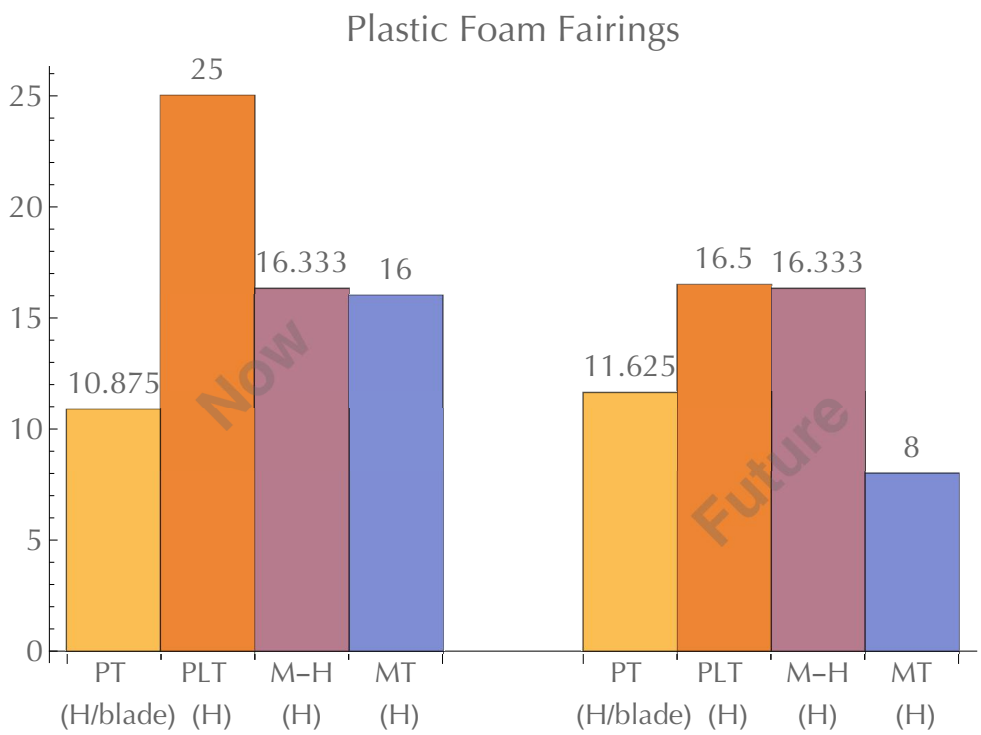

Figure 5.16: Plastic Foam Fairing times: current and future states

Table 5.13: Times for Plastic Foam Fairings process

PLASTIC FOAM FAIRINGS			
	Current state	Proposed future state	Percent Variance
Process time (H/blade)	10.88	11.63	6.90%
Process Lead time (H)	25	16.5	-34%
Man-hours (H)	16.33	16.33	0%
Machine time (H)	16	8	-50%

Other useful fluctuations inferred by the above results are presented in Table 5.14.

Table 5.14: Waiting in Process Time and Value Percent of Time for Plastic Foam Fairing process

	Current state	Proposed future state
Waiting in Process Time (H)	14.13	4.88
Value Percent of Time / blade (%)	42.17%	68.43%
Value Percent of Time / batch (%)	92.67%	91.92%

Additionally would be suggested to carry out the pouring of the fairing material right at the oven exit thus shortening the unnecessary lager route shown in Figure 5.17.

Figure 5.17: Route from oven to pouring area

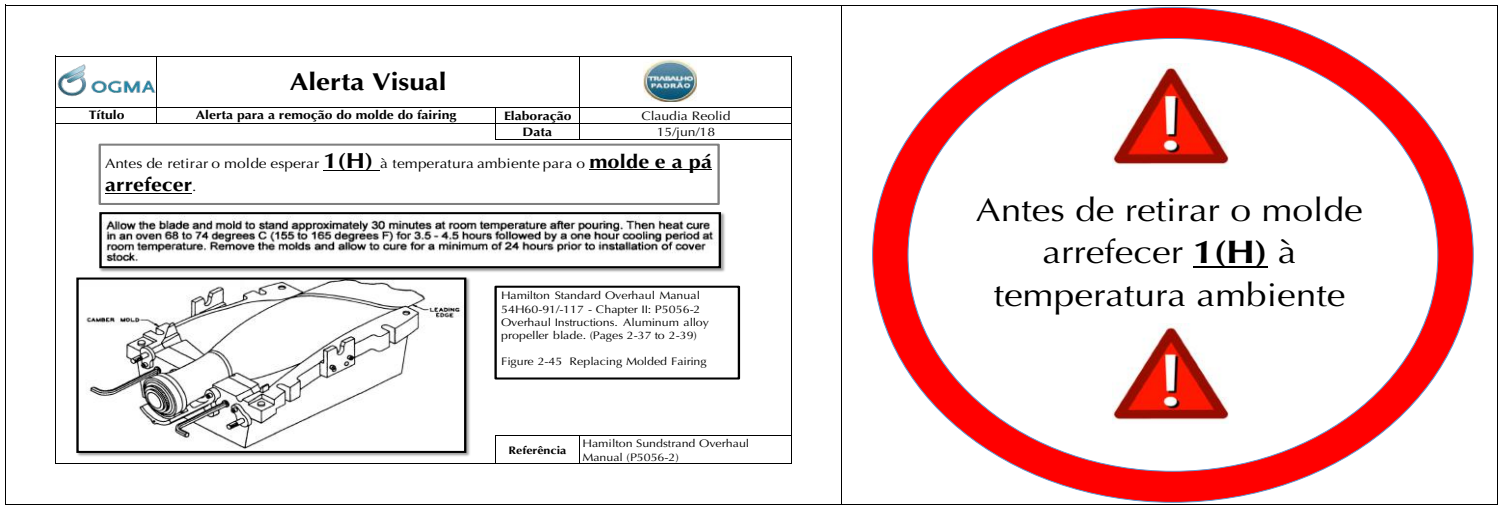

Figure 5.18: Visual Alerts for molds removal

OGMA	**Procedimento**		TRABALHO PADRÃO
Título	**Procedimento a seguir na estufa e na remoção dos moldes (fairings)**	**Elaboração**	Claudia Reolid
		Data	15/jun/18

Veio: Preparação dos fairings ⟶ **Está:** Estufa, mistura e vertemento, remoção dos moldes ⟶ **Vai:** Instalação do cover stock

- Pré-aquecer a pá e o molde para **43,33 ºC - 54,44 ºC** antes de verter a mistura.

- Suspender a pá com a ponta para baixo no vazamento.

- Misturar os dois componentes do sistema de espuma criando material do fairing.

- Verter simultaneamente as quantidades de mistura nas cavidades da borda de ataque e de fuga do molde.

- Deixar a pá e o molde em repouso por aproximadamente **30 (MIN)** em temperatura ambiente após o vazamento.

- Aquecer a cura na estufa a **68 - 74 ºC** por **3,5 - 4,5(H)**

- Esperar **1(H)** à **temperatura ambiente** para o molde e a pá arrefecer.

- Remover os moldes e deixar curar por um período mínimo de **24(H)** antes da instalação do cover stock.

CUIDADO! NÃO LEVANTE A PÁ PELO FAIRING.

Hamilton Standard Overhaul Manual 54H60-91/-117.
Chapter II: P5056-2, task 2-159.

Referência	Maintenance Manual P5056-2

Figure 5.19: Oven procedure

5.3 Solutions summary diagram

Finally through the diagram presented at Figure 5.20, the different countermeasures exposed along this chapter are summarized up.

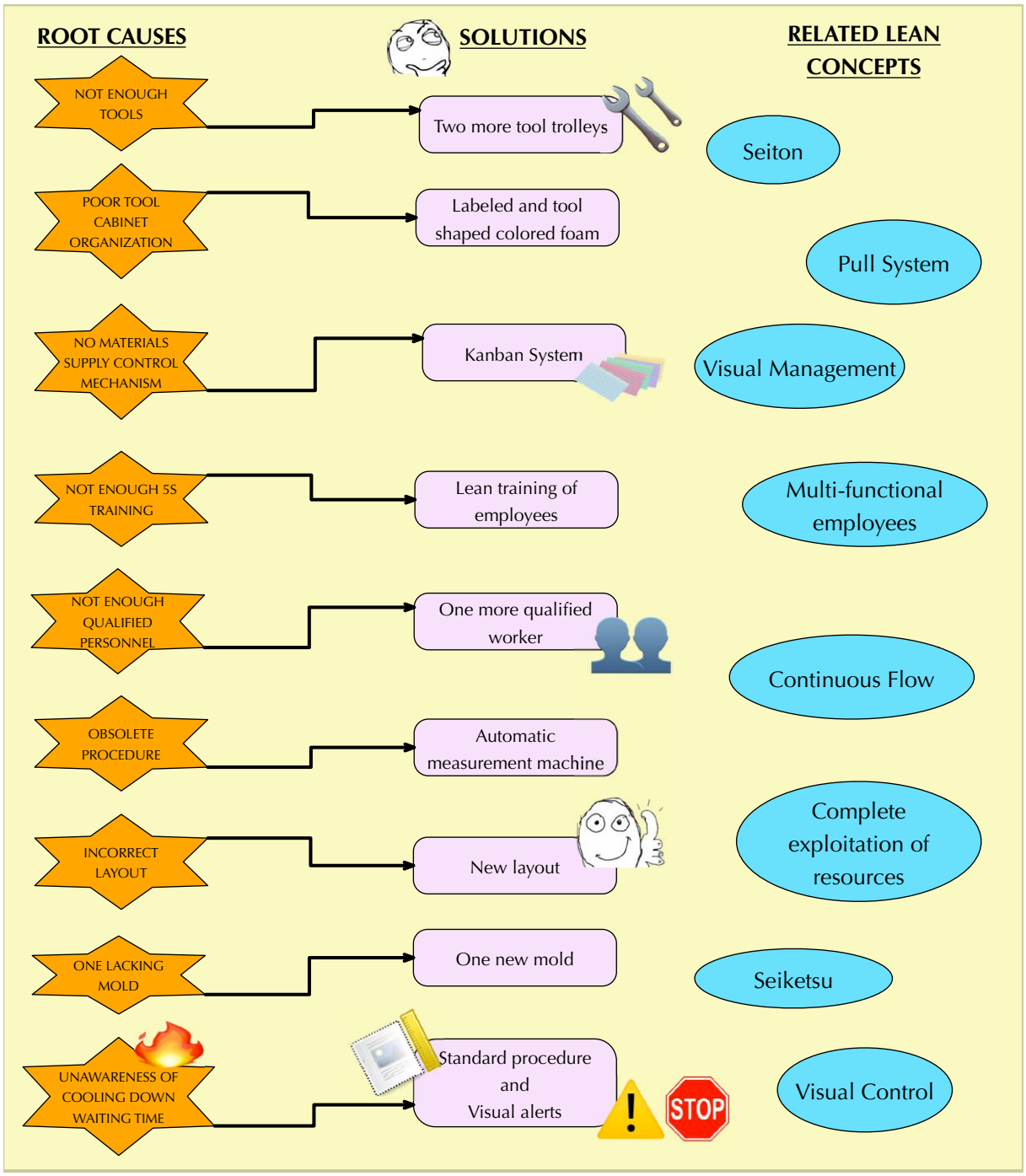

Figure 5.20: Countermeasures summary diagram

Chapter 6

Conclusions

In this final chapter the different Lean Manufacturing techniques employed along the thesis will be outlined, the overall envisioned gains in terms of Lead Times will be shown and some future work will be suggested.

6.1 Recapitulation of lean techniques employed and proposed solutions

With the main objective of understanding and developing the study of times and methods of the different processes which constitute the the case of study of this thesis, Genchi Genbutsu technique has been used, that is to say, going to Gemba and seeing in first hand what was actually happening and how each process was carried out. Patience, time and asking a lot of questions were essential ingredients for the success of this task.

In other to show the overall Overhaul process in a graphical and easy to understand way that could map the flow of the process at the current situation, as well as allowing to signal which subprocesses would be examined in the thesis and which ones would remain outside the domain of analysis, that is to say, to clarify the case of study, two flowcharts (Figure 3.4 and Figure 3.5) portraying the expertise and blades repair processes have been presented.

Since 5S are fundamental steps for a successful lean implementation, a 5S Audit has been carried out in order to portrait the 5S current situation. The results obtained helped to stand out which of the five steps are currently the worst implemented or adopted by the employees, signaling at the same time some Kaizen opportunities and the necessity of a better awareness among workers about the 5S: lean training is fundamental to create a continuous improvement culture, workers need to embody the lean philosophy, most of the proposed solutions will be futile if some of the basis of Lean (as the 5S) are not implemented correctly.

Once the diagnosis was completed, 5 Whys technique has been employed in other to get to the root cause of the different spotted problems.

Difficult to quantify their impact were the suggested solutions related with the acquisition of two new tools trolleys and its better organization in a more visual way, as well as the design of a Kanban System which could help to prevent situations of lacking materials or the excess of materials inventory, and so that move towards a more lean environment and Pull ordering relationship with the warehouse. 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 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.

Some barriers to flow were detected among some of the processes which comprised the case of study.

In Borescope Inspection process in orther to improve flow has been suggested the convenience of one more qualified employee to perform this task.

Regarding to Dimensional Control processes a more radical approach (Kaikaku) has been suggested: a complete innovation of the procedure by the adquisition of an automatic measurement machine. If this technique were implemented besides the monumental gains in time that would be attained, also big savings in Man-hours would be achieved: more than one full time equivalent employee.

For the cases of Blade Surface Repair, Polishing Re-work and Fairing Finishing, the fact that Overhaul process is carried out in a “Batch-and-Queue” way makes critical the impact of an incorrect layout. Impeding the four blades to be worked simultaneously, this fault in the layout creates three unnecessary bottlenecks by duplicating each Process Lead Time. The countermeasure proposed includes the design of a new layout that will improve the Overhaul process flow and allow a full exploitation of current resources.

Finally, for Plastic Foam Fairing process, the proposal for the betterment of the process includes the acquisition of a new mold that would allow the full oven exploitation. Also a preventive approach has been suggested in order to try to avoid a possible recurrence of mold rupture: visual alerts to put over the molds that would indicate the time that should be waited before their removal have been designed, also a standardized procedure to place at oven area has been developed wherein the different steps involved in the process according to the maintenance manual are indicated, from fairings preparation to cover stock installation.

6.2 Lead Time gains

In this section the Lead Time savings that would be attained through the implementation of those proposed solutions whose results have been possible to foreseen and quantify are going to be presented.

In the following table (Table 6.1) appear all processes that constituted the case of study, this is to say, blade processes carried out inside propellers hangar, and their current and future Lead Times.

Table 6.1: 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.

6.3 Future work

The most critical Lead Times inside the Overhaul process correspond to those processes carried out outside propellers area which were not the object of study of this thesis (yellow colored ones in Figure 3.4 and Figure 3.5, such as: Painting, Etching, Anodizing, etc). The Activity Ratio of those processes is really small in comparison with all the other ones: transporting and waiting times are really important there, this is because in those processes the resources available must be shared with other OGMA products, so queuing is frequent since the blades might not be the priority or they do not want all the resources to be monopolized by the four blades batch whose process completion requires more time than most of the other products processes. 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”. 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 always be future work.

Bibliography

[1] Lean Enterprise Institute. What is lean ? https://www.lean.org/WhatsLean/. [Online; accessed 18-July-2018].

[2] Strategos Company. A History of Lean Manufacturing. http://www.strategosinc.com/just_in_time.htm. [Online; accessed 18-July-2018].

[3] The Official Website of Toyota Motor Manufacturing Kentucky. The Toyota Production System. http://toyotaky.com/tps1.asp. [Online; accessed 18-July-2018].

[4] Toyota Industries. The Story of Sakichi Toyoda. https://www.toyota-industries.com. [Online; accessed 18-July-2018].

[5] K. Yang and B. El-haik. *Design for Six Sigma A Roadmap for Product Development*. McGraw Hill Professional, 2003.

[6] J. P. Womack, D. T. Jones, and D. Roos. *The Machine That Changed the World*. Free Press, 1990.

[7] T. Ohno. *Toyota Production System: Beyond Large-Scale Production*. Productivity Press, 1978.

[8] The Official Website of Toyota Motor Corporation. http://www.toyota-global.com/. [Online; accessed 18-July-2018].

[9] Y. Suzuki. *Structure of the Japanese production system: elusiveness and reality*, volume 3. Asian Business and Management, 2004.

[10] M. Yasuhiro. *Toyota Production System: An Integrated Approach To Just-in-Time*. Industrial Engineering And Management Press, 1993.

[11] M. Grunow. The 3 Ms of Lean. Technical report, TUM School of Management, 2018.

[12] J. P. Pinto. *Lean Thinking: Introdução ao pensamento magro*. Comunidade Lean Thinking, 2008.

[13] J. P. Womack and D. T. Jones. *Lean Thinking: Banish Waste and Create Wealth In Your Corporation*. Simon & Schuster, 1996.

[14] N. R. Tague. *The Quality Toolbox*. WIliam A. Tony, Second edition, January 2005.

[15] T. Hessing. W. Edwards Deming. *Six Sigma Study Guide*, December 2013.

[16] R. Consultancy. PDCA Cycle. https://rmpconsultancy.com/home/pdca-cycle/. [Online; accessed 18-July-2018].

[17] LEANBOX. Value Stream Mapping. https://leanbox.es/value-stream-mapping/. [Online; accessed 18-July-2018].

[18] Windpower Engineering Development. Tools of RCA: 5 Whys? https://www.windpowerengineering.com/. [Online; accessed 18-July-2018].

[19] Sigma Grupo Consultor. SISTEMA 5S. http://sigmagrupoconsultor.com/5s-en-monterrey.html. [Online; accessed 18-July-2018].

[20] J. Lee. Lean 5S. Technical report, TUM School of Management (Production and Supply Chain Management), 2018.

[21] Planview LeanKit. What is a kanban board? https://leankit.com/learn/kanban/kanban-board/. [Online; accessed 18-July-2018].

[22] A. A. Romero. La Gestión Visual. *Aar management*, 2015.

[23] i-nexus Strategy Execution Software. Lean Visual Management. https://www.i-nexus.com. [Online; accessed 18-July-2018].

[24] R. Anjoran. Lean Visual Management Boards In Factories: Keep It Simple! *China Manufacturing Improvement Blog*, 2017.

[25] Vorne - OEE. OEE Factors. https://www.oee.com/oee-factors.html. [Online; accessed 18-July-2018].

[26] Karen Martin & Associates. Lead Time vs. Process Time. www.ksmartin.com. [Online; accessed 18-July-2018].

[27] J. Bresnahan. Speed! *CIO mag*, Vol. 11(No. 4), 1997.

[28] United States Environmental Protection Agency. Lean Government Metrics Guide. www.epa.gov/lean. [Online; accessed 18-July-2018].

[29] OGMA. Flying with you since 1918 (Company profile). http://www.ogma.pt. [Online; accessed 18-July-2018].

[30] Aprovada privatização da ogma (actual.). *TSF Rádio Notícias*, 2004.

[31] *Hamilton Standard Maintenance Manual 54H60-91/-117*, Chapter II: P5056-2 Overhaul Instructions edition.

[32] Shadowfoam. Laser cut foam inserts for tool boxes. https://www.shadowfoam.com. [Online; accessed 18-July-2018].

[33] K. Suzaki. *The New Manufacturing Challenge: Techniques for Continuous Improvement*. New York: Free Press, 1987.

[34] S. Cimorelli. *Kanban for the Supply Chain: Fundamental Practices for Manufacturing Management*. CRC Press, Second edition, April 2016.

[35] Visual Workplace Inc. Idea Library: Inventory Gallery. `http://www.visualworkplaceinc.com/sign-shop/sign-shop-examples/inventory-gallery/`. [Online; accessed 18-July-2018].

[36] The Official Website of AeroScan propeller metrics company Corporation. Why use Aeroscan M5? `http://www.aeroscanm5.com`. [Online; accessed 18-July-2018].