5S Implementation in a Mechanical Maintenance Warehouse

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Abstract

Founded in 1912, BA Glass is a well-established company in the glass industry with an international reputation for excellence in the production and distribution of glass packaging and for providing innovative and sustainable solutions.

This dissertation was carried out as part of a curricular internship at BA Glass in Avintes, more specifically in the Mechanical Maintenance Department. Initially, the goal was to implement the 5S in the Workshop, but it started to be implemented in the Warehouse. It is worth mentioning that this experience was an opportunity to improve theoretical and practical knowledge in the area of continuous improvement and maintenance.

Initially, a follow-up of the workers was done and a 5S audit was performed to identify and understand the main problems faced. Through this approach and the application of the GUT matrix, it was possible to guide the project to solve the most critical and challenging challenges.

In this sense, the implementation of 5S was carried out in the department's Warehouse, where a specific layout was created for all the spare parts so that they were located according to defined areas and criteria. This approach helped to optimize storage space and made it easier to locate the equipment.

A stock management system was also created that allows more specific control of the available spare parts, enabling better organization and forecasting of replacement needs, as well as cost reduction and efficiency improvements.

Additionally, preventive maintenance plans were also developed for some equipment, through the use of SAP software.

Finally, a final audit was performed to evaluate the implemented changes, and the results were very positive, with a significant improvement in several aspects, such as, for example, the MTTR had a very large decrease.

Resumo

Implementação de 5S num Armazém de Manutenção Mecânica

Fundada em 1912, a BA Glass é uma empresa bem estabelecida na indústria vidreira com reputação internacional pela excelência na produção e distribuição de embalagens de vidro e por fornecer soluções inovadoras e sustentáveis.

Esta dissertação foi realizada no âmbito do estágio curricular na BA Glass em Avintes, mais concretamente no Departamento de Manutenção Mecânica. Inicialmente, o objetivo era implementar os 5S no Workshop, mas começou a ser implementada na Warehouse. Vale ressaltar que esta experiência foi uma oportunidade de aprimorar conhecimentos teóricos e práticos na área de melhoria contínua e manutenção.

Inicialmente, foi feito um acompanhamento dos trabalhadores e realizada uma auditoria 5S para identificar e entender os principais problemas enfrentados. Através desta abordagem e da aplicação da matriz GUT, foi possivel orientar o projeto para solucionar os desafios mais críticos e desafiantes.

Nesse sentido, a implementação de 5S foi realizada na Warehouse do departamento, onde foi criado um layout específico para todas as peças de reserva, de forma a serem localizadas de acordo com áreas e critérios definidos. Essa abordagem ajudou a otimizar o espaço de armazenamento e facilitou a localização dos equipamentos.

Com efeito, foi também criado um sistema de gestão de stock que permite um controlo mais específico das peças de reserva disponíveis, permitindo uma melhor organização e previsão das necessidades de reposição, bem como a redução de custos e melhorias de eficiência.

Adicionalmente, foram também desenvolvidos planos de manutenção preventiva para alguns equipamentos, através do uso do software SAP.

Por fim, foi realizada uma auditoria final para avaliar as mudanças implementadas, sendo que os resultados obtidos foram bastante positivos, tendo existido então uma melhoria significativa em diversos aspetos, como por exemplo, o MTTR teve uma diminuição bastante grande.

Acknowledgements

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Apart from this, I would also like to thank all my friends and colleagues who have directly or indirectly contributed to me reaching this stage of my life. I thank you for your friendship and patience during all these years.

Finally, what could not be missed, a special thanks to my parents and grandparents, who have been my greatest strength all these years. Without them it would have been impossible to come this far.

To my parents and grandparents

Contents

Acronyms and Symbols

5S - Sort, Set in Order, Shine, Standardize and Sustain

AV - Avintes

TPS - Toyota Product System

JIT - Just in Time

SMED - Single-Minute Exchange of Die

VSM - Value Stream Mapping

KPI - Key Performance Indicator

MTTR - Mean Time to Repair

MTBF - Mean Time Between Failure

MWT- Mean Waiting Time

OEE - Overall Equipment Effectiveness

QR - Quick Response

SAP - Systems Applications and Products in Data Processing

DMM - Department of Mechanical Maintenance

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Chapter 1

Introduction

As part of the MSc project of the 2nd semester of Mechanical Engineering at the Faculty of Engineering of the University of Porto, this project was carried out in collaboration with BA Glass, as part of the curricular unit "Dissertation", with a duration of approximately 5 months. The topic of the project is "5S Implementation in a Mechanical Maintenance Warehouse".

In this sense, this chapter describes the structure of the dissertation and aims to make known the company as well as the objective of the work and the methods used to carry it out.

1.1 BA Glass History and Evolution

BA Glass is a multinational company based in Portugal, specialized in the production, transformation, and distribution of glass products for various industries. Its history begins in 1912, when Raul da Silva Barbosa and Domingos de Almeida founded the company.

Since then, BA Glass has invested in technology and automation, gradually improving its production processes. In 1969, the company relocated to Avintes, where the first machine IS was installed, significantly increasing production capacity. Subsequently, in 1993, the company acquired a large stake in "Companhia Industrial Vidreira", which gave access to another plant with three melting furnaces in Marinha Grande. In this sense, over time, the company expanded internationally, so currently there are 12 factories in 7 different countries, including Portugal, Spain, Germany, Poland, Romania, Bulgaria, and Greece. On the other hand, there are several offices in other locations. As for the production of bottles, the company produces 11 different colors with unique characteristics and exports to more than 80 countries. On average, the company produces 8 billion bottles per year.

One of the main pillars of BA Glass is its willingness to make every effort to provide its customers with the best quality and safety products, always maintaining social responsibility and sustainability. Thus, one of the company's mottos is "zero accidents" philosophy, which ensures

that there are fewer failures and defects. In terms of sustainability, the company promotes the use of natural resources and recycling to reduce carbon emissions.

In summary, the company values are humbleness, emotion, ambition, rigor, and transparency, meaning that one should be focused, help the team and demonstrate ownership and think in simple ideas. BA Glass effort to be sustainable has been well recognized, as it was determined as the most sustainable glass industry company by World Finance in 2020. Additionally, it had the highest score (A) on the Carbon Disclosure Project performance (CDP, 2022). Industry 4.0 is being instrumental to the company's success, as it enables it to produce a high volume of products and maintain operational efficiency.

1.2 Project Framework and Purpose

Warehouses are a key component of supply chain management and are used to store, organize, and distribute equipment or materials. However, there are several difficulties in making these operations efficient, and various problems can occur, such as disorganization, waste, and low productivity.

In response to these challenges, the implementation of the 5S methodology focuses on organizing, cleaning and standardizing the work environment to increase productivity and reduce waste, which significantly improves the flow of operations.

In this case, the warehouse under study belongs to the Mechanical Maintenance Department, and it is fundamental that there is an excellent organization of spare parts, as well as a clean and easily movable area, and the existence of an inventory management system.

1.3 Objectives of the work performed

The main objectives of this project are:

- **Improving productivity and efficiency**: One of the main goals of 5S implementation is to improve worker efficiency and productivity, as workers spend less time on a given task by organizing and optimizing the workplace;
- **Improving safety:** Another goal of 5S implementation is to aim for safety in the workplace, making it cleaner and more organized, which in turn reduces the risk of accidents;
- **Optimize inventory management:** Establishing a system to update store inventory will enable better management of practices by identifying which parts and materials are in greater demand and which are in less demand, thereby reducing costs;

- **Promote continuous improvement:** Continuous improvement will be promoted daily, changing the mindset of everyone directly or indirectly involved in this workplace.

1.4 Methodology

The Action-Research principle put forward by Kurt Lewin served as the foundation for the technique used in this dissertation. This strategy included a number of phases that were carried out methodically:

- **Problem identification:** The challenges and problems that the Mechanical Maintenance Department faced were carefully analyzed. This investigation included a review of literature, giving a thorough comprehension of the situation and the challenges encountered.
- **Data Analysis:** Employee responses were collected and analyzed through questionnaires. This analysis allowed to identify valuable insights and better understand employee perspectives on problems and possible solutions.
- **Planning:** Using the PDCA (Plan-Do-Check-Act) method, a detailed action plan was drawn up with the objectives to be achieved. The established schedule determined the activities and deadlines to implement the proposed solutions.
- **Development and implementation of the solutions:** On the basis of the data analysis, workable solutions to the problems found were suggested. These solutions were created while taking into account the available literature and the Mechanical Maintenance Department's practical experience. The solutions were implemented gradually and progressively, allowing for the necessary modifications.
- **Evaluation of results:** After the solutions were implemented, evaluations were conducted to measure their effectiveness and impact.
- **Reflection:** Throughout the process, continuous reflections were conducted to evaluate the effectiveness of the actions taken, identify lessons learned, and promote further improvements. This reflective approach contributed to the improvement of the implemented solutions and to the development of practical knowledge in the field of mechanical maintenance.

1.5 Document Structure

Chapter 1 has begun with a brief introduction of the company and the presentation of the project to be developed, especially its purpose and the conditions under which it was developed.

Chapter 2 summarizes the literature required for the project and is central to understanding the following topics as well as the solutions implemented.

Chapter 3 identifies the problems encountered in the baseline and describes the analysis that was conducted to understand the main issues to be resolved. This chapter also describes how the work department operates and how glass production takes place.

Chapter 4 explains the solutions found and presents the final results, as well as the methodology used to solve the problems.

Finally, Chapter 5 presents the final conclusions and future perspectives.

Chapter 2

Literature Review

This chapter mainly deals with theoretical concepts that form the basis of the dissertation work. It plays an important role as it contributes to a better understanding of the applied concepts.

2.1 Lean Production

Lean manufacturing is a production system that was originated and developed in Japan. Womack and Jones were among the first to use the term "lean" and were mentioned in the book "The Machine that Changed the World" (Chauhan and Qureshi, 2015). The system has been used by industry as well as other types of organizations such as institutes, the public sector, etc. However, to understand the emergence of lean, it is necessary to go back a few years and understand the context that existed in the post-World War II, because at that time Japanese workers faced the problem of reduced material, but also financial problems and poor human rights conditions (Abdullah, 1996). Hence the need to create a system that eliminates waste in all aspects of the manufacturing process, including production, transportation, inventory, lead time, post-processing, and other defects that may exist.

Around the same time, a member of Toyota's founding family and Toyota's chief production engineer, K. Toyoda and T. Ohno, respectively, visited some Ford factories to observe their operations (Čiarnienė and Vienažindienė, 2012). After this observation, they drew several conclusions and ideas and significantly changed their process and working method to present more positive results. In other words, by establishing a set of principles to increase productivity and quality, the Toyota Production System (TPS) was created (Pereira, 2017). For example, they concluded that weekly deliveries are not profitable at all, nor do they add value to the product, since they only increase costs. So they concluded that with small daily deliveries, they would eliminate many operations that do not add value.

It is important to reiterate that Toyota's new system of processes and work philosophy revolutionized the industry. One of their changes was "only" to end the final inspection of the product

and ensure quality at every station, which may seem simple at first glance, but was crucial to the growth of the company, including the lean concept, and drastically reduced existing inventories. So, it can also be said that the confidence and satisfaction of the workers were fundamental to the success, as the mistakes identified at each station had to be corrected and they were forced to demand more from themselves. To make a metaphorical comparison: a team of workers is like a soccer team because to be victorious you have to work as a team and fight for the same goals.

Therefore, these small major changes have contributed to the emergence of revolutionary concepts such as Just-in-Time and Milk-Run. The first concept aims to produce only what is needed to reduce costs, lead times, and waste, and to improve quality and efficiency. Compared to other methods, the benefits are considerable, as it makes manufacturing much more flexible than before, which is important for competitiveness (Costa and Silva, 2021). Also, the fact that safety stocks are lower allows companies to reduce their capital expenditure (Taghipour et al., 2020). The second concept aims to consolidate deliveries from suppliers on a single route with only one vehicle to reduce logistics costs and waiting time. This requires good communication with suppliers, and it takes a few weeks or months to see positive results. The cost of this process depends on the distance and duration of the trips, taking into account that the prescribed route must be followed (Meyer, 2017) (Ohno, 1978).

In short, lean manufacturing is a method that aims to minimize waste and maximize the efficiency of any type of process, and aims to eliminate activities that have no value (overproduction, waiting time, excess inventory, defects, etc.). There are two basic pillars: continuous improvement and respect for people. In the context of continuous improvement, it is crucial to understand value creation and encourage employees to develop an appropriate mentality for the desired goals in order to be more competitive than the competition. In this sense, the appreciation of the work team is very important (Barros Basto, 2022).

In addition to the previously mentioned JIT and Milk Run, there are several tools such as Value Stream Mapping, Kaizen, Poka-Yoke, Kanban, Jidoka, SMED, and 5S. However, depending on the nature of the problem faced by the particular company or institution, other tools may be used as part of this philosophy.

2.1.1 Principles of Lean Production

As already mentioned, Lean is understood as a way of thinking that allows openness to change, continuous development, and learning, always with the aim of aligning production with demand, eliminating waste and being creative, and involving the forces of all workers in work activities, because without commitment and a good relationship between team and suppliers, the concept of success cannot be achieved (Lyons et al., 2011).

So this management model contains the following principles:

- **Identify the value:** Value is usually defined by what the customer is willing to pay for the service or final product, which means that first, it is very important to understand what the customer values and then make efforts to achieve those values. In fact, each company and organization has different values depending on the objective and type of customers, which require different priorities and different efforts. Therefore, in order to accurately determine the value of the product, it is necessary to understand and precisely define the requirements of quality, quantity, time, and service (Womack and Jones, 1997).

- **Value Stream Mapping:** The value stream is a sequence of activities necessary to deliver the product or service to the customer. Therefore, it is essential to map the entire existing process in order to eliminate possible errors or activities that do not add value, thus reducing production and waiting times as well as costs. In this way, only what is needed is produced and the accumulation of stock is avoided. It is important to remember that this process also serves to balance the interests of all parties involved (Costa, 2019).

- **Continuous flow:** It is important and necessary that the production runs without interruptions, and continuously, and for this it is necessary to produce only what the customer wants, to reduce the set-up times, and to introduce pull systems. It is often necessary to redesign the entire process and introduce new technologies to eliminate interruptions and the associated waiting times.

- **Pull manufacturing:** "Sell, one. Make one" is the phrase that describes this principle (Womack and Jones, 1997). This principle is related to Just-In-Time production, since only the quantities that the customer wants are produced, i.e., the waste that would eventually arise from overproduction is avoided. In other words, production only occurs when there is a customer order. Therefore, the company no longer pushes the product to the market, since it is now the customer who pulls the product (de Almeida, 2015).

- **Perfection and continuous improvement:** After the implementation of the above principles, it is important that the philosophy of continuous innovation is present in all people directly or indirectly involved in the work in question because this will lead to the perfection of processes, as well as the elimination of waste, value creation, cost reduction and significant improvement in the quality of products and services (Imai, 1970).

- **Employee Involvement:** It is important not to forget that respect for people is one of the most important steps to success, because they represent a very large asset of the company, for which they should always be appreciated and, above all, respected. In this sense, Lean Manufacturing aims to create a healthy and safe working environment, with opportunities for growth and development (Liker and Convis, 2012).

2.1.2 Types of waste

As it can be seen in Figure 2.1 usually in a common process, about 95% of the waste represents the total waste time. Therefore, logically, only about 5% are associated with value-adding functions and activities. Therefore, it is important to distinguish the different types of waste, so that over time it is possible to increase and enhance the value of the different phases and activities of the company. According to Toyota, waste is "anything in excess of the minimum amount of equipment, materials, parts and labor time absolutely necessary for production (Tools, 2015).

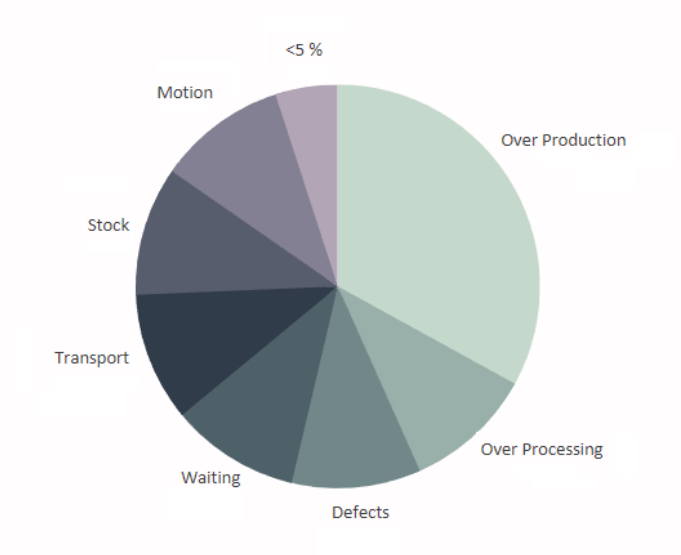


Figure 2.1: Value Add vs Non-Value Adding Process - Adapted From (Tools, 2015)

According to Toyota Production System, it is important to eliminate *"muda"* (anything that does not add value), and this requires a process focus where managers can develop sustainable processes by using *"genchi genbutsu"* (collecting facts and data about the current problem). Then, continuous improvement is implemented into the process through Kaizen, always with respect for employees. It is important to emphasize the importance of *"muda"* as it reduces costs, improves quality and process cycle time, and creates a stable value map.

On the other hand, the *"genchi genbutsu"* provides the necessary information to know where work is needed. One of the most widely used concepts is the "5 Whys Rule", which typically is asked why 5 times until it is identified the root cause of the problem (Sutherland, 2007). In this sense, as it can be seen in Figure 2.2 there are several types of wastes.

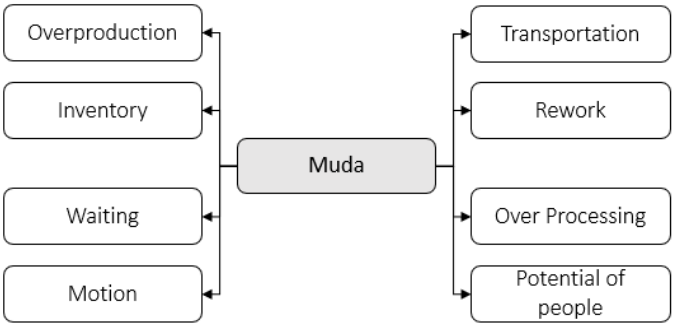


Figure 2.2: Different type of Wastes

The eight wastes identified in lean manufacturing are:

- **Overproduction:** This is the worst kind of waste because it can create other types (Tools, 2015). Producing more than necessary can lead to overstocking and even a waste of resources. Usually, this problem is due to a lack of workable procedures, unstable schedules, unbalanced departments, and incorrect information about current demand. Therefore, to avoid this type of problem, value chain mapping or pull production is usually used. However, depending on the case, other solutions can also be used.

- **Inventory:** Stockpiling a very large amount of materials leads to very high costs and also poses operational risks. One of the solutions that has already been discussed is the application of the just-in-time concept. This problem is the opposite of a continuous flow. It can be caused by various reasons, such as inefficient processes, failure of the first-in-first-out system, etc (Tools, 2015).

- **Waiting:** Downtimes, such as the loss of employees or machinery, breakdowns, and stock failures, affect the necessary production activity. In other words, this happens when two or more processes are not fully synchronized.

- **Motion:** Any unnecessary or excessive movement consumes increased financial expenses, as well as company time and energy. One of the reasons for this type of problem may be, for example, a poor layout that results in unnecessary movement (Costa, 2019). So, it is advisable to have an organized workplace in terms of the location and position of the tools so that the stations can work more effectively.

- **Transportation:** Any unnecessary movement of materials, parts, or products, such as providing employees or transportation, results in increased costs.

- **Rework:** The defects can be caused by a variety of reasons, such as lack of training or skills, processes that are unable to meet customer needs, errors in operations, excessive inventory, or transportation and suppliers. This requires additional work such as additional inspections or scrapping of products (Costa, 2019).

- **Over Processing:** This process is symbolized by placing more value on the product than on the customer itself, e.g., eliminating areas that were not necessary, paying attention to tolerances that were not necessary, etc. In short, the goal is simply to do what the customer wants so that the service and product are useful. This is due to the lack of standardization of techniques and the lack of orders (Tools, 2015).
- **Wasted Potential of People:** This manifests itself in a lack of manpower and available business resources or intellectual capabilities. On the other hand, there may be other reasons, such as social barriers, discrimination, or personal circumstances (Portugal, 2022).

2.1.3 Benefits and Risks of Lean Manufacturing

Lean manufacturing is a management philosophy that is gaining more and more "fans" around the world, as it offers a number of benefits to the companies that apply it. Therefore, the implementation of the above principles can be defined as a series of actions and processes that start with planning a change and defining the success factors, i.e., the desired Key Performance Indicators, and end with the implementation and measurement of progress (Čiarnienė and Vienažindienė, 2012).

On the other hand, it is important to consider the balance between benefits and risks when implementing this philosophy, and this is a task for the company (Laaper and Kiefer, 2020). However, the benefits have a very positive weight for the organization.

Therefore, according to (Kaur, 2021) the main benefits are:

- **Higher Productivity:** Once the reduction of unnecessary movements occurs, the working methods will be more efficient and consequently produce more products at the same price, increasing the profit.
- **Better Quality:** With the reduction of waste, the processing time will be optimized, and there will be a significant improvement in the quality of the process and subsequently in the company.
- **Better Flexibility:** Since there is the optimization of resources and costs, workers can easily produce a wider range of different products with the same resources as before.
- **Better management:** The agreed-upon philosophy makes it possible to "do more with fewer people" because reducing waste means not needing as many workers and as much space to work. In this way, a better-organized system and a higher level of qualification are created, where workers will always try to improve their performance.
- **Less Cycle Time:** As waiting times are reduced, production times are consequently also reduced.

- **Lower lead time:** The same happens here, with the decrease of the cycle time, logically the lead time will be lower.

- **Fewer Defects:** Through this philosophy in the production processes, it is considered that any physical waste must be avoided, and considering all the other parameters that will be implemented, there will be fewer defects in the final product or service.

- **Skills of the workers:** By using the various lean tools, workers will have a much better understanding of the process and the concepts that should be implemented to strive for continuous improvement. In this way, workers will have more knowledge and more skills.

- **Waste reduction:** There are several types of waste. These wastes consume money and energy and have no value for the final customer. Thus, transportation, waiting time, space, unnecessary movements, etc. are reduced. This advantage is one of the main objectives of the implementation of lean manufacturing.

- **Financial Benefits:** With the implementation of this philosophy, by reducing waste and errors and improving quality, profits are greatly increased. Also, the reduction of inventories facilitates stock management, which has a positive effect on the balance sheet.

- **Improved customer service:** One of the main goals and principles of lean manufacturing is to delight and prioritize the customer with the final product. Through this improved service, customers get what they want, when they want it, and where they want it. This is fundamental to building good, long-term relationships between the company and its customers.

2.1.4 Lean Production Tools

Lean tools play a key role in the successful implementation of the concept because they provide methods and techniques that identify and eliminate waste, improving efficiency and quality in the areas of the respective organization. Thus, here it will be addressed some of the main tools, but there are several that exist, as shown in Figure 2.3.

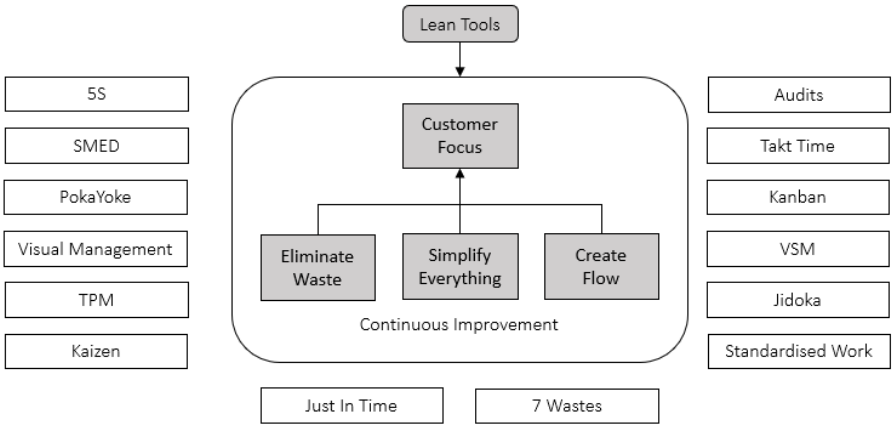


Figure 2.3: Lean Production Tools - Adapted From (Tools, 2015)

2.1.4.1 Kaizen

Kaizen is a Japanese term that originated after World War II as a way to combat inefficiency and productivity. It refers to the practice of continuous improvement regarding organizational or even personal developments. In this sense the concept means "change for the better," and it has become very popular, especially in manufacturing industries. Small, big changes, over time, will have a very positive impact on organizations, so the Kaizen concept emphasizes the importance of all employees being involved in the continuous improvement process, and many companies that have implemented Kaizen have seen great results and improvements in productivity, quality and customer satisfaction (Imai, 1970).

Therefore, it can be said that continuous improvement is necessary to sustain market competitiveness, however, its success depends on several factors, such as teamwork, leadership involvement, motivation, initiative, employee practice, etc (Balaji et al., 2014). It is important to mention that kaizen activities can and should stimulate workers to think positively, which is quite important because with the right mindset, they can contribute with ideas for improvements, i.e. a consensus and enthusiasm for change is created in people (Knechtges and Decker, 2014).

2.1.4.2 PDCA Cycle

The PDCA cycle is a cycle known as a continuous improvement model because it teaches organizations to plan an action, carry it out, and verify that it is consistent with the previously established plan. Previously, this cycle was known by two other names, namely: Stewhartt cycle and Deming cycle (N. Johnson, 2002). In this way, it can be said that it is a simple but quite powerful tool and that the customers' needs must constantly feed back into the supplier's standards (Costa, 2019).

In effect, this cycle consists of four steps: Plan, Do, Check, and Act (Costa, 2019) (Pereira, 2017):

- **Plan:** It consists of identifying and analyzing the cause of the problem in order to establish goals for the project in question and then developing proposals and establishing a plan for improvement.
- **Do:** In this step the previously defined action plan is put into practice, and it is important that everyone involved is aware of the activities to be carried out, as well as their roles. On the other hand, it is crucial to collect information, such as performance indicators, in order to carry out the next steps.
- **Check:** The previously removed performance indicators can be used to analyze the status of implementation, allowing comparison of the results with the goals previously set in the first phase.
- **Act:** It is used to ensure timely maintenance, standardizing the actions that have led to the achievement of the objectives. On the other hand, here also the cycle starts again in the planning phase if the actions have not brought the expected results. In other words, it is important to act and understand the lessons learned.

2.1.4.3 Kanban

The word "Kanban" in Japanese means "visual signal" or "card", which in itself is one of the main indicators that the process uses. The idea of this visual system allows people to visualize the work of items in real-time, to ensure that work is proceeding properly, and to ensure efficient communication with external and internal operations regarding production and delivery schedules (El Abbadi et al., 2018).

In other words, this tool plays a very important role in JIT production systems and also has the advantage that it can be applied to almost all movement activities, whether in industry or commerce (Panneerselvam, 2007).

On the other hand, for this method to work, it is important to follow rules, otherwise, it will be difficult to succeed. However, the rules may vary from strategy to strategy, but there is a logic that is usually followed (Ortiz, 2011):

- Identify all the materials that are meant to keep in stock;
- Separate them by category;
- Identify how much of each material should be kept;

- Identify when to reorder;
- Decide where the supplies will be located in the room;
- Implement 5S, to have a viable organization;
- Label each item;
- Print kanban cards and place 1 card per bin near the item.

It is important to mention that the Kanban card must have the possibility to note the description of the item, as well as its reference code and the minimum and maximum quantity that must be present since it is the card that provides the entry of the shortage.

In short, this tool can bring benefits to the process category, the people, and the organization. With regard to the former, the visibility and transparency of the team can be improved, as well as better control of activities and facilitation in identifying obstacles in the process. Usually, the workflow also improves significantly and products are brought to market faster, as priorities are better defined. In this way, errors decrease, and quality increases. In the "people" category, it is noted that communication, team motivation, and customer satisfaction improve as the organization implements a continuous improvement system (Ahmad et al., 2018). In short, Kanban is a visual tool whose main goal is to make processes and routines more productive and efficient.

2.1.4.4 Value Stream Mapping

The value stream map is a flowchart that allows visualizing each phase of a product or service and identifying their relationships. It can be defined as a standardized method for mapping processes and information about their current state. In this way, the waste that occurs can be identified (Sriputtha and Satuprapakarn, 2021). Due to the fact that the information can be analyzed in a short time and in any type of company, this method has gained great popularity in the field of continuous improvement, as it helps to identify problems in order to optimize them (Cerón et al., 2022). It can be said that it is more than just a tool and is considered by many as a successful technique for strategic management.

In effect, the first step to put into practice is to create a current state map, which involves creating the process of the moment allowing for the identification of actions that add value and actions that do not add value. Afterward, the next stage is to create a map of the future state (to be processed), that is, to examine the present state in order to identify flaws and opportunities for improvement, such as long inventories or cycles and lead times that are too long. Finally, after suggesting and implementing the necessary changes, it is necessary to measure the results to understand if there were effective improvements and progress (Sriputtha and Satuprapakarn, 2021).

In short, Value Stream Mapping is a tool to identify improvements in a process. It enables the identification of bottlenecks, losses, and delays, making companies more efficient and delivering better services.

2.1.4.5 Visual Management

Visual management means visualizing a lot of information and processes in order to improve different aspects, such as communication, understanding, and decision-making in the team. In this way, anyone who does not know what actions to take can easily understand what needs to be done and the pattern in which it should be done. It can be said that Visual Management is a support for other practices such as Kanban, 5S, space organization, etc (Algan Tezel, 2009).

In this sense, visual controls are very powerful in their contribution to lean management, because they connect people to their roles. Thus, the discipline of the team will evolve, because of the easy reading comprehension. On the other hand, it brings other advantages, such as accessibility, and flexibility, and it is not something that is expensive (Mann, 2005).

In terms of 5S, the main goal is to ensure that each object stays in the programmed place, and with the visual tool, this function is facilitated. However, for such a successful implementation, it is necessary to determine the location of each tool/object beforehand, to visually represent its state and standard procedures, as well as the intended performance indicators (Ortiz, 2011).

2.1.4.6 Spaghetti Diagram

The spaghetti diagram is a very powerful visual tool used in optimizing movements and transporters to create more effective and efficient layouts (Guzel and Shahbazpour Asiabi, 2022). It consists of a graphical representation that often makes it possible to identify the bottlenecks in the processes and determine in which process steps there are inefficiencies in the flow of production or information (Wilson, 2010).

In this way, this type of tool allows the user to visualize how all the elements of the process relate to each other, which in a way help to avoid unnecessary repetitions, excessive procedures, as well as steps that do not add value to the process itself. In other words, its use is fundamental for identifying problem areas that may be improved (Venkat Jayanth et al., 2020).

One of the main advantages of the spaghetti diagram is the fact that it is easy to interpret and can be used by any person, even without technical knowledge, and it can even be created manually, although there is a possibility that it can be created with special software.

2.1.4.7 Audits

Audits can be conducted at various levels of the organization in question, from individual processes to entire departments. Their purpose is to make sure that everything is being done according to what was previously planned so that if something is not so good, there is an opportunity for improvement.

Since the main goal is to improve the efficiency, quality of products and services, it is important that audits are performed at regular intervals. There are several types of audits, but the most common are the 5S audits, which measure the current standards and serve as feedback for the evaluation of the plan (Paterson, 2015).

2.1.4.8 5S

According to (Scotchmer, 2008), 5S is a quality management program developed in Japan that offers the possibility of changing the way people view their work. In other words, this method enables a change in the way people work and develops a culture focused on continuous improvement that promotes quality, productivity, safety, morale, corporate image, etc. In short, it helps build a strong team with the ability to solve problems and promote a good environment.

- **1st S - Sort (Seiri):** The first step is to sort the material, separating what is needed from what is not. Although this seems like a simple step, people are often unsure of what can and cannot be considered waste, which can make this step difficult. To avoid this, it is important to know what types of waste there are, because it is important to clean up the excessive inventory. For this sorting, it is advisable to use Red Tags, as they allow to easily identify the materials that should no longer be used and even indicate the reason why the material was considered waste.
- **2nd S - Set in Order (Seiton):** The second step consists in orienting and organizing the work environment, determining the place for each material to ensure that everyone knows where to find it and where to put it after use, thus improving the workflow as the arrangement is optimized. In other words, this step aims to reduce and eliminate unnecessary movements during workers' activities. One of the ways to achieve this goal is the use of visual management because in this way productivity is increased and the detection of possible errors is facilitated. In this sense, there are several visual management techniques that can be used, and the appropriate solution depends on the type of problem that the workplace is facing.
- **3rd S - Shine (Seisou):** This third step is mainly aimed at keeping everything clean, even the places you "can not see". It is important to emphasize that everyone is responsible for this step, because only with everyone's help and effort is it possible to keep the place neat and clean. This step also includes the responsibility to keep all the equipment and machinery in good condition, because it is important that they are well maintained.

- **4th S - Standardise (Seiketsu):** This pillar is to maintain the pillars mentioned before because when workplaces are sorted, ordered, and cleaned, it is important to take photos so that people remember what the place should look like, and that then becomes a standard that must be followed. So the standard is a specification that contains information that must be followed strictly as if it were a rule. In other words, this step is a cultural step that promotes the management of the 5S application and helps consolidate the activities of the previous steps. Indeed, to meet the standards established, it is important to perform audits, for example, to understand the general evolution of the workplace.
- **5th S - Sustain (Shitkuse):** The last pillar is the most difficult phase to implement because it is difficult to motivate the people involved in such a way that the previous processes remain as good or better. Therefore, communication plays a very important role in this phase, and it is advisable to hold a meeting in the morning before starting work.

2.1.4.9 SMED

SMED stands for Single-Minute Exchange of Die and is a process improvement method whose main goal is to reduce the setup time or tool change of a machine or system. The goal of this lean tool is therefore to reduce time to the minimum possible, which is very important for production and maintenance processes, as it allows companies to produce in smaller batches, have lower inventories, and therefore be more flexible and responsive (Shingo, 1983).

This methodology can be divided into 4 phases:

- **Initial phase:** Where internal and external activities have not been distinguished;
- **Phase 1:** Separation of internal and external phases;
- **Phase 2:** Conversion of internal tasks into external ones;
- **Phase 3:** Reducing the number of tasks.

2.1.5 Examples of Case Studies

Following are some examples of case studies that show the benefit of implementing lean tools:

- **Case Study 1 (Rosa et al., 2017b):** The main objective of this study was to reduce set-up times by using various lean tools such as 5S, visual management, etc., in order to increase the flexibility and productivity of an assembly line for seat cords. Improvement actions such as the organization of tools and their respective labeling, including the reorganization of external and internal tasks, as well as visual aids and training for operators were implemented. In this way, 58.3% of downtime, or 210 minutes, was reduced.
- **Case Study 2 (Ribeiro et al., 2019):** This work was carried out in a plastics company with the main objective of shortening lead times and reducing complaints for the products in

question. The tools used were 5S, visual management, SMED, standard work, and OEE. Through the analysis of the problems, proposals were implemented and the results were remarkable, as 70% of the transportation time was reduced in the coating production line and the OEE increased by 18% in the injection molding process, 16% in the wheel covers painting production line and 17% in the Front Bumpers painting production line.

- **Case Study 3 (Costa et al., 2018):** The project was carried out in a company that works with metal and the main tool to be used was the 5S, although it was necessary to use others directly or indirectly. With the execution of this work, it was possible to obtain improvements in the field of safety in the workplace, as well as to increase productivity and drastically reduce the waste generated.
- **Case Study 4 (Rosa et al., 2017a):** This continuous improvement work was done in an automotive company that needed to significantly increase productivity, reduce costs, and increase competitiveness, but could not find the financial resources to do so. The only solution they found was to improve assembly lines using one of the lean tools known as PDCA. In this way, they developed solutions to improve the process. In the end, the productivity of the production line was increased by 41%, and despite the investments, the company expects payback in 4 months. Consequently, losses were saved.

2.2 Maintenance

This Section will cover the topic of Maintenance.

2.2.1 Introduction to Maintenance

In today's industry, maintenance is recognized as one of the most important areas with the greatest impact on production performance, safety, product quality, interpersonal relationships, company profitability, etc. The key to good maintenance is to find the balance between company benefits and costs (Cabral, 2006).

Maintenance management is primarily aimed at ensuring the performance and safety of machinery and equipment and avoiding breakdowns and repairs. However, in addition to the technical side, it also includes a range of activities aimed at meeting regulatory requirements, certifications, social sustainability, safety, etc (Cabral, 2009).

In short, maintenance management is a key area for the proper functioning of equipment and facilities, regardless of the industry. According to NP EN 13306, this requires planning, coordinating, and ultimately controlling activities, maximizing operational efficiency, and reducing costs, as the proper application will extend the life of the equipment. All management activities must define the objectives, strategy, and consequently, the responsibilities related to maintenance. This can be done in various ways, such as planning, control, monitoring, and improvement of organizational

methods, and possibly taking into account economic aspects.

2.2.2 Types of Maintenance

Regarding the types of maintenance, there are two types, namely: preventive and corrective.

As for corrective maintenance, it can be said that it is the action carried out after the fault has been detected and aims to restore the normal state. This type can be considered maintenance that is not part of the plans and that requires urgent attention, as it is a key element for the maintenance activity (Dhillon, 2006).

Indeed, the failure that causes this maintenance may have occurred as a result of:

- **Intrinsic failure:** is justified by the loss of function due to an internal cause of the equipment itself, e.g. a broken or worn element (Cabral, 2009).
- **Extrinsic failure:** is justified by the exterior of the equipment, e.g., an accident or collision (Cabral, 2009).

On the other hand, preventive maintenance is performed at predetermined intervals to reduce the likelihood of a malfunction at a facility. It is an important element of maintenance and one of its main objectives is to improve the production cycle of the plant, as well as to reduce production downtime and improve the health and safety of maintenance personnel. Within preventive maintenance there are different types, namely:

- **Systematic:** This is based on a set interval for performing certain maintenance tasks that are carried out regularly and periodically, regardless of the condition of the machine. As a rule, this is applied to equipment that has a significantly high failure rate (Cabral, 2009).
- **Conditioned:** Conditional preventive maintenance is based on the current condition of the equipment/machine, i.e., maintenance is performed only when the equipment actually shows signs of wear, and unlike the systematic approach, this approach is applied to machines that have a low failure rate. This allows costs to be reduced as the number of interventions is lower (Cabral, 2009).

2.2.3 Maintenance objectives and advantages

According to (Cabral, 2009), it is important to have a set of parameters that are necessary for the objectives to be achieved, namely:

- **Leadership:** It is important to have a leader with ambition, but also with personal humility and professional will, and preferably one who comes from within the company.

- **Team:** First of all, it is important to choose the right people to work with, and only then should you decide and set the direction of the project. People are not the most important asset of a company, but the right people are.
- **Facts:** It is essential to have a discipline that allows one to face the facts, no matter how hard they may be.
- **Disciplined culture:** If everyone is disciplined, there is no need for hierarchy, because then there is no need for excessive control.
- **Technology accelerators:** Technology alone is not the main cause of decline or rise, it is necessary to pay attention to the other parameters.

Thus, the main objectives of maintenance management in a plant are: ensuring efficient operation of machinery, achieving yields close to nominal values, minimizing the number of defective products to avoid failures, minimizing energy consumption, reducing costs, and increasing safety.

In analytical terms, it is assumed that good maintenance management results in no more than one breakdown per month, average repair time of no more than 2 hours and breakdown response in less than 15 minutes, availability of no less than 95%, and maintenance costs of less than 4% of billing.

In short, maintenance management must create technical resources that enable people to effectively pursue their goals using performance and outcome measures (Gross, 2002).

2.2.4 Maintenance Management Indicators - KPI

To ensure optimal maintenance, it is critical to begin by calculating performance indicators, as they play a crucial role in achieving desired goals. KPIs serve as benchmarks to measure whether a company is operating within acceptable parameters and remaining competitive in its industry. A key aspect of effective maintenance is having qualified technicians who perform regular inspections. The primary purpose of these inspections is to identify failures and take preventative measures to avoid recurrence. By emphasizing the importance of KPIs and thorough inspections, organizations can strive for excellence in maintenance practices. (Berger, 2014).

In this sense, each plant will have its own KPIs that will determine its safety, productivity, and efficiency. Maintenance performance depends on many factors, for example, internal or external factors such as location, culture, services, age, procedures, etc. In short, maintenance performance is the result of complex activities. According to NP EN 15341, maintenance indicators allow the comparison of performance, the identification of strengths and weaknesses, and the control of the process over time. On the other hand, the indicators used can be periodic or punctual, when they are used in the monitoring of a budget and evaluation or in audits or studies.

It is also important to reiterate that it is recommended that organizations spend 85% of their time on planned maintenance and less than 15% on unplanned activities. In fact, according to (Berger, 2014) the 4 main KPIs are MTTR, MTBF, MWT, and OEE.

2.2.4.1 MTTR

Mean Time to Repair is a metric used to measure the average time required to repair a failure or disruption of a system, process, or equipment, and is calculated from the time the failure is detected until restoration occurs and normal operations take place. A very long MTTR can have a dramatic effect on organizations, as it can cause the creation of defective products, lost orders, etc. and to mitigate this it is necessary to invest in maintenance teams.

This tool provides a wealth of information that can assist workers in making decisions, such as determining whether it is more cost-effective to replace or repair a part. It can also predict the life-cycle cost of new systems. Typically, MTTR is measured in hours and is used to identify areas that require improvement with the ultimate goal of increasing efficiency and minimizing downtime, as shown in the Equation. 2.1.

$$\text{MTTR} = \frac{\text{Total Service Time}}{\text{Number of Repairs}} \tag{2.1}$$

2.2.4.2 MTBF

The Mean Time Between Failures is a metric, usually expressed in hours, used to estimate the reliability of a system, equipment, or product, and is defined as the average time that the system in question can operate without failure.

"Mean Time Between Fail is a great way to quantify the reliability of a system or component."

Jeff O´Brien, Customer Sucess

This tool can be very important for companies, because it allows them to evaluate the quality and reliability of the product or system, i.e. a high MTBF value is positive, because it means that the chance of failure is reduced and reliability is high, which leads to lower maintenance costs and consequently to higher customer satisfaction, as it can be seen in Equation 2.2.

$$\text{MTBF} = \frac{\text{Total Working Time - Total Breakdown Time}}{\text{Number of Failures}} \tag{2.2}$$

2.2.4.3 MWT

This refers to waiting times regarding for example travel or administrative times.

2.2.4.4 OEE

In Equation 2.3 it can be seen that Overall Equipment Effectiveness is calculated with 3 components, namely: how well the equipment is available, how well it is performing according to specifications, and how good the quality is.

$$OEE = \text{Availability} \times \text{Performance} \times \text{Quality} \tag{2.3}$$

- **Availability:** According to EN 13306 2007 it is the ability of an asset to perform a given function under given conditions at a given instant and time interval, taking into account that it is necessary to ensure the supply of external resources. This concept depends on the reliability of maintenance. Ideally, availability should be 90%, however, the average is around 79%.

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR} + \text{MWT}} \times 100\% \tag{2.4}$$

- **Performance:** Performance, or efficiency, is the measure of how well a piece of equipment is performing at its maximum capacity. The ideal value is 95%, however, the average is around 80%.

$$\text{Performance} = \frac{\text{Work Done}}{\text{Planned Work}} \times 100\% \tag{2.5}$$

- **Quality:** This refers to the percentage of well-produced products in relation to the total that is manufactured. It should be around 99%, however, the average is around 95%.

$$\text{Quality} = \frac{\text{Time of Work Done}}{\text{Time of Planned Work}} \times 100\% \tag{2.6}$$

In this sense, the OEE metric is used to evaluate the efficiency and productivity of machines or equipment. It is important to reiterate that it is crucial to calculate the 3 different elements, in order to make it easier to identify where improvements might be possible and consequently put the focus there. In practice, OEE measures the losses that can affect equipment, of which there are 6 major losses:

- Equipment failures;
- Lost time due to changes;
- Downtime due to errors;

- Reduced speed due to wear or malfunction of equipment;
- Defects in an operation or process;
- Reduced yield.

2.2.5 Warehouse and materials management

The objective of warehouse management is to provide maintenance, in case of need, the immediate logistics of the necessary items for its performance, contributing to better economical and technical conditions for the organization (Cabral, 2006). In this sense, warehousing can be defined as the logistics function of a company that is responsible for managing inventories, starting with the receipt from the supplier and ending with their consumption, and it is important to take into account the inventory status, location and other timely characteristics (Ross, 2015).

The warehouse must be managed according to a rule called "perpetual inventory", which has the philosophy of knowing what is there in real time, from the quantities, their value, etc., and it is legally required to take an inventory count of all items annually.

2.2.5.1 Stock management methods

Stock can be considered the existence of any item or resource used in an organization, and can be classified as raw materials, finished goods, components, supplies, or work in progress. In fact, they retain the advantages of independence of operations in order to provide flexibility. On the other hand, stocks have some drawbacks, such as taking up a lot of space and tying up financial resources.

In short, stocks must be well managed in order to find a balance between minimum cost and positive performance. In this sense, there are several methods that can be used for stock management, such as:

- **Variable frequency and fixed quantity ordering system (continuous review):** The variable frequency and fixed quantity ordering system is an approach to stock management that aims to define a fixed quantity of products to be ordered, taking into account the minimization of excess stock, thus reducing costs associated with ordering and storage activities. That is, in this system the same quantity is ordered whenever the stock level reaches the order point (Bozarth and Handfield, 2006). The formula of order point can be seen in equation 2.7.

$$\text{Ordering point} = \text{Average consumption} \times \text{Average lead time} + \text{Safety stock} \tag{2.7}$$

- **Fixed periodicity and variable quantity system (periodic review):** In the periodic revision system, a variable quantity is ordered with a fixed periodicity, with the objective of

restoring the stock to the maximum level. In this sense, it is ordered periodically what is consumed in the previous period. It can be said that this system is appropriate for places where the articles have, for example, a small variation of consumption, low cost, same supplier, etc (Cabral, 2006). An example of an application of this system is, for example, a grocery store, where eventually there are low-cost items that are regularly replenished, and there is a larger supply than the demand of that moment (Bozarth and Handfield, 2006). The formula of the maximum stock can be seen in equation 2.8.

$$\text{Maximum stock} = \text{Average consumption} \times (\text{Revision period} + \text{Average lead time}) + \text{Safety stock} \tag{2.8}$$

- **Maximum and minimum system:** This approach is used to mainly ensure that there is a sufficient quantity of products available for the desired demand so that overstock does not exist unnecessarily. Therefore, maximum stock and minimum stock are established and whenever minimum stock is reached an order is placed equal to the quantity needed to reestablish the maximum level (Fadah et al., 2020).
- **ABC:** This system allows the classification of stock items based on their importance or value to the company, which contributes to more efficient management. In this way, this type of management is based on the principle that materials or parts of a given inventory do not have the same importance, and that such importance can be divided into 3 classes (Chapman et al., 2008):
  - **Class A**: These are the most important items, which usually represent a small number of the total inventory, but which have a great value to the company, and can be considered critical and of special attention needed.
  - **Class B:** They are of intermediate importance and represent a moderate number in the total stock, and there must be a balance between the cost of stock and its availability to the demand.
  - **Class C:** They have the least importance and can usually exist in large quantities, but represent a lower value, and for the company, their management is neither a priority nor as important.

In this sense, the ABC system increases work performance and optimize financial and operational resources, improves the control of items from major to minor importance, and eventually removes some existing bottleneck because it eliminates the concern with things without value (Mahal and Hossain, 2015).

Chapter 3

Problem Identification and Analysis

In this chapter, the initial situation of the Mechanical Maintenance Department is studied and analyzed in order to define the main points to be improved and optimized. Originally, before the start of the project, the proposed improvement idea was the 5S implementation in the workshop, but its course underwent slight changes because it was necessary to adapt the original solution to the needs of the company.

In this way, it can be considered that the Mechanical Maintenance Department can be physically formed by the workshop and the warehouse. In this sense, there are different problems that depend on the different physical locations of the workplace.

3.1 Mechanical Maintenance Department

BA Glass factory in Avintes represents the largest source of revenue in the BA Group.

Therefore, it is important to reiterate that organized maintenance is essential, if not mandatory, to help solve existing problems. The presence of rigor is key to the success of any company that aims and tries to create a set of conditions that allow it to do what is necessary, with the aim of minimizing costs.

In this sense, the place where the project was carried out was the Mechanical Maintenance Department, a department that works with practically all areas of the plant and therefore has many tasks.

Specifically, the duties of this department include:

- Performing preventive maintenance on machinery and equipment to ensure that there is safe and efficient operation;

- Collaborate with other departments to ensure established goals and objectives are met;
- Implement equipment improvements to reduce operating costs;
- Coordinate mechanical maintenance activities to minimize equipment downtime;
- Managing spare parts inventories to ensure they are always available when needed.

It is important to mention that the department's team consists of several professionals, including mechanics, operators, maintenance technicians, and engineers, who always collaborate with other departments to achieve the desired quality and efficiency goals.

In this sense, maintenance plays a crucial role in the glass industry, as it ensures that the production of machinery and equipment can be operated at a good level. The main task of the maintenance department is to prevent equipment failures and reduce the time for unplanned maintenance work.

Therefore, one of the main tasks is to develop and implement a good maintenance program that specifies preventive measures for each machine and equipment. These measures usually include cleaning, lubrication, inspection, and calibration of the equipment to ensure its efficiency.

On the other hand, one of the most critical aspects of the department is corrective maintenance, because it involves repairs that are not scheduled when the equipment stops working. These can involve different types of problems, and several tests must be performed to determine the cause of the problem. Therefore, the department is also responsible for making upgrades and changes to equipment and machines to improve their performance.

In summary, the role of the Mechanical Maintenance Department in the glass industry is to ensure that equipment is operating as efficiently as possible and to reduce the risk of failure. The initial layout of the workshop and warehouse of the department in question can be seen in Figure 3.1 and has a direct and indirect impact on several problems faced by the team.

Figure 3.1: Initial Workshop and Warehouse Layout

3.1.1 Audit

The first two weeks were essential for the integration into the department team. The main purpose was to get to know the team members, as well as their routines and work dynamics. Initially, some problems were detected, which will be addressed later, but it was decided to perform an audit.

5S audits are a very important tool in the implementation and maintenance of the 5S system in an organization, as they allow the evaluation and identification of improvement opportunities. In fact, they serve as a way to monitor the progress of this implementation, helping to ensure that the previously established goals and objectives are achieved, as well as standardizing actions and confirming that employees have the best dynamics and routines, improving efficiency and reducing any type of waste.

In this sense, a questionnaire was created for conducting the audit. The questionnaire, as shown in Annexe A, consists of 25 questions, 5 questions about each S and each answer to the question could have a scale of 1-5. This method was used because it is practical and easy for the workers to answer and to allow the main problems of each principle to be evaluated separately, and with the answers collected it is possible to identify the problems existing in the department. That is, an answer with a high value indicates that the team is following the principle well, while an answer with a low value indicates the opposite.

Thus, a day was chosen to conduct the audit in questionnaire format. So, in the first meeting in the morning, the workers were told what was going to happen, and later they were given the

questionnaire. Regarding the questionnaire, it is important to say that it was given to the 6 workers of the team, as well as to the engineer in charge of the department, collecting in total 7 answers. In this sense, the submission of the answers was anonymous, so as not to interfere with each person's opinion.

As can be seen in Table 3.2, the average result of the answers for the different types of questions was classified as "Poor" according to the defined classification, as shown in Table 3.1.

Table 3.1: Audit Scale

Color	Meaning	Score	Total Score
	Very Poor	5	25
	Poor	6-10	26-50
	Medium	11-15	51-75
	Good	16-20	76-100
	Excellent	21-25	101-125

Table 3.2: First Audit Results

Type of S	Mean Score	Total Score
1st	6.71	35.29
2nd	5.86	
3rd	7.86	
4th	7.29	
5th	7.57	

In fact, these results can be considered poor and may be due to several factors, namely due to:

- **Lack of knowledge about the 5S tool:** Workers may not be very familiar with this methodology and may not have understood the audit questions;
- **Lack of knowledge and awareness:** Many workers are not aware of the importance of 5S, which results in them not being motivated to participate in audits;
- **Resistance to change:** Many of the employees disagree with the way they work and have no interest in implementing the 5S philosophy, which may have been the cause of the low responses in the audit.

On the other hand, it is important to investigate and understand what are the causes behind the bad audit responses, in order to be able to address these problems. In this sense, analyzing these results and analyzing the work locations, several problems were identified, as can be seen in the following subsection.

3.1.2 Analysis of results and detected problems

The radar chart analysis of the average audit responses, shown in Figure 3.2, allows to visualize the differences and similarities between the different S's. Since all scores are low, this indicates that performance is well below desired levels and there are opportunities for improvement.

As shown in Table 3.2 the values are lowest in the specific case of Seiton and Seiri, indicating that there are problems with the organization and cleanliness of the equipment and machines. On the other hand, these values may indicate that the work environment is not kept in order.

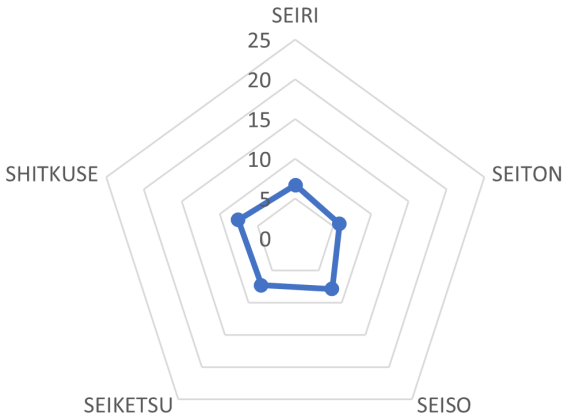


Figure 3.2: Radar Chart before Implementation of 5S

Therefore, with the interpretation of the audit results and the personal analysis of the space and staff, the following problems were found:

- **Lack of digitalization:** The absence of a digital system to manage information, KPI, and processes for the department makes it difficult to access important information quickly, which causes inefficiencies that could be solved by investing in digitalization;
- **Lack of training:** The implementation of the 5S methodology and stock management requires a cultural change in the company, which is difficult because the workers have not had any kind of adequate training, causing some lack of adherence to the new tool;
- **Lack of communication between workers:** The lack of communication between workers was detected early on, and it indirectly affects the team's performance during work.
- **Lack of working standards:** The lack of working standards results in inconsistencies in maintenance activities and consequently in results;
- **Bad time management:** In several activities the expected time to accomplish a certain task was not met, which led to delays in maintenance activities;
- **Lack of KPI monitoring:** The lack of KPI monitoring makes it difficult to know what improvements should be implemented;

- **Lack of preventive maintenance plans:** It was detected that there was neither the use nor the implementation of preventive maintenance plans, which was the reason for many of the problems faced by the equipment being used. The company was in the process of digitizing maintenance plans for SAP software which was difficult to implement;

- **Lack of organization in Workshop:** As can be seen in Figure 3.3 the workshop is disorganized, which creates difficulties for 5S implementation. This lack of organization leads to other problems, such as problems with stock. The workers don't know where they have things, and different types of equipment are mixed up and scattered all over the place. It can also be added that some of the material that was stored was either waste or else of no value, as it had not been used for a relatively long time;

Figure 3.3: Initial State of Workshop

- **Lack of organization in Warehouse:** Regarding the warehouse, as can be seen in Figure 3.4, its initial state was quite disorganized and with a lot of obsolete material, which caused great difficulty in locating spare equipment;

Figure 3.4: Initial State of Warehouse

- **Lack of stock control:** The department has no stock control, which causes problems with equipment and machine management. This can eventually cause a lack of spare parts needed for maintenance, negatively affecting factory productivity.

  It is also important to emphasize that in the audit the answer to question 5 "Is there control over the materials that are in the warehouse?" was answered by all participants equally, and they answered with the minimum quotation, thus evidencing the serious problem that exists regarding the organization and location of existing spare parts.

  In this sense, this can be confirmed by Figure 3.5, which shows the initial state of the spare parts, scattered around the factory in different places and without identification and of the disorganization of the warehouse.

  This demonstrates the difficulty that workers have in locating some equipment that is needed to perform any maintenance activity, and even, in the initial state, many times it was impossible for them to find out if they had a certain kind of equipment.

Figure 3.5: Initial State of Spare Parts

3.1.3 Definition of the main problems

In this sense, the main problems are identified in the cause-and-effect diagram, as shown in Figure 3.6.

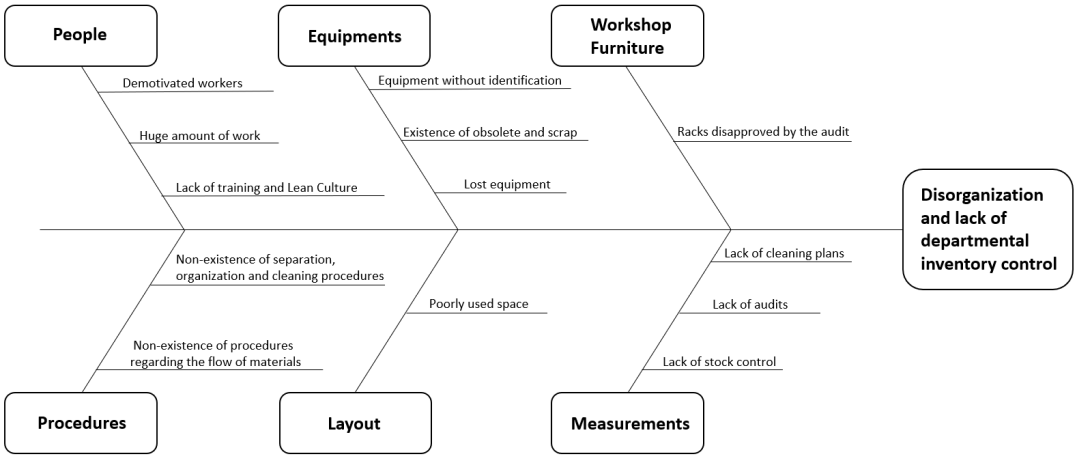


Figure 3.6: Cause-and-effect diagram

Therefore, the Matrix of Priorities (GUT) was elaborated as it can be seen in Table 3.4, where the causes mentioned earlier in the Cause-Effect Diagram can be assigned a scale between 1-5 as it can be seen in Table 3.3, evaluating three parameters: gravity, urgency, and tendency.

Table 3.3: Scale of GUT Matrix

Color	Meaning	Scale
	Not serious	1
	Less serious	2
	Serious	3
	Very serious	4
	Extremly serious	5

Table 3.4: GUT Matrix

GUT Matrix				
Cause	**Gravity**	**Urgency**	**Tendency**	**Score**
Demotivated employees	4	4	5	80
Huge amount of work	4	4	5	80
Lack of training and lean culture	3	4	5	60
Lack of separation, organization and cleaning procedures	4	4	5	80
Lack of procedures for material flow	4	4	5	80
Equipment without labeling	4	4	5	80
Presence of obsolete material and scrap	5	5	5	**125**
Lost equipment	5	5	5	**125**
Poorly used space	3	4	4	48
Shelves rejected during inspection	3	4	3	36
Lack of cleaning schedules	3	3	3	27
Absence of audits	4	4	4	64
Absence of stock control	5	5	5	**125**

In this sense, through the Pareto Principle, 20% of the causes with the highest scores were selected, being them:

- Existence of obsolete and scrap
- Lost equipment
- Lack of stock control

In this way, it was possible to find out what the priority to be solved was, and find solutions for it, as will be seen in Chapter 4.

3.1.4 Practical example of an occurred problem

Following the context of the problems mentioned above, this sub-section depicts an actual practical example that happened in the factory concerning the lack of a stock system control and communication between workers, and the event is depicted in the following quote.

> *"A lock for an annealing cabinet broke and the respective reserve was not found, so it was necessary to urgently ask the supplier, who only had it in stock in a warehouse in Spain."*
>
> Mechanical Maintenance Supervisor at BA Glass

In Figure 3.7 regarding situation 1, it can be seen the worker´s route through the different areas of the department looking for the required part. Therefore, in Table 3.5 we can see the replacement time, material search time, and delivery time for the 3 different situations.

In this sense, regarding situation 1 it is important to mention that the spare padlock was in the factory, but due to the huge disorganization and lack of a stock control system, it was impossible to locate it at the moment of pressure, which caused directly (by buying a new padlock) and indirectly (stopping the line) a huge cost to the company. Situation 2 refers to a change in a fan turbine, and the production line had to be stopped. Situation 3, it is associated with the corrective maintenance of a water pump motor.

Therefore, it should be reiterated the importance of having some tool that allows the stock control of spare parts, in order to avoid these events and ensure that the necessary materials are in stock with the minimum quantity and that it is possible to obtain its location, reducing the MTTR.

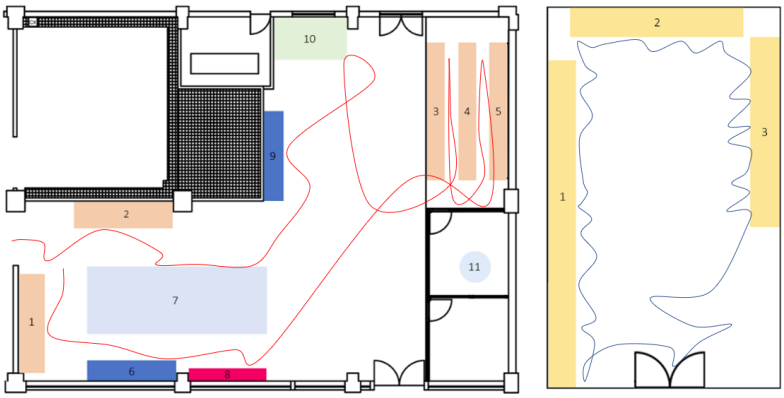


Figure 3.7: Spaghetti Diagram of the search for the lock

Table 3.5: MTTR Simulation Before 5S Implementation

Situation	Material Search Time (h)	Material Delivery Time (h)	Replacement Time (h)
1	2	5	0.5
2	1	0	2
3	1.5	0	2

According to the Equation 3.1 the MTTR of the mentioned situation can be calculated, as it can be bellow:

$$\text{MTTR} = \frac{2+5+0.5+1+2+1.5+2}{3} = \frac{14}{3} = 4.66 \tag{3.1}$$

Chapter 4

Methodology and Results

This chapter deals with the solutions found to overcome the above problems. In this way, it covers the different strategies applied.

In this sense, not only the implementation processes of the solutions are described, but also the challenges faced in their implementation, as well as the results achieved and the corresponding performance metrics, comparative analysis, and feedback.

4.1 PDCA Project Cycle

In order to have a better organization and execution of the project it was essential to implement the PDCA cycle, which consists of the phases: Plan, Do, Check, and Act. In this sense, the flowchart in Annex B represents the thinking method, and Table 4.1 demonstrates the meaning of each color used.

Table 4.1: Color of each phase of the PDCA cycle

Color	Phase
	Plan
	Do
	Check
	Act

On the other hand, taking into account the actions required to fulfill the action plan, a schedule has also been established to facilitate the follow-up of each activity carried out, as shown in Annex C.

4.2 5S Implementation in the Warehouse

As mentioned in Chapter 3, by using the GUT Matrix (Table 3.4) it was possible to determine that the main problems were related to the lack of a warehouse for spare parts, including the lack of a stock control system.

Thus, it was decided to keep the focus on spare parts, and then implement 5S in the Warehouse, since the main scope of work of this Department is to do corrective maintenance of equipment, and a spare part may be needed at any time. This decision was based on the following facts:

- **Productivity improvement:** With better-organized parts, the time spent searching for them decreases and efficiency increases;
- **Security improvement:** By cleaning and organizing the stock the risk of accidents is reduced, because the storage areas are unobstructed;
- **Increased worker satisfaction:** A clean and organized work environment makes for a much more pleasant work environment, which increases motivation;
- **Quality Improvement:** It can be guaranteed that a certain spare part will or will not be available at a certain time.

4.2.1 Sort

The first S had as its main objective to analyze the work area, that is, in this case, the warehouse, in order to understand what spare parts and equipment were present, as well as their usefulness and condition. In addition, in this step, it was also necessary to find the spare parts in the whole plant and define criteria to organize them.

This step is critical to building a solid foundation for 5S adoption.

4.2.1.1 Finding spare parts and relocation

First, it was necessary to make a thorough survey of all existing spare parts, which were lost around the factory, which was something worrying since it would be impossible to predict what actually existed or not. The involvement of the employees was fundamental in this phase, as they had practical knowledge of where the equipment was located.

Through Figure 3.5 it can be seen the state of the spare parts, as well as their lack of identification, location, and organization. On the other hand, Figure 4.1 shows the transportation of the spare parts next to the warehouse.

This step had to be done first, in order to allow further steps to be carried out, namely the sorting of spare parts and their proper classification, as will be seen next.

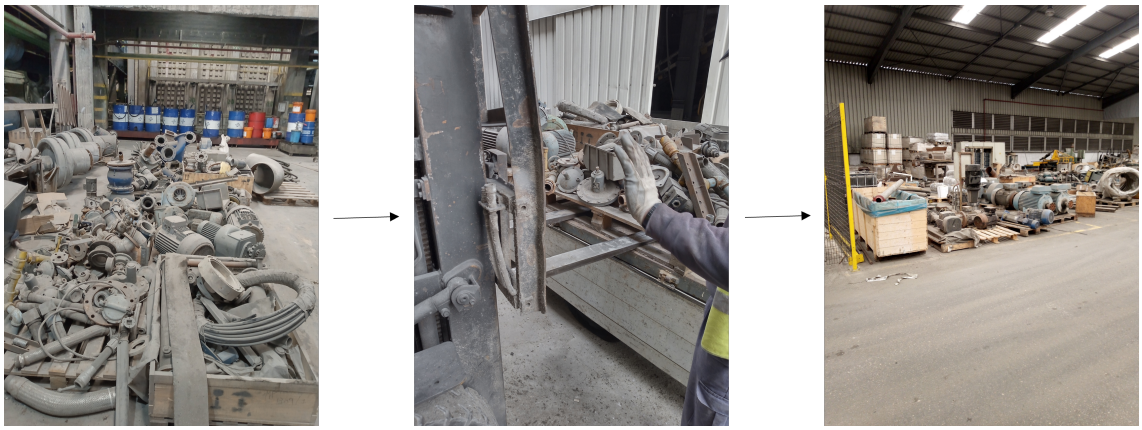


Figure 4.1: Transport of Spare Parts

4.2.1.2 Red Tags & Red Zone & Lista Red Tag

Before the sorting of spare parts could begin, it was necessary to use Red Tags, which are attached to equipment that is classified as unnecessary or obsolete. Usually, the tags contain information such as the marking date, a description of the material, and the reason why it should be discarded.

In Figure 4.2 can be seen the example of a Red Tag and the example of its application in an equipment.

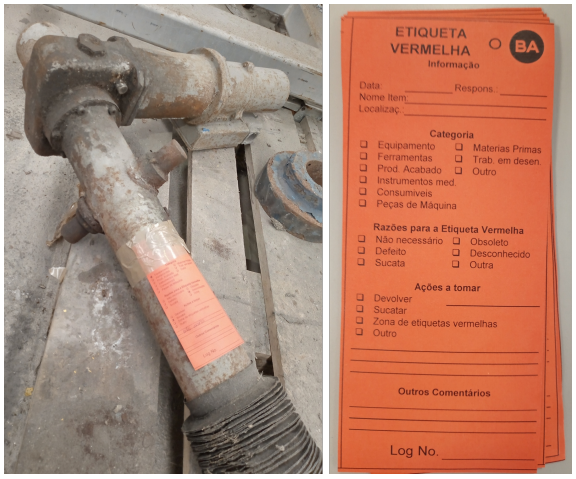


Figure 4.2: Example of a Red Tag and its application in equipment

That said, the next step to be implemented is the creation of the Red Zone, which is the appropriate destination for this type of equipment. After gathering all the spare parts in that zone there are usually several options, and in this case, the most viable option was to sell the material to an external company, as it can be seen in Figure 4.3.

Indeed, through this it was possible to achieve several benefits, namely:

- **Freeing up space:** Since more than 8 tons of scrap metal was sold, more space has become available;
- **Cost reduction:** Eliminating unneeded material avoided wasting resources;
- **Increased productivity:** As the work environment became more organized, the time to find spare parts was reduced;
- **Increased safety:** The space was much more organized, with no unneeded materials, which contributed to the next step of sorting the spare parts.

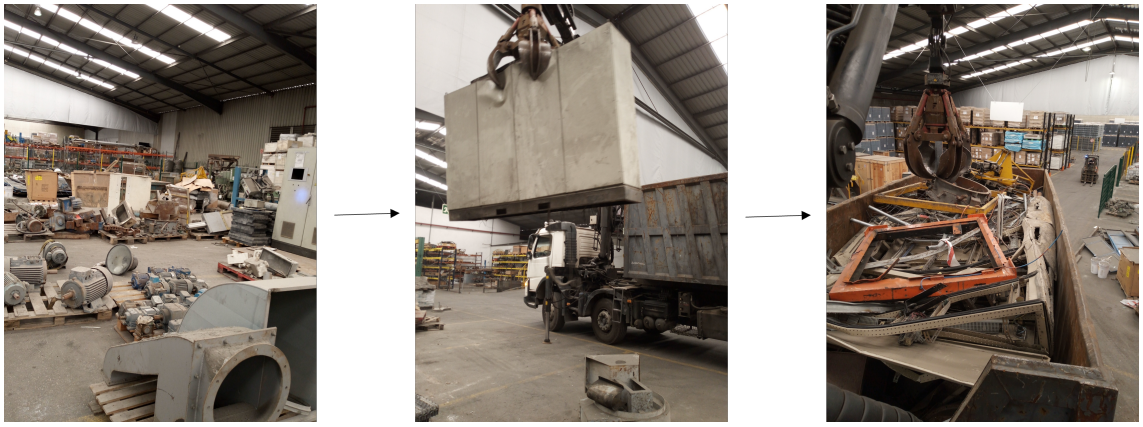


Figure 4.3: Red Zone and Scrap Picking

4.2.2 Set in Order

This step was essential to define the criteria established to organize and create a space for the spare parts.

4.2.2.1 Defining Selection Criteria

In order to facilitate the sorting and selection of spare parts, a table with several classes was built, namely: Class, Family, Sub-Family, and Name. The main purpose of this approach was to organize and categorize the equipment according to different criteria.

The "Class" column shows a larger category where parts can be grouped. For the "Family," a subdivision of the class is provided, thus allowing an even more specific categorization of the equipment. The "Sub-Family" goes even deeper into the characterization of the pieces, because it offers something additional. As for the "Name", it is made up of codes and numbers, and in most cases, it is the designation used to identify equipment.

In this sense, using this table makes the classification and organization of spare parts more efficient, which consequently makes it easier to locate the parts needed when the need arises to

replace or repair a specific component. It also facilitates inventory control and stock management.

Thus, after a study of the spare parts existing in the plant, five Classes were considered: "Zona Quente", "Composição", "Água", "Ar e Gás" and "Recuperados". In Figure 4.4 can be seen a part of the Table presented in Annex D.

Class	Family	Sub-Family	Name
ZQ (Zona Quente)	**FO** (Fornos)	**001** (Refratários)	ZQ.FO.001
		002 (Mangueiras queimadores)	ZQ.FO.002
		003 (Cortinas arrefecimento)	ZQ.FO.003
		004 (Kit Bacia)	ZQ.FO.004
		005 (Ventilador)	ZQ.FO.005
		006 (Manta)	ZQ.FO.006
		007 (Proteção)	ZQ.FO.007
		008 (Liras)	ZQ.FO.008
	EF (Enfornas)	**009** (AV2)	ZQ.EF.009
		010 (AV4)	ZQ.EF.010
		011 (AV5)	ZQ.EF.011
	C (Caleiras)	**012** (Cone)	ZQ.C.012
		013 (Proteção Queda Gota)	ZQ.C.013
		014 (Curvas Tubo da Gota)	ZQ.C.014
	A (Arcas)	**015** (Redes)	ZQ.A.015
		016 (Recirculadores)	ZQ.A.016
		017 (Motores)	ZQ.A.017
		018 (Cadeado)	ZQ.A.018
		019 (Motoredutor)	ZQ.A.019

Figure 4.4: Example of the Criteria Table

4.2.2.2 Racking organization and layout

One of the crucial steps was to define the layout of the shelves and introduce a numbering system to make it easier to find the spare parts in the inventory.

First, a study was made of the available space in the warehouse, taking into account the dimensions and constraints in terms of circulation. In this way, a plan was developed to maximize the use of space and optimize the workflow to reduce the search time for equipment.

The numbering system was designed in a logical and intuitive manner, taking into consideration the way teams work and how they identify materials. In fact, the use of this system facilitates inventory management and allows more precise control of the locations of spare parts.

Figure 4.5 shows the numbering system created for the three different existing racks, and their layout is shown in Figure 3.1.

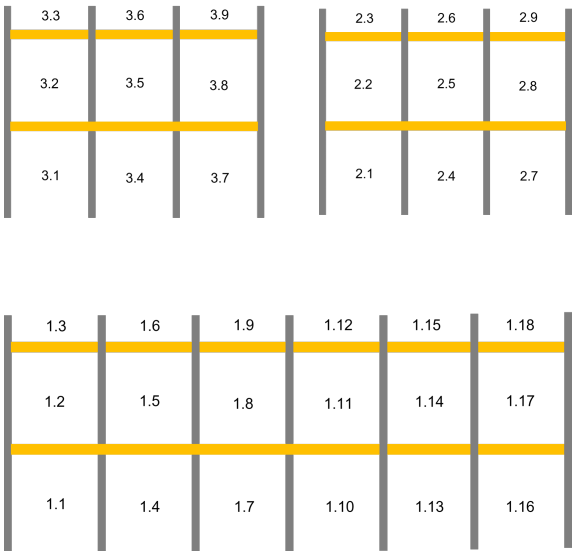


Figure 4.5: Racks Numbering System

4.2.2.3 Inventory

After the step mentioned above, when the sorting was performed, the inventory was created. This step was crucial to the success of the Implementation of 5S in the warehouse because it allowed the collecting of important information about the existing spare parts. However, it was a very time-consuming and difficult step, because there was a large amount of spare parts and their movement required the constant use of a forklift truck, as can be seen in Figure 4.6.

Figure 4.6: Lifting spare parts with a forklift truck

In this way, the inventory created was made taking into account the following characteristics:

- **Figure:** The equipment figure is extremely useful for workers to identify the spare part quickly and effectively, helping to avoid errors and confusion while locating it;
- **Equipment Name:** Registering the name of the equipment in the inventory allows the identification of each spare part, avoiding ambiguities;
- **Reference:** The reference number of the spare part is essential to know details about its specifications.
- **Zone:** The zone indicates which of the 5 zones the equipment belongs to, and in this case, the spare parts were placed in the racks by zones, allowing a more efficient management.
- **Location ID:** Allows the identification of the location of each piece of equipment in each rack, making the process much more efficient;
- **ID:** Each spare part has an ID, making it easy to manage stock and track its movement;
- **Stock quantity:** Records the current quantity of each spare part in stock, allowing and preventing missing parts needed;
- **Reorder Level:** Is a predefined value that indicates the minimum stock for each spare part.
- **Reorder Warning:** It is a visual indication that alerts employees when equipment reaches or falls below the established Reorder Level limit.

After performing all the sorting, the final layout for the arrangement of the shelves was reached, and the final result can be seen in Figure 4.7.

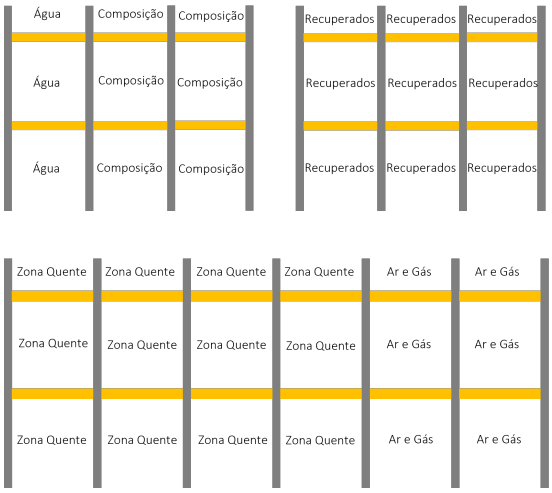


Figure 4.7: Arrangement of Racks Zones

On the other hand, the inventory was placed on the BA Share Point platform, so that in the future the company's employees have access to it. Figure 4.8 depicts part of the inventory removed and in this case, the equipment "Ventilador Arrefecimento", is below the minimum stock stipulated, and so a warning was created.

Figure	Title	Reference	Zone	Location ID	ID	Stock quantity	Reorder level	Reorder
	Ventilador SKID AV2	DIETZ AF 100L/2L-11L 2367784401-5	ZQ (Fornos)	1.6	20	2	1	1
	Ventilador SKID AV2	5V5 250/2 (900 410 50092)	ZQ (Fornos)	1.6	21	1	1	0
	Ventilador Arrefecimento	5497	ZQ (Fornos)	1.6	22	0	1	-1

Figure 4.8: BA Share Point - Inventory Example

4.2.2.4 Provisional Spare Parts Identification

Finally, the last step of the 2nd S was the provisional identification of the equipment that was in the racks, as the example in Figure 4.9 indicates. The purpose of the identification was to provide easy access to the necessary spare parts.

At this stage, the identification tags are made of plasticized paper, and the goal is to have the tags made of PVC, a more resistant material.

Figure 4.9: Provisional spare part identification

4.2.3 Shine

Although the 5S implementation was focused on the Warehouse, it was also decided to create a Cleaning Plan for both the Warehouse and the Workshop, as can be seen in Figure 4.10. A cleanup plan is extremely important as it makes the work environment much safer, as errors are diminished and the risk of injury is reduced.

Apart from that the prevention of diseases and contamination is also a reality to take into account, since there is interaction with several pieces of equipment that are already quite old, it is important to be able to remove germs and bacteria in order to maintain the integrity of the spare parts and protect the health of the employees.

Regarding the preservation of spare parts, it should be mentioned that it is essential that they are in good condition, and regular cleaning helps to remove dust and other residues that can cause damage over time, thus reducing the likelihood of corrosion and oxidation, and consequently increasing operational efficiency.

On the other hand, as can be seen in Figure 4.10 it is also necessary to have a Cleaning Plan to ensure that the regulations are followed, in order to avoid fines or other types of punishments.

CLEANING PLAN - MECHANICAL MAINTENANCE DEPARTMENT						
Area	**Description**	**Type of Action**	**Responsible**	**Frequency**	**Equipments**	**Safety Equipment**
Workshop	Workbenches (Main and Welding)	Cleaning	Department Workers	1x per day	Damp Cloth	---
	Hand Wash	Cleaning	Department Workers	After use	Damp Cloth + Degreaser	Latex Gloves
	Floor	Cleaning (Slight)	Department Workers	1x per day	Broom + Shovel	---
		Cleaning (In Depth)	Cleaning Team	1x per month	Auto Washer	---
	Wall	Cleaning	Department Workers	1x per week	Damp Cloth + Degreaser	Latex Gloves
	Garbage Collection	Garbage Collection	Cleaning Team	When it is full	---	---
	Tools and Equipment	Cleaning	Department Workers	1x per day	Damp Cloth + Degreaser	Latex Gloves
	Tool Trolley	Cleaning	Department Workers	1x per day	Damp Cloth + Degreaser	---
Warehouse	Floor	Cleaning (Slight)	Department Workers	1x per week	Broom + Shovel	---
		Cleaning (In Depth)	Cleaning Team	1x per month	Auto Washer	---
	Racks	Cleaning	Department Workers	1x per month	Damp Cloth + Degreaser	Latex Gloves
	Spare Parts	Cleaning	Department Workers	1x per month	Damp Cloth	Latex Gloves
	Unrepaired Equipment	Cleaning	Department Workers	1x per month	Damp Cloth	Latex Gloves
	Pest Control	Control	Cleaning Team	1x per year	Specialized Product	Latex Gloves
	Clean Tags	Cleaning	Department Workers	1x per month	Damp Cloth	Latex Gloves
	Forklift Truck	Cleaning	Department Workers	1x per month	Damp Cloth + Degreaser	---

Figure 4.10: Cleaning Plan

Apart from this, regarding the warehouse, after placing the spares on the racks, it was necessary to clean the floor, as shown in figure 4.11.

Figure 4.11: Warehouse Cleaning

4.2.4 Standardise

Standardization is a fundamental step in the implementation of 5S because it has the objective of establishing uniform rules for the efficient and safe operation of the warehouse.

In this sense, this sub-section aims to explore the guidelines used to ensure that the work environment was organized and efficient. Various techniques were used, some of them being visual and written instructions.

4.2.4.1 Color Standardization

One of the first standardization steps was to associate a color for each previously established Zones.

The association of colors to each zone within the warehouse is intended to provide quick and intuitive identification of the areas and corresponding spare parts. In this way, this visual approach increases efficiency and reduces the time spent searching for parts, while also minimizing misplacements. Thus, it ends up working as a complement to the identification tags.

As figure 4.12 indicates, "Zona Quente" was assigned the color orange, "Ar e Gás" the color green, "Água" the color blue, "Composição" the color red, and "Recuperados" the color gray.

Figure 4.12: Color Standardization of the zones

After the color standardization was done, it was decided to paint lines with the corresponding color in the warehouse, so that workers could easily identify the location of the desired spare part.

Figure 4.13 shows the final result of this standardization.

Figure 4.13: Result of the painted lines

On the other hand, in order for the identification tags to be in accordance with the defined standardization, new tags were created, in which the symbol and the name of the material are in the color of the respective zone, as shown in the example of Figure 4.14.

Figure 4.14: Standard Identification Tags

4.2.4.2 Stock Management Method applied

Throughout this process, a method for stock control and management was developed. This method consists of the creation of 2 QR Codes, corresponding to incoming and outgoing material, respectively.

These QR Codes open a Forms questionnaire, which is linked to the warehouse inventory in the BA Share Point, and the workers must answer some questions, in order to identify the spare part to be removed or added, depending on the case.

It is important to mention that it was necessary to connect the BA Share Point with the Forms, so that the inventory would be automatically updated, as soon as any worker submitted his answer, either to add or to remove.

This strategy can be considered user-friendly for the workers, which is quite important, as they don't have to write down the inputs and outputs on paper.

It is central to emphasize the importance of this method that was created because it brings numerous benefits, the main ones being:

- **Real-time monitoring:** The stock is controlled at the moment, which allows for quick identification of problems or missing spare parts. In addition, in case of a missing piece of equipment, an alert is issued to the department supervisor;
- **Efficiency:** Tasks are automated and operations are performed with greater ease;
- **Cost reduction:** Stock control avoids expenses with obsolete products, excessive storage, etc.

In Figure 4.15 it can be seen the Flowchart of the procedure that workers must follow in case they want to remove or add a spare part.

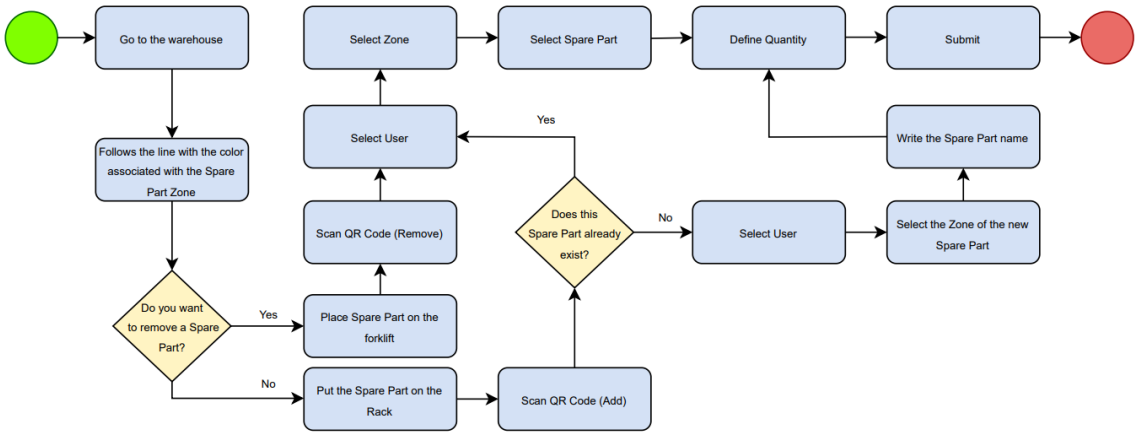


Figure 4.15: Flowchart of the Stock Management Method

Indeed, Figure 4.16 demonstrates the simulation of using this method to remove a spare part, in this case, the "Bomba Água #110".

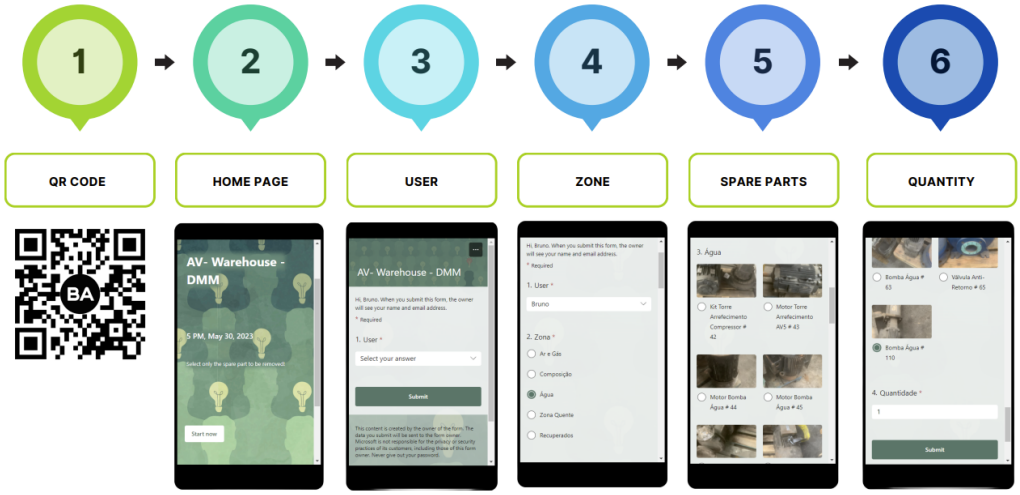


Figure 4.16: Example of Removing a Spare Part

4.2.5 Sustain

In order to evaluate the progress made, as well to compare the results with the initial audit (Annex A), the same audit was performed, and the results are shown in Table 4.2.

Table 4.2: Second Audit Results

Type of S	Mean Score	Total Score
1st	22	82
2nd	19.57	
3rd	12.71	
4th	15.14	
5th	12.57	

Thus, as expected, the results obtained showed an improvement. Through the previous table and the Radar Chart 4.17 it can be seen that these improvements were mainly due to the fact that there was an optimization of the organization, the management of spare parts stock, as well as the implementation of visual management systems and process standardizations.

It is important to reiterate that these practices helped to make the process much clearer and facilitated the detection of possible continuous improvements.

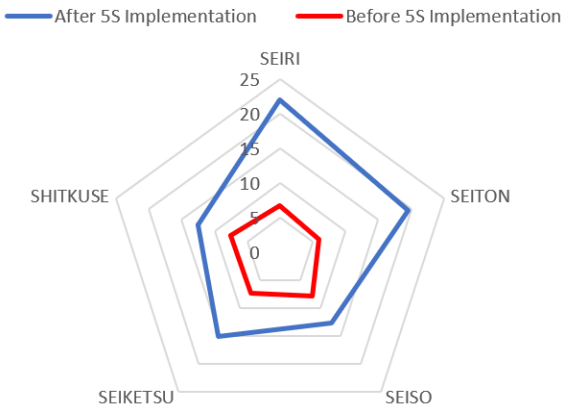


Figure 4.17: Radar Chart after Implementation of 5S

In this sense, in relation to the initial state of the Department, according to the total score of the initial audit and the final audit, an improvement of approximately 132.47% has occurred, which is a positive result.

On the other hand, it was decided to make a simulation of the three situations mentioned in the previous chapter, described in Table 3.5. In fact, the "Replacement Time" variable was kept, because in this case, no change was necessary. However, it can clearly be seen in Table 4.3 that the "Material Search Time" was shorter, as expected, since the workers only had to open the Stock Management Method applied and go to the warehouse to get the intended spare part. Thus, as is shown in Equation 4.1, MTTR decreased 94.92%.

Table 4.3: MTTR Simulation After 5S Implementation

Situation	Material Search Time (h)	Material Delivery Time (h)	Replacement Time (h)
1	0.20	0	0.5
2	0.17	0	2
3	0.33	0	2

$$\text{MTTR} = \frac{0.20+0.17+0.33}{3} = \frac{0.7}{3} = 0.233 \tag{4.1}$$

4.3 Workshop Changes and Proposals

As stated earlier, the focus of the project was on the Warehouse, yet it was decided to address improvements in the Department workshop. However, it was informed that the workshop would be moved to another location soon, which led to the decision to only make minor changes and make future proposals for stock methods, in this case of consumables or small tools, as it can be seen in Chapter 5.

4.3.1 Changes made

Thus, as already mentioned, the workshop was in a very disorganized and messy state, and there was a lot of trash all over the space. In Figure 4.18 it can be seen that the parts and tools were placed in a more organized way on the shelf, which somehow promotes efficiency in the workshop. Thus, locating the parts was made easier.

Apart from that, in the workers' office, the layout of the space has also been changed, and a desk with a computer has been placed so that they can access the warehouse's inventory of spare parts.

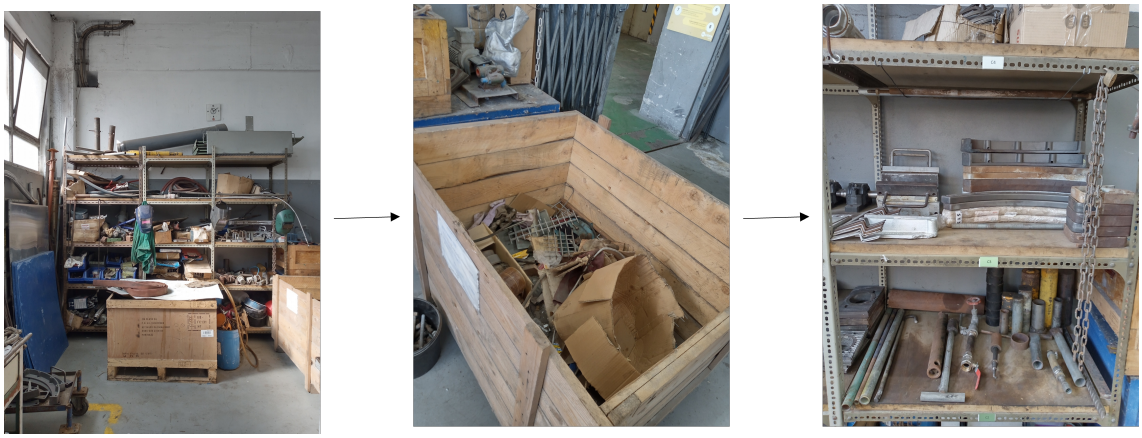


Figure 4.18: Organization of the workshop racks

4.4 Implementation of Preventive Maintenance Plans in SAP

As an additional and complementary work, it was decided to create equipment maintenance plans using the software SAP. In this sense, this section presents what has been achieved.

At an early stage, it was important to understand the priorities of the DMM, and to this end, it was necessary to meet with the workers and the supervisor of the department.

That said, after that meeting, it was decided that there were several equipment that needed preventive maintenance plans to be created, the main ones being the most urgent:

- Ventilators;
- Filters;
- Water Pumps.

In this sense, the use of manuals, but mainly the experience of the workers was fundamental for the plans to be created in order to improve the maintenance processes, and the 3 main procedures to be performed were determined as Registration, Checks, and Cleaning.

In fact, it is important to mention that some of the operations are performed only by workers from the department, others together with workers from other departments, and sometimes external companies also do certain tasks. In other words, the existence of preventive maintenance plans not only promotes organization during work but also promotes efficiency and decreases expected failures and costs.

4.4.1 Ventilator

This subsection explains the process of creating a preventive maintenance plan for the Ventilator.

In this sense, to create a maintenance plan in SAP, the first step consisted in listing all the Fans as it can be seen in Figure 4.19, being defined by transaction "IE05". It should be noted that the class referring to ventilators is "VNTL" and it is this terminology that is used in the company, with the equipment code consisting of 4 letters and 5 numbers.

Equipment	Description of technical object	Functional Location	Description of functional location
VNTL00022	Ventilation I.S. Machine L-20		
VNTL00023	Ventilation I.S. Machine L-21		
VNTL00024	Ventilation I.S. Machine conveyor L21		
VNTL00025	Ventilation I.S. Machine L-22		
VNTL00026	Ventilation I.S. Machine conveyor L22		
VNTL00027	Ventilation -Cooling air Left. AV2	AVB020FVT03	Cooling Air Ventilation Fan Left AV2
VNTL00028	Ventilation -Cooling air Right. AV2	AVB020FVT04	Cooling Air Ventilation Fan Right AV2
VNTL00029	Ventilation Combustion Air Nº-1 - AV2	AVB020FVT01	Combustion Air Ventilation Fan nº1 AV2
VNTL00030	Ventilation Combustion Air Nº-2 - AV2	AVB020FVT02	Combustion Air Ventilation Fan nº2 AV2
VNTL00031	Ventilation Electro. Filter AV2/4	AVB00EFVT01	Furnace Exhaust Ventilation Fan AV2/4
VNTL00032	Throat Cooling Ventilation AV4	AVB040FVT05	Throat Cooling Air Ventilation Fan AV4
VNTL00033	Ventilation -Cooling air Left. AV4	AVB040FVT03	Cooling Air Ventilation Fan Left AV4
VNTL00034	Ventilation -Cooling air Right. AV4	AVB040FVT04	Cooling Air Ventilation Fan Right AV4
VNTL00035	Ventilation Combustion Air Right. - AV4	AVB040FVT01	Combustion Air Ventilation Fan nº1 AV4
VNTL00036	Ventilation Combustion Air Left. - AV4	AVB040FVT02	Combustion Air Ventilation Fan nº2 AV4
VNTL00037	Ventilation ABB-Cooling air Left. AV5	AVB051BVT03	Cooling Air Ventilation Fan Left AV5
VNTL00038	Ventilation ABB-Cooling air Right. AV5	AVB051BVT04	Cooling Air Ventilation Fan Right AV5
VNTL00039	Ventilation Combustion Air Right. AV5	AVB051BVT01	Combustion Air Ventilation Fan nº1 AV5
VNTL00040	Ventilation Combustion Air Left. AV5	AVB051BVT02	Combustion Air Ventilation Fan nº2 AV5
VNTL00041	Ventilation Exhaust Air AV5	AVB05EFVT01	Furnace Exhaust Ventilation Fan AV5
VNTL00042	Ventilation Blank Mold L.51		
VNTL00043	Ventilation Blow Mold L.51		
VNTL00044	Ventilation Conveyor L.51		
VNTL00045	Ventilation Blank Mold L.52		
VNTL00046	Ventilation Blow Mold L.52		
VNTL00047	Ventilation Conveyor L.52		
VNTL00048	Ventilation Blank Mold L.53		
VNTL00049	Ventilation Blow Mold L.53		
VNTL00050	Ventilation Conveyor L.53		
VNTL00051	Ventilation Blank Mold L.54		
VNTL00052	Ventilation Blow Mold L.54		
VNTL00053	Ventilation Conveyor L.54		
VNTL00084	Ventilation I.S. Machine L.41		
VNTL00085	Ventilation Conveyor L.41		
VNTL00086	Ventilation I.S. Machine L.42		
VNTL00087	Ventilation I.S. Machine L.43		
VNTL00088	Ventilation Conveyor L.43		

Figure 4.19: Ventilators Listing

The next transaction is "IP01" and consists of creating a maintenance plan with the weekly strategy (X_SEM), as indicated in Figure 4.20, and the periodicity is rated as 2, as indicated by the scale in Table 4.4.

In this sense, the name of the plan created is "DMM - Manutenção Semanal Ventiladores AV" and all ventilators will be associated with this maintenance plan.

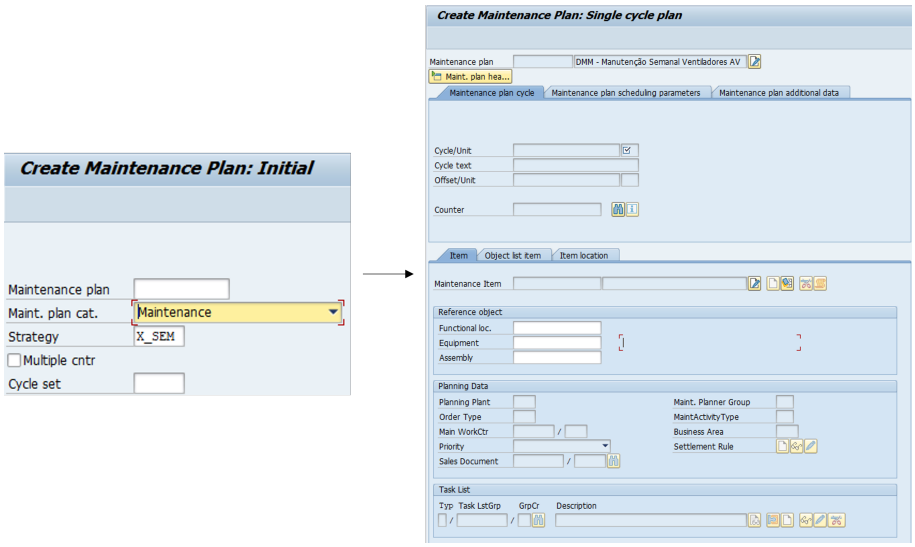


Figure 4.20: Creation of the Maintenance Plan

Table 4.4: Periodicity in SAP

Periodicity Code	Real Periodicity
2	1 week
6	1 month
20	3 months
28	6 months
32	1 year
38	2 years
44	4 years

That said, through the transaction "ZPM_PREV_TASK_LIST" a list of 3 different tasks was created, as mentioned above, namely: Registrations, Checks, and Cleaning, as shown in Figure 4.21.

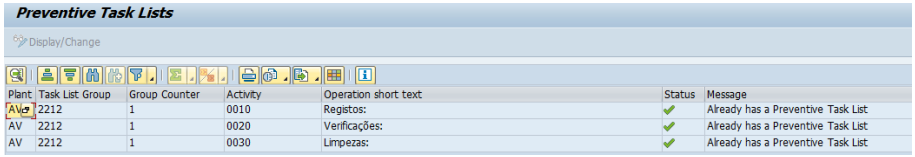
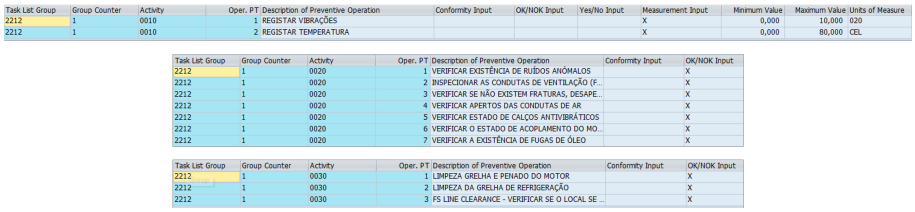


Figure 4.21: Types of Tasks

For each of the lists, certain activities that must be performed have been input, as shown in Figure 4.22, and for the Registers it is indicated the maximum values that they must have in the Temperature and Vibrations measurements.



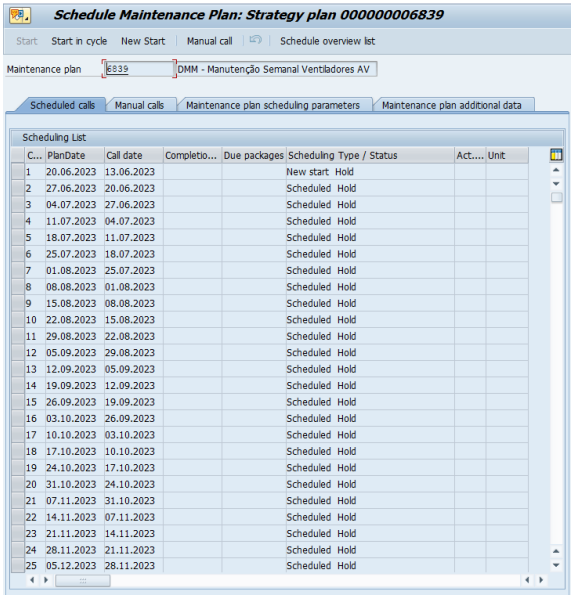
Task List Group	Group Counter	Activity	Oper. PT	Description of Preventive Operation	Conformity Input	OK/NOK Input	Yes/No Input	Measurement Input	Minimum Value	Maximum Value	Units of Measure
2212	1	0010	1	REGISTAR VIBRAÇÕES				X	0,000	10,000	020
2212	1	0010	2	REGISTAR TEMPERATURA				X	0,000	80,000	CEL

Task List Group	Group Counter	Activity	Oper. PT	Description of Preventive Operation	Conformity Input	OK/NOK Input
2212	1	0020	1	VERIFICAR EXISTÊNCIA DE RUÍDOS ANÓMALOS		X
2212	1	0020	2	INSPECIONAR AS CONDUTAS DE VENTILAÇÃO (F...		X
2212	1	0020	3	VERIFICAR SE NÃO EXISTEM FRATURAS, DESAPE...		X
2212	1	0020	4	VERIFICAR APERTOS DAS CONDUTAS DE AR		X
2212	1	0020	5	VERIFICAR ESTADO DE CALÇOS ANTIVIBRÁTICOS		X
2212	1	0020	6	VERIFICAR O ESTADO DE ACOPLAMENTO DO MO...		X
2212	1	0020	7	VERIFICAR A EXISTÊNCIA DE FUGAS DE ÓLEO		X

Task List Group	Group Counter	Activity	Oper. PT	Description of Preventive Operation	Conformity Input	OK/NOK Input
2212	1	0030	1	LIMPEZA GRELHA E PENADO DO MOTOR		X
2212	1	0030	2	LIMPEZA DA GRELHA DE REFRIGERAÇÃO		X
2212	1	0030	3	FS LINE CLEARANCE - VERIFICAR SE O LOCAL SE ...		X

Figure 4.22: Required tasks to be performed

Finally, through the "IP10" transition the schedule of the strategy to be implemented was programmed, as it can be seen in Figure 4.23 and in this case as the plan is weekly the activities are the same for all the Ventilators.



C...	PlanDate	Call date	Completio...	Due packages	Scheduling Type / Status	Act....	Unit
1	20.06.2023	13.06.2023			New start Hold		
2	27.06.2023	20.06.2023			Scheduled Hold		
3	04.07.2023	27.06.2023			Scheduled Hold		
4	11.07.2023	04.07.2023			Scheduled Hold		
5	18.07.2023	11.07.2023			Scheduled Hold		
6	25.07.2023	18.07.2023			Scheduled Hold		
7	01.08.2023	25.07.2023			Scheduled Hold		
8	08.08.2023	01.08.2023			Scheduled Hold		
9	15.08.2023	08.08.2023			Scheduled Hold		
10	22.08.2023	15.08.2023			Scheduled Hold		
11	29.08.2023	22.08.2023			Scheduled Hold		
12	05.09.2023	29.08.2023			Scheduled Hold		
13	12.09.2023	05.09.2023			Scheduled Hold		
14	19.09.2023	12.09.2023			Scheduled Hold		
15	26.09.2023	19.09.2023			Scheduled Hold		
16	03.10.2023	26.09.2023			Scheduled Hold		
17	10.10.2023	03.10.2023			Scheduled Hold		
18	17.10.2023	10.10.2023			Scheduled Hold		
19	24.10.2023	17.10.2023			Scheduled Hold		
20	31.10.2023	24.10.2023			Scheduled Hold		
21	07.11.2023	31.10.2023			Scheduled Hold		
22	14.11.2023	07.11.2023			Scheduled Hold		
23	21.11.2023	14.11.2023			Scheduled Hold		
24	28.11.2023	21.11.2023			Scheduled Hold		
25	05.12.2023	28.11.2023			Scheduled Hold		

Figure 4.23: Schedule of Preventive Maintenance Plans for Ventilators

Finally, the weekly preventive maintenance plan for the Ventilators can be seen in Annex E.

Chapter 5

Conclusion and Future Work Perspectives

This chapter presents the conclusions of the project and prospects for the future.

5.1 Conclusions

The implementation of 5S in the Warehouse of the BA Glass Mechanical Maintenance Department was quite a challenging process, but highly beneficial to the organization. The initial goal was to implement 5S in the Workshop, but due to operational needs, the implementation was carried out in the Warehouse, providing significant improvements in terms of efficiency, organization, and stock control.

Through the 5S audit and the application of the GUT matrix, it was possible to prioritize and address the most critical and challenging challenges, ensuring a focused and effective approach.

The creation of a specific layout in the Warehouse, with clear criteria for the organization of spare parts, was one of the key points of the process. This new layout allowed optimization of the storage area, facilitated the location of the equipment and contributed to a safer and more efficient work environment.

Additionally, the implementation of a more accurate inventory management system provided a better organization of spare parts, enabling more accurate forecasting of replacement needs. This resulted in cost savings and improvements in operational efficiency, as unscheduled downtime due to missing parts was significantly reduced. It also resulted in an improvement in the second 5S audit responses by 132.47% and for the 3 stipulated situations a decrease in MTTR by 94.92%.

Another important aspect covered in this internship was the development of preventive maintenance plans for some equipment, using the SAP software. This approach allowed greater efficiency in maintenance, ensuring better performance of the equipment.

5.2 Future Work Perspectives

In the future, it is important to ensure that there is follow-up work so that the employees do not lose the habits created through the philosophy of continuous improvement.

Thus, 5S audits should be done monthly, as well as meetings to understand the state of play and see what is getting better or worse, with the main focus being to keep workers motivated and involved in the new processes.

Apart from this, it is important to continue to make preventive maintenance plans for other equipments, but above all, it is necessary that the routine for workers to fulfill this function is implemented.

Finally, it would be interesting to implement a KPIs meter system, so that the department would have weekly meetings to understand the evolution of those values.

Regarding the future of the workshop, although its new location is still unknown, it is recommended that the stock management of tools and consumables be done through one of the following options:

- **ABC Method:** Allows the concentration of management and control efforts on the most important materials, avoiding unnecessary expenses with low-value parts.
- **Kanban Method with Colors:** Allows through visual control the management of the workflow in a very simple and effective way. It is based on the use of cards that represents the part, and the colors add a visual coding that indicates the status of the availability of materials. Namely:
  - **Green:** Items available in sufficient quantity from stock.
  - **Yellow:** Items in low stock, requiring attention.
  - **Red:** Items out of stock, indicate the need for replacement.

In this sense, these two methods can be complementary, with the ABC method determining the importance of materials and the Kanban system method helping to visually control the state of stock availability.

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Appendix A

Audit

5S AUDIT

BA

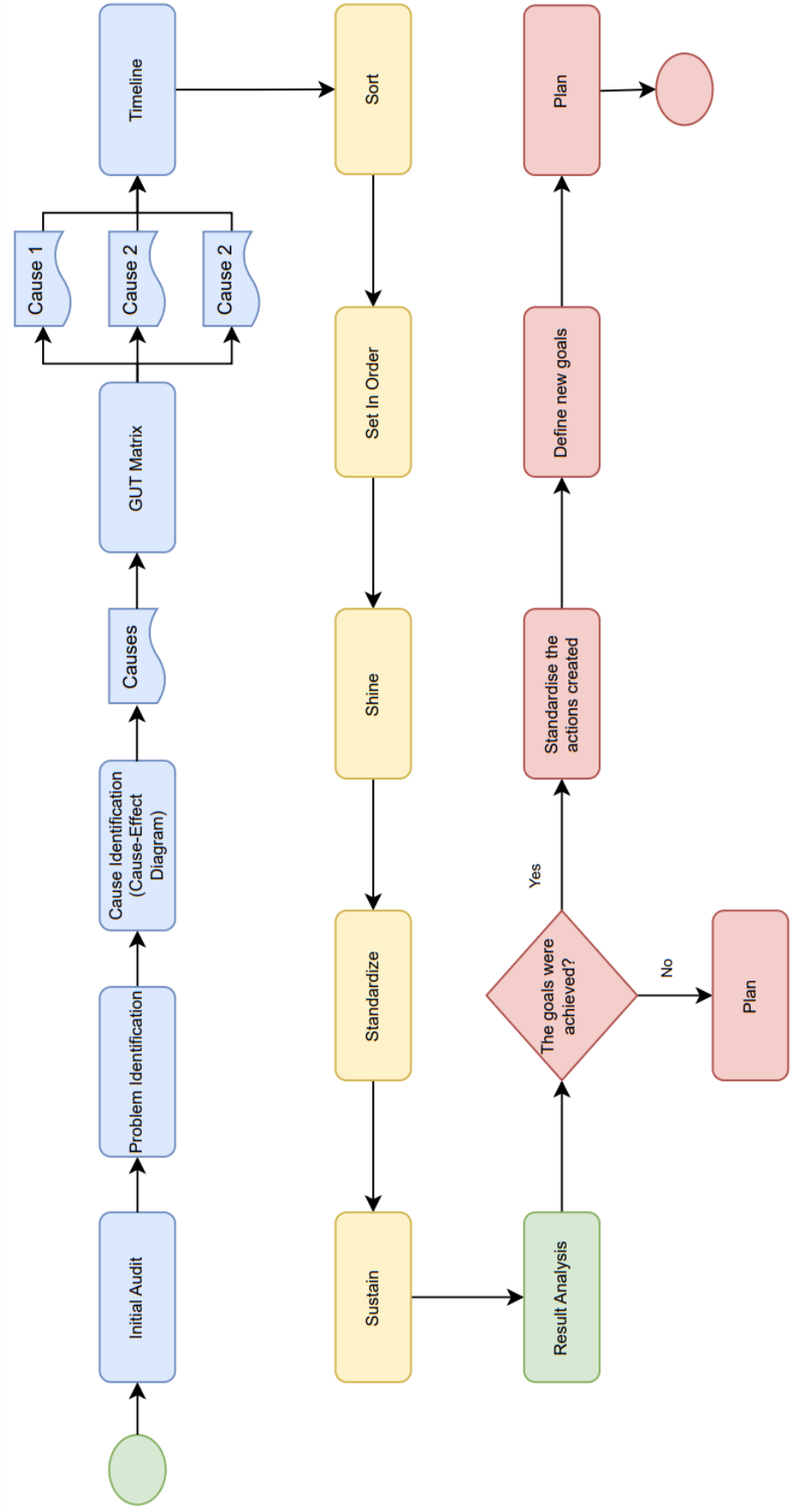
1 = Very Poor 2 = Poor 3 = Medium 4 = Good 5 = Excellent

	Put a cross for each question and comment if you think it is necessary	1	2	3	4	5	Comments
SORT	How often are materials and equipment well separated and do you remove items that are not needed?						
	How well are parts and equipment organized in the warehouse?						
	How easy is it to find the equipment and parts that are needed?						
	How often is the warehouse reviewed and organized?						
	Is there control over the materials that are in the warehouse?						
	Sub Total						**Comments**
SET IN ORDER	How are the parts and equipment organized in the warehouse?						
	How often is there a stock review of the warehouse?						
	How easy is it to locate the needed part and equipment?						
	How often are control vision systems used to help identify parts and equipment?						
	How often is the warehouse cleaned and organized to maintain the set order?						
	Sub Total						**Comments**
SHINE	How often is the space and equipment cleaned?						
	How well is the workspace cleaned?						
	How often do you inspect the safety of the space where you work?						
	Are the responsibilities and roles of each worker well defined?						
	How do the schedules stipulated for cleaning the warehouse work?						
	Sub Total						**Comments**
STANDARDIE	How well are the procedures documented in the warehouse?						
	How often are the procedures reviewed and updated if necessary?						
	Is there information in the warehouse about 5S with signs and colors for the attention of workers?						
	How easy is it to get the emergency kit in case of need?						
	How often are lists made to point out tasks to be done?						
	Sub Total						**Comments**
SUSTAIN	How well is there a philosophy of maintaining the 5s principles in the warehouse?						
	How often do workers have workshops and training on the importance of practicing 5S in the workplace?						
	Are the stipulated workplace practices followed by everyone?						
	Is there a Kanban Board? If yes, is it visibly displayed for everyone in the warehouse?						
	How good is the atmosphere and team communication?						
	Sub Total						**Score**

Department:_____ **Supervisor:**_____ **Date:**_____

Appendix B

Flowchart of the PDCA Cycle


Initial Audit
Problem Identification
Cause Identification (Cause-Effect Diagram)
Causes
GUT Matrix
Cause 1
Cause 2
Cause 2
Timeline
Sort
Set In Order
Shine
Standardize
Sustain
Result Analysis
The goals were achieved?
Yes
No
Standardise the actions created
Define new goals
Plan
Plan

Appendix C

Timeline

Month	Februrary				March				April				May				June	
Week	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**
Implementation of the 5s tool																		
1. Seiri																		
Definition of warehouse space																		
Find spare parts and move them near the warehouse																		
Creation of table concerning families and classes of materials																		
Creation of Red Zone																		
Implementation of Red Tags																		
Scrap collection																		
2. Seiton																		
Inventory Creation																		
Shelf Layout by Zones																		
Warehouse shelving organization																		
Identification of provisional parts																		
3. Seiso																		
Cleaning the Warehouse																		
Creating Cleaning Plans																		
4. Seiketsu																		
Minimum stock definition of spare parts																		
Creation of stock control software																		
Visual Management (Placards)																		
Visual Management (Color Lines)																		
Visual Management (Placard of Security)																		
Preventive maintenance plans in SAP Fiori																		
5. Shitsuke																		
Final Audit																		

Appendix D

Criteria Table

Class	Family	Sub-Family	Name
ZQ (Zona Quente)	FO (Fornos)	001 (Refratários)	ZQ.FO.001
		002 (Mangueiras queimadores)	ZQ.FO.002
		003 (Cortinas arrefecimento)	ZQ.FO.003
		004 (Kit Bacia)	ZQ.FO.004
		005 (Ventilador)	ZQ.FO.005
		006 (Manta)	ZQ.FO.006
		007 (Proteção)	ZQ.FO.007
		008 (Liras)	ZQ.FO.008
	EF (Enfornas)	009 (AV2)	ZQ.EF.009
		010 (AV4)	ZQ.EF.010
		011 (AV5)	ZQ.EF.011
	C (Caleiras)	012 (Cone)	ZQ.C.012
		013 (Proteção Queda Gota)	ZQ.C.013
		014 (Curvas Tubo da Gota)	ZQ.C.014
	A (Arcas)	015 (Redes)	ZQ.A.015
		016 (Recirculadores)	ZQ.A.016
		017 (Motores)	ZQ.A.017
		018 (Cadeado)	ZQ.A.018
		019 (Motoredutor)	ZQ.A.019
C (Composição)	M (Maceiras)	---	C.M
	T (Tapetes)	---	C.T
	D (Despoeiramentos)	---	C.D
	AL (Alcatruzes)	---	C.AL
	MR (Misturadores)	---	C.M
	V (Vibradores)	---	C.V
A (Água)	B (Bombas)	---	A.B
	VA (Válvulas)	---	A.VA
	P (Passadores)	---	A.P
	VAR (Válvulas Retenção)	---	A.VAR
	JE (Juntas Expanção)	---	A.JE
	RI (Rede Incêndio)	---	A.RI
AG (Ar e Gás)	R (Reservatórios)	---	AG.R
	VA (Válvulas)	---	AG.VA
	CP (Cilindros Pneumaticos)	---	AG.CP
	LI (Liras)	---	AG.LI
	AP (Acessorios Pneumaticos)	---	AG.AP
	Q (Queimadores)	---	AG.Q
	VE (Ventiladores)	---	AG.VE
R (Recuperados)	V (Vibradores)	---	R.V
	RD (Rodas Dentadas)	---	R.RD
	LI (Liras)	---	R.LI
	Q (Queimadores)	---	R.Q

Appendix E

Weekly Preventive Maintenance Plan for Ventilators

Furnace	Ventilator	Procedure	Periodicity
AV5	Ventilador ABB-AR Arrefecimento Esq. AV5	Registar vibrações	Weekly
	Ventilador ABB-AR Arrefecimento Drt. AV5		
	Ventilador Ar Combustão Dir. AV5		
	Ventilador Ar Combustão Esq. AV5	Registar temperatura	
	Ventilador Ar Exaustão AV5		
	Ventilador Molde Principiar L.51		
	Ventilador Molde Final L.51		
	Ventilador Tapete L.51	Verificar a existência de ruídos anómalos	
	Ventilador Molde principiar L.52		
	Ventilador Molde Final L.52		
	Ventilador Tapete L.52	Inspecionar as condutas de ventilação (fugas de ar)	
	Ventilador Molde Principiar L.53		
	Ventilador Molde Final L.53		
	Ventilador Tapete L.53	Verificar se não existem fraturas, desapertos, fissuras, corrosões e amolgadelas	
	Ventilador Molde Principiar L.54		
	Ventilador Molde Final L.54		
	Ventilador Tapete L.54		
AV2	Ventilador Máquina I.S L.20	Verificar o aperto das condutas de ar	
	Ventilador Máquina I.S L.21		
	Ventilador Tapete Rápido L.21		
	Ventilador Máquina I.S L.22	Verificar o estado de calços antivibráticos	
	Ventilador Tapete Rápido L.22		
	Ventilador Ar Arrefecimento Esq. AV2		
	Ventilador Ar Arrefecimento Drt. AV2	Verificar o estado de acoplamento de motor	
	Ventilador Ar Combustão Nº1 AV2		
	Ventilador Ar Combustão Nº2 AV2		
	Ventilador Filtro Eletro. AV2/4	Verificar a existência de fugas de óleo	
AV4	Ventilador Ar Arrefecimento à Garganta AV4		
	Ventilador Ar Arrefecimento Esq. AV4		
	Ventilador Ar Arrefecimento Drt. AV4	Limpeza à grelha e penado do motor	
	Ventilador Ar Combustão Drt. AV4		
	Ventilador Ar Combustão Esq. AV4		
	Ventilador Máquina I.S. L.41	Limpeza da grelha de refrigeração	
	Ventilador Tapete Rápido L.41		
	Ventilador Máquina I.S. L.42		
	Ventilador Máquina I.S. L.43	FS Line Clearance - Verificar se o lugar fica limpo	
	Ventilador Tapete Rápido L.43		