Implementation of an X-ray machine in the cork industry

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Master's Dissertation

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“You miss 100% of the shots you don’t take”

Wayne Gretzky

Abstract

This dissertation describes the development of a project carried out in the cork industry with the aim of implementing a new X-ray machine which analyzes the stoppers before packaging and shipping to clients.

The project focused on three major problems, which were the poor productivity and organization of the packaging sector, the high percentage of orders with mixtures, and the high lead time of the flow of cork stoppers between the previous sector and packaging for rejected lots.

This type of machine had never been used in the factory, thus requiring a deep knowledge in order to understand its operation and specifications and for this the time spent on the factory floor was fundamental. In a following phase, the initial situation of the sector and the machine itself was characterized, in order to identify possibilities of change in the sector according to the needs of the machine and to detect problems that did not allow the machine to operate at its maximum capacity. Afterward, all the improvements proposed throughout the project were addressed, as well as all the actions put into practice through operator training and the development of a standard work. The following points indicates some of the results achieved.

- Increased the machine productivity in 60%.
- Reduction of 41% of lots detected with mixtures.
- 63% increase on OEE.
- Reduction of 44% on the lead time between sectors.

Finally, the results are analyzed in order to understand whether the machine is capable of fulfilling the production needs of the sector in which it has been integrated and whether it will be able to meet the requirements defined by the company for 2023.

Resumo

Esta dissertação retrata o desenvolvimento de um projeto realizado na indústria corticeira com o intuito de implementar uma nova máquina raio-X que visa analisar as rolhas antes de serem embaladas e expedidas.

O projeto focou-se em três grandes problemas, sendo eles a fraca produtividade e organização do setor de embalagem, a elevada percentagem de encomendas com misturas e o elevado lead time do fluxo de rolhas entre o setor anterior e a embalagem para lotes reprovados.

Este tipo de máquina nunca tinha sido utilizado na fábrica, obrigando assim a um conhecimento profundo de forma a perceber o seu funcionamento e as suas especificações para tal foi fundamental o tempo passado no chão de fábrica. Numa fase seguinte foi caracterizada a situação inicial do setor e da máquina em si, de maneira a identificar possibilidades de mudança no setor de acordo com as necessidades da máquina e detetar problemas que não permitiam que a máquina operasse na sua capacidade máxima. Posteriormente foram abordadas todas as melhorias propostas ao longo do projeto, assim como todas ações colocadas em prática através de formação dos operadores e criação de um método de trabalho. Os seguintes pontos indicam alguns dos resultados alcançados:

- Aumento da produtividade da máquina em 60%
- Redução de 41% nos lotes detetados com mistura.
- Aumento de 63% no OEE.
- Redução de 44% no lead time entre setores.

Por fim, são analisados os resultados de maneira a perceber se a máquina é capaz de satisfazer as necessidades produtivas do setor em que foi integrada e se conseguirá cumprir com as exigências definidas pela empresa para 2023.

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Abbreviations and symbols

CTC – Cork Treatment Center

EE – *Escolha eletrónica*

ERP – Enterprise Resource Planning

HMI – Human Machine Interface

MES – Manufacturing Execution System

PLC – Programmable Logic Controller

S.A – *Sociedade Anónima*

S.G.P.S – *Sociedade Gestora de Participações Sociais*

SMED – Single Minute Exchange of Die

SVE - Seal Verification System

TCA – 2,4,6-trichloroanisole

TPM – Total Productive Maintenance

TPS – Toyota Production System

VSR - Vacuum System Reduction

WIP – Work In Process

1 Introduction

This chapter will set out the motivations that led to the realization of this dissertation, as well as a brief contextualization of the project and the objectives that are expected to be achieved. In addition, the methodology adopted in the various phases of the project and a short presentation of the company will be presented.

1.1 Context and Motivation

This project was carried out in a business environment, more specifically in Amorim Cork which is a world leader in the cork stoppers sector. The main objective is to identify and apply improvements in the natural cork stoppers packaging sector, namely by exploring the configuration and integration capabilities of the recently acquired X-Ray machine in order to reduce lead time, increase the production flow and improve product quality.

1.2 Objectives

This project is centered on the integration of an X-ray machine in the act of packaging and has as its main objective decreasing the production of cork stoppers with natural defects, with a view of reducing the number of complaints by clients and avoiding false rejections as much as possible.

Previously, in this sector, only the counting and packaging of stoppers were done. With the integration of this machine, it is possible to segregate the stoppers with defects, making two separate processes into one.

The focus of this dissertation will be directed to 3 problems, being them:

- Lack of productivity in the packaging sector - 20% increase.
- High percentage of mixtures in the orders - 20% reduction.
- Leadtime of 1.5 days for rejected lots - 30% reduction.

The inclusion of a completely new machine requires a total renovation of the sector in organizational terms with the need to redefine the layout of the sector itself, it also implies the training of all operators who will operate the machine, as well as the detection of problems and possible technical improvements in the machine to be discussed with the manufacturer.

1.3 Methodology

To develop this project, an approach plan based on the action-research (AR) methodology was defined. AR seeks to comprehend issues (research) and provide justification for them through practice (action), implying that it is a practical process. The research, as well as the action, are both outcomes of this process. Furthermore, because the analysis is done collaboratively, the organization's engagement in the research promotes both the authenticity and credibility of the results. Consequently, researchers acquire more rigorous information, and the study is more beneficial to the organization conducting it[1]. This methodology can be described by the following points:

- Characterize the initial situation.
- Identify the main problems.
- Plan the solution.
- Implement the solutions.

- Verify.
- Analyze the improvements.
- Standardize the acquired knowledge.

Initially, at the time of the integration into the organization, it was proceeded to an observation of the industrial environment, which involves the study of the entire production flow, as well as all the procedures for the process control. Following that, additional in-depth monitoring of the packaging sector where this project was integrated in order to detect problems, collect data and plan potential improvements.

Subsequently, it was conducted the implementation of the solutions always with constant monitoring to ensure compliance and correct possible failures. After the implementation, it is verified if the solution effectively solved the problem. Once the problem was solved, conclusions were drawn and standardized so that they would be well established within the team.

Finally, a comparison was made between the initial and the final states of the project, either visually, in terms of the area organization, or through indicators calculated during the project.

1.4 Structure of the Dissertation

This document is structured in seven chapters.

The first chapter, the introduction, is dedicated to the framing of the theme, what are the objectives that this project will focus and a description of the methodology used in the realization of the project.

In the second chapter the background concepts related to the project are discussed, as well as the methodologies used for its optimization.

In the third chapter is presented the industrial environment where the project was developed, as well as a brief explanation of the raw material used by the company.

Then follows the fourth chapter, where the initial situation of the project is described and the identified problems are presented, which are also contextualized according to the company's needs and the project's objectives.

The fifth chapter provides the development and implementation of the proposed solutions to the main problems identified.

In the sixth part, final considerations are made regarding the results obtained and suggestions for possible future work are given. It is also analyzed whether the objectives initially defined were achieved.

Finally, the seventh chapter is reserved for presenting the conclusions drawn from this project, as well as proposals for future developments that could accompany the work done so far.

2 Background review

This chapter presents the theoretical concepts, the tools, and the analysis of methodologies that allowed to sustain the proposed improvements, in order to allow a better framing and understanding of the issues addressed and their functionality in an industrial context.

2.1 Lean Manufacturing

Local subsidiaries of Ford and General Motors (GM) formed in the 1920s dominated the Japanese marketplaces. Regardless of the conditions, Toyota Motor Company President Toyoda Kiichiro established a three-year aim to close the competitive gap between his industry and the one from United States. Production was disrupted by World War II, and even after the war, Japan's terrible economic position resulted in increasing stocks of unsold vehicles, causing financial difficulties that prohibited Toyota from paying its employees. As a result, major labor issues caused the separation of Toyota Motor Manufacturing and Toyota Motor Sales in 1950, as well as Kiichiro's retirement from the firm, which was headed by his cousin Eiji Toyoda [2].

While the inexpensive and adaptable machinery Kiichiro acquired in the 1930s enabled many of the vital concepts of the Toyota Production System (TPS), it was Taiichi Ohno who provided the critical inspiration for building TPS capable of economically generating large variety in small volumes. Ohno had no prior expertise in the vehicle manufacturing industry, and it has been stated that his "common-sense approach" with no preconceived notions was important in increasing production and lowering costs by avoiding waste[2].

Fuji Cho, one of Taiichi Ohno's students, designed a house-shaped scheme, seen in Figure 1, to highlight the system's essential principles and the reality that the system's performance is dependent on various elements, exactly like a house. The foundation is the standardization and stabilization of operations, which allows the second phase, Heijunka, to level production. These two technologies, among other things, enable inventory reduction by identifying and standardizing the minimum needed amount of stock to be held while accounting for demand variation[3].

Figure 1 - TPS house. Adapted from [3]

The house's two pillars are Just-In-Time (JIT) and Jidoka, also known as Autonomation. The first pillar is the production of the required goods in the appropriate quantity and time. The second pillar complements the first by utilizing autonomous machine defect control, which prevents defective products from progressing to the next step by immediately stopping the machine when defects are identified. At the center is the Kaizen, or Continuous Improvement concept which is focused on the never-ending pursuit of excellence via waste reduction and the involvement of everyone in the business. Finally, the roof incorporates TPS's five key objectives: Best Quality, Lowest Cost, Shortest Lead Time, Best Safety and High Morale [3].

Toyota progressively discovered ways to combine the benefits of small-lot production with economies of scale in manufacturing and procurement, and contrary to popular belief, this implementation required a long time, in reality, a decades-long iterative learning cycle. TPS first gained traction during the first oil crisis in 1973, since Toyota was the only automobile manufacturer that could account for gains amid the oil shocks [2].

Mr. Krafnik coined the term "Lean Manufacturing" in 1988 when he published his paper Triumph of the Lean Production System, and it was later used by his thesis advisor Womack, in the title of his well-known book *The Machine that Changed the World*, in which he compares TPS with other production systems around the world.

To summarize, Lean can be characterized as a method, a philosophy, an approach, a concept, a set of tools and procedures, a system, a program, a manufacturing paradigm, or a model. Its application is primarily motivated by the following goals: achieving a greater variety of products with fewer defects, integrating product development, supply chain management, and operations management, reducing lead time, leveling production, improving quality at a low cost, removing waste from the system, minimizing inventory, improving productivity and product quality, and achieving business flexibility [4].

The 3M and the 8 Wastes of Lean

The goal of lean manufacturing is to eliminate waste from the manufacturing process. It is critical to identify the eight wastes before digging into it. Waste is defined as any undesirable action or activity that reduces the value of a product and for which customers are unwilling to pay. Taiichi Ohno recognized seven categories of waste: transportation, inventory, movement, waiting, overproduction, overprocessing, and defects. Western Industries later recognized an eighth waste: the failure to capitalize on human capability and innovation. This waste occurs from disrespect for employees' knowledge, expertise, and capacity about manufacturing procedures[5].

Ohno recognized and defined the seven most common industrial wastes[5]:

1. Transport: It refers to the needless transportation of items between sectors. Any mode of transportation is a waste since it adds no value to the product. Furthermore, excessive movement wears out equipment.

2. Inventory: Retention of raw materials, work in process (WIP), and finished products. Excessive stock means more accessible storage and handling space, which can lead to overprocessing.
3. Motion: Similarly, unnecessary human movements are a waste of time. They take time that could be employed to generate or create value. These motions are frequently linked to poorly defined layouts and disorganized tools.
4. Waiting: All delays and waiting times that add no value to the product are regarded here. This waste happens when machines or people are interrupted for reasons such as a lack of material or knowledge, or a lack of available equipment.
5. Overproduction: It happens when a company produces more than what is required to service the client. Each stage must generate exactly what the following process requests, no more and no less, so that the value chain satisfies the actual need. Producing in excess of what is required wastes resources, creates stocks, and causes displacements. It is known as the "mother" of wastes since it aggravates all the others.
6. Over-processing: Repairs or rework of products or services caused by faulty execution of operations or processes. Operations conducted to produce items of higher quality than required by clients are also viewed as waste, because the client is unwilling to pay more for these enhancements.
7. Defects: Considers all anomalies in items that require correction or repair. Correction and repair of items require the investment of materials, time, labor, and equipment, resulting in additional expenses.

The presented wastes are part of a concept, conceived by Taiichi Ohno, called the 3M[6]:

<u>Muda</u> - Waste - Represents all wastes created by the company, unintentionally and likely to be eliminated. Mudas do not provide any added value. These are therefore the easiest wastes to identify, track and discard.

<u>Muri</u> - Excess - This is linked to activities that are difficult for operators to perform, particularly because of the company's equipment and materials. It can also cause overload, in terms of work and weight. These losses are created through unreasonable activities and their consequences, such as work accidents.

<u>Mura</u> - Variability - Include irregularities and variations in the production chain, as well as in the work of operators. It represents the fact of making cuts, pauses, machine stops due to a lack of equipment, material or an operator. The ideal is to create a work rhythm.

2.2 The 5 Principles of Lean Manufacturing

According to Womack and Jones, there are five fundamental guiding principles when incorporating this philosophy within an organization. These principles are represented in Figure 2 and will be described next[7].

Figure 2 - Lean principles, Five principles of lean manufacturing by planet together [7]

Define Value: It consists in the identification of value by the final consumer. This is characterized as the most critical step in this process since it determines how much the customer is willing to pay for a given product and/or service. Thus, after identifying the aspects valued by the customer, it is necessary to eliminate what does not add value.

Map Value Stream: it is necessary to precisely identify the value chain and remove the "waste" steps, from raw materials to finished product, passing through the flow of physical transformation and information. There are two types of waste: non-value added but essential waste and non-value and unneeded waste. The latter is pure waste and should be avoided, whilst the former should be decreased as much as possible.

Create Flow: After the first two principles are assured, we proceed to establish a production without interruptions, stoppages, waiting, and other types of waste, which means a production with a continuous flow that allows us to respond, as quickly as possible, to the costumer’s needs.

Establish Pull System: Demand must determine production since the company only produces what the consumer wants when it is requested and in the desired quantity.

Pursue Perfection: Companies should aim for perfection, that is, to deliver the product according to the customer's needs and expectations within the agreed-upon timeframe and in perfect condition.

2.3 Lean Manufacturing Tools

In this sub-chapter some of the Lean tools will be presented, such as Kaizen or Continuous Improvement, 5S Methodology, which support the identification as well as the elimination of the previously mentioned wastes.

2.3.1 Kaizen

Kaizen is the Japanese word for improvement and is a concept that focuses on improving the process by eliminating the waste associated with it. As such, it provides the basis for lean manufacturing aimed at continuous improvement [8].

It is a combination of two Japanese words: "Kai" meaning change, and "zen" meaning for the better, so Kaizen is a change for the better. It is a Japanese philosophy focused on small improvements achieved by the continuous effort of all parties involved in an organization from directors to operators[8].

As illustrated in Figure 3, Kaizen is an umbrella term that encompasses numerous strategies such as Kanban, total productive maintenance, automation, recommendation systems, and productivity enhancement.

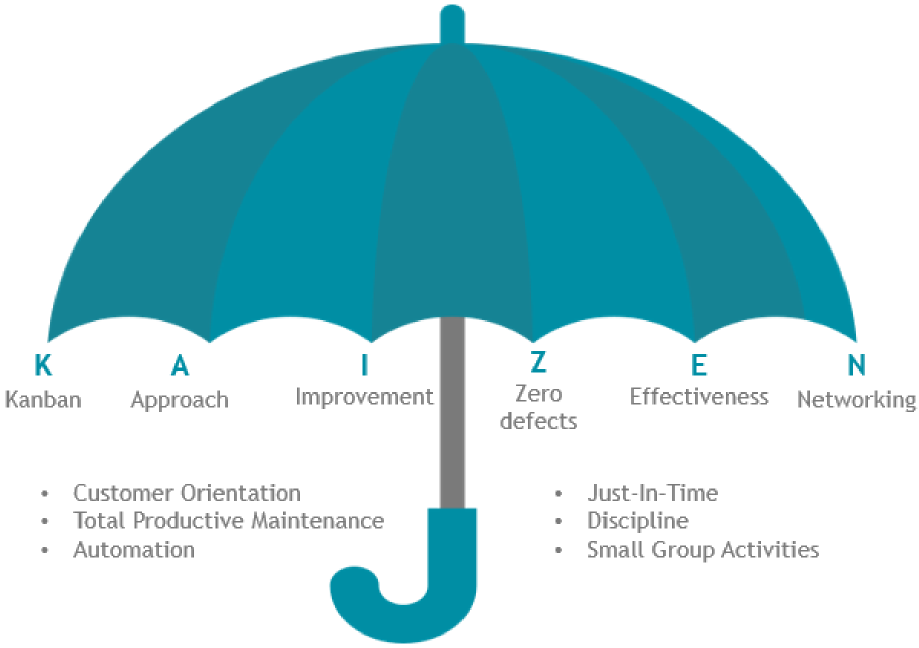


Figure 3 - Kaizen Umbrella. Adapted from [8]

Kaizen allows people to be flexible to changes that occur and to incorporate these changes into their daily work routine. Its basic purpose is to improve three parameters: quality, cost and delivery time. The important elements of this concept are to ensure standardization and to create systems so that the degree of change is maintained[8].

2.3.2 Kanban

Kanban is a Japanese word that means card and indicates three pieces of information that have to be present on it[9]:

- Customer information.
- Information about the product.

- Designated place in the production process and storage area.

For this system to work the company will have to adopt a pull production system, being the ideal the usage of Just-in-time system since it is based on the lean system. Most researchers concluded that the kanban system could reduce lead time and achieve excellence in production[9].

2.3.3 PDCA

The PDCA (plan-do-check-act) is an iterative four-step cycle, demonstrated on Figure 4, used primarily as a scheme of quality improvement process. It is a concept based on four key management categories, which can be considered as management functions and basic production procedures: planning company activity, manufacturing products, ensuring quality, and monitoring manufactured and sold products. The stages of PDCA can be caracterized as follows[10]:

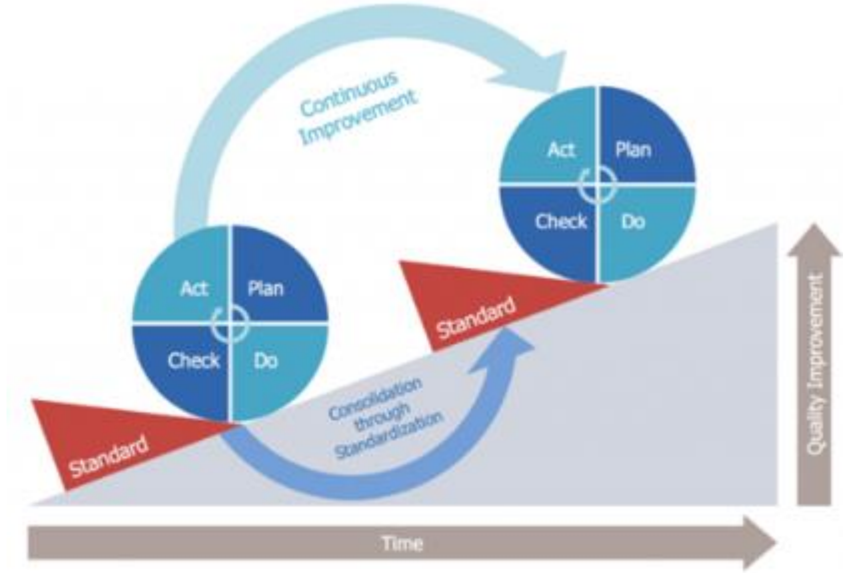


Figure 4 - PDCA cycle. Adapted from [10]

Plan: Determine what has to be accomplished and how you will know if it is achieved. Determine the objectives (in measurable terms) and the strategies to obtain them.

Do: Follow through on what has been planned. Carry out the test by executing the plan and implementing the methods.

Check: Have the plan's objectives been met? Analyze the possible deviation from the plan and test the plan accordingly to the information gained during cycle.

Act: What can be taken from the cycle? Adopt and sustain strategies that have proven to be effective in achieving goals. If not, identify the core causes and correct the implementation.

The PDCA cycle has no conclusion since as soon as an improvement occurs, the resulting status becomes the base of the next cycle, as shown in Figure 4. This cycle means never being satisfied with the current state following the philosophy of continuous improvement.

2.3.4 5S tool

The 5S tool - originated by Takashi Osada in the 1980s - is a work methodology that contributes for a development of a business system for organizing and controlling manufacturing activities that takes less human effort, space, capital, and time to produce fewer defective items. It promotes a disciplined, clean, and well-organized work atmosphere[11].

For the implementation of this tool it is necessary to understand the following five Japanese practices[11]:

- Seiri (Sort): Sort out unnecessary items from the workplace and discard them.
- Seiton (Set in order): Arrange necessary items in good order so that they can be easily picked up for use. If the item is not important enough to be tagged means it should be discarded.
- Seisio (Shine): Clean the workplace completely to make it free from dust, dirt and clutter.
- Seiketsu (Standardize): Formulation of standards and procedures to institutionalize the improvements employed in the previous steps.
- Shitsuke (Sustain): Train and motivate people to follow good housekeeping disciplines autonomously.

When 5S is applied correctly, it produces a visual factory that enables immediate determination of workplace status. Managers and supervisors can notice when things are out of order, when production has slowed or stopped, or when work in progress is not where it should be[11].

2.3.5 Total Productive Maintenance

To be successful and attain world-class manufacturing in today's highly competitive climate, firms must have both efficient maintenance and effective manufacturing strategies. The proper integration of the maintenance function with engineering and other manufacturing functions within the business can help to save a significant amount of time, money, and other valuable resources when dealing with reliability, availability, maintainability, and performance issues[12].

Total Productive Maintenance (TPM) is a production-driven improvement methodology aimed to increase equipment reliability and ensure efficient management of plant assets. TPM is a change philosophy that has considerably contributed to the accomplishment of considerable changes in manufacturing organizations in the West and Japan. Its major objective is to obtain the following steps[12]:

- Increasing equipment effectiveness through improving equipment availability, performance, efficiency, and product quality.
- Developing a preventative maintenance strategy for the whole equipment life cycle.
- Covering all departments, including planning, user, and maintenance.
- Including all employees, from senior management to shop floor workers.
- Encouraging enhanced maintenance through small-group autonomy.

The basic practices of TPM are often called the pillars or elements of TPM. The entire edifice of TPM is built and stands on the following eight pillars represented on Figure 5[12]:

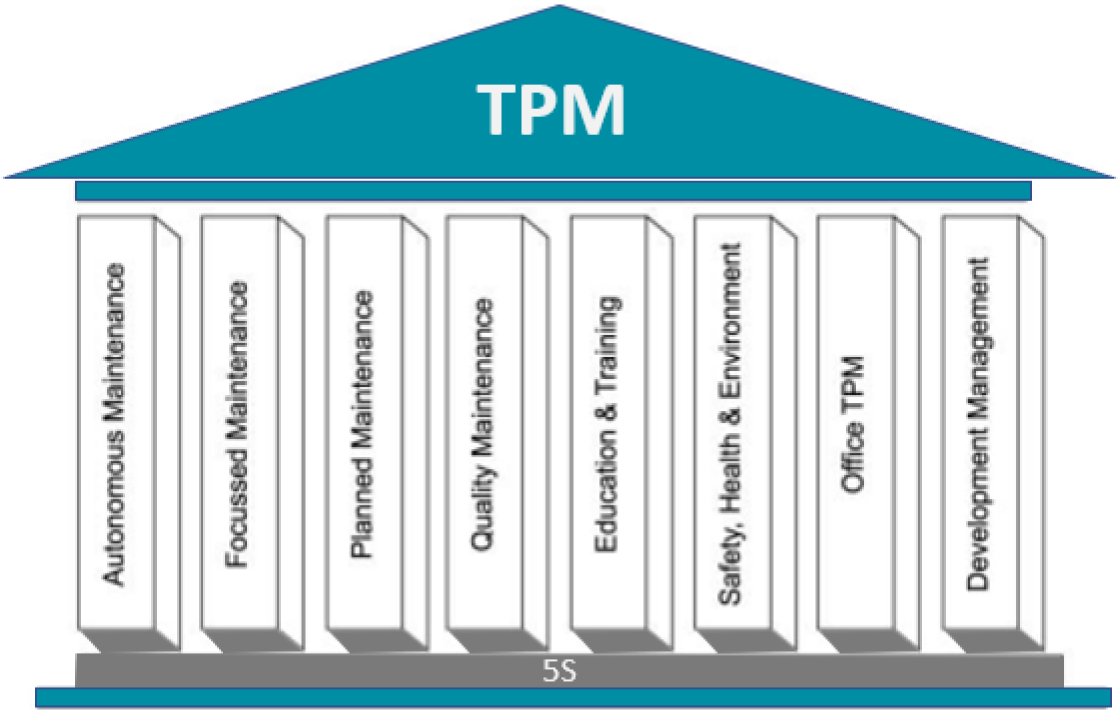


Figure 5 - TPM pillars. Adapted from [12]

1. Autonomous Maintenance: Developing operator's ability to perform minor repairs as well as inspections on the equipment in order to preserve its optimal operating conditions.
2. Focused Maintenance: Elimination of waste and losses associated to materials, labor, and equipment existing in the production process, in order to improve the efficiency of the equipment and the production system.
3. Planned Maintenance: Creating routine maintenance of the equipment to replace the corrective maintenance that existed until then, performing preventive and proactive actions that result in the reduction of the occurrence of failures and malfunctions.
4. Quality Maintenance: Establish inspection and monitoring standards for the machines so that the necessary conditions for zero defects are met.
5. Education and Training: Continuous employee training, both technical and social, is an essential component of this methodology, as it has a significant impact on the TPM evolution process.
6. Safety, Health and Environment: Continuously reducing environmental and safety concerns while boosting working conditions in order to achieve zero accidents on work and in the environment.
7. Office TPM: Strategic applications of TPM practices in activities that support production systems, such as logistics and administrative operations that affect the effectiveness and efficiency of production.
8. Development Management: Early equipment maintenance is to build in high efficiency from the design stage. This step will help to design equipment in a way that is easy to operate and maintain and is delivered to the site in a condition that is equal to autonomous maintenance standards.

Before the integration of the pillars described, it will be necessary to implement the 5S, a tool that is the base of TPM, as it will only be possible to visualize and identify problems in an organized place.

Overall Equipment Effectiveness and The Six Big Losses

Nowadays, the development of automation and robotization has led to organizations replacing most manual processes with machines, implying that the effectiveness of the equipment has a significant impact on an industry's success[13].

Overall Equipment Effectiveness (OEE) is a quantitative metric used by TPM to measure the performance of a productive system. OEE is the major indicator used to monitor the efficiency of a TPM implementation effort[13].

This indicator allows the identification of all the problems related not only to the machines but also to the production process, materials, and people, that is, all the problems that are affecting production, allowing them to be seen as opportunities for improvement[13].

OEE can be obtained by the following equation:

$$OEE = Availability\ (A) \times Performance\ efficiency\ (P) \times Rate\ of\ quality\ (Q) \qquad (1)$$

Availability refers to the proportion of time in which the machine does not produce, resulting from unplanned downtime such as breakdowns, material shortages, and setups. This element is obtained by dividing the actual run time by the planned production time, thus highlighting the time lost to unplanned downtime[14].

For the calculation of this category, it is necessary to distinguish the run time from the planned production time. As can be seen in Figure 6, the planned production time results from subtracting the planned stops (lunch breaks, snack breaks, cleaning) from the shift time[14].

The run time results from subtracting the availability losses which take 5 minutes or more, such as tune-ups and material shortages from the planned production time. By excluding performance losses from the run time, the net run time is obtained[14].

Finally, the time in which the machine is adding value to the product, called fully productive time is obtained by extracting all stops and losses from the shift time or by subtracting quality losses from the net run time[14].

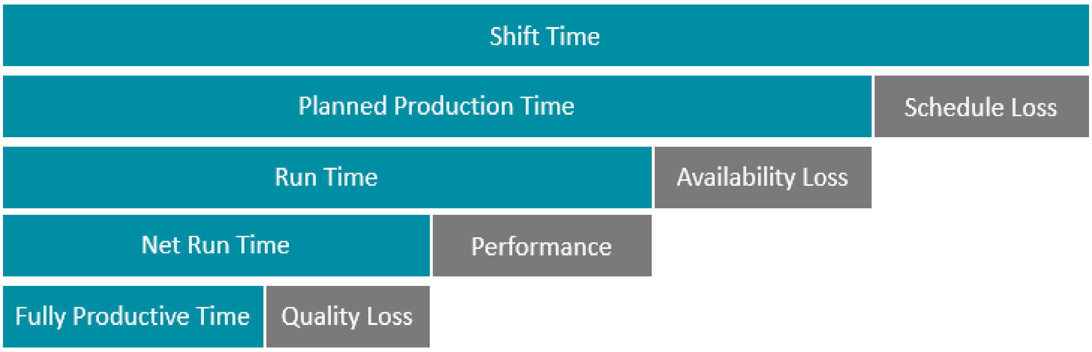


Figure 6 - Systematic representation of the times used on OEE calculation, Understanding OEE in Lean Manufacturing by Vorne Industries [13].

After obtaining the values of the production planned and run time, it becomes possible to determine the availability of the equipment under study through the following formula[14].

$$Availability\ (\%) = \frac{Run\ time}{Planned\ Production\ Time} \times 100 \tag{2}$$

The second element, performance efficiency, accounts for when the process is running slower than its theoretical top speed and can be calculated as[14]:

$$Performance\ Efficiency(\%) = \frac{Ideal\ Cycle\ time\ \times Total\ Count}{Run\ Time} \times 100 \tag{3}$$

Where Ideal Cycle Time is the quickest cycle time that the process can accomplish under ideal conditions. As a result, multiplying it by the total number of parts manufactured (total count) results in Net Run Time, which represents the fastest time to make the parts[14].

The third and final criterion required for determining the OEE is quality, which reflects the proportion of conforming items produced only by the equipment or production line under consideration in the totality of produced parts. The formula described below is used to calculate the value of this category[14].

$$Quality\ (\%) = \frac{Good\ Count}{Total\ Count} \times 100 \tag{4}$$

The OEE is a performance indicator whose value should be maximized. It provides a highly valuable insight and an accurate representation of how well the manufacturing process is working, making it easier to track process improvements over time[13].

The Six Big Losses, Table 1, categorize productivity loss from an equipment perspective. They align directly with OEE and provide an additional and actionable level of detail about OEE losses [15]

Table 1- The six big losses, Six Big Losses In Lean Manufacturing by Vorne Inudstries [15]

OEE Losses	Six big Losses	Description	Examples
Availability Loss	Unplanned stops	Period of time in which equipment is scheduled for production but is not running due to unplanned events.	•Equipment breakdowns; •Tool failures; •Lack of operators or materials; •Unplanned maintenance;
	Planned stops	Period of time in which equipment is scheduled for production but is not running due to planned events.	• Changeovers; • Tolling adjustments; • Cleaning; • Quality inspections;
Performance Loss	Small Stops	Small Stops occur when equipment stops for a short period of time (typically a minute or two) with the stop resolved by the operator	• Incorrect settings; • Misaligned or blocked sensors; • Misfeeds;
	Slow Cycles	Slow Cycles occur when equipment runs slower than the Ideal Cycle Time	• Dirty or worn-out equipment; • Poor lubrication; • Operator inexperience;
Quality Loss	Production defects	Production Defects are defective parts produced during stable production	• Incorrect equipment settings; • Operator or equipment handling errors;
	Startup defects	Defective parts produced from startup until stable production is reached	• Suboptimal changeovers; • Equipment that needs “warm up” cycles;

As shown above, these major Losses are related to the OEE performance categories, so their value is inversely proportional to their occurrence, allowing you to measure the impact that these obstacles have on the operation of the equipment.

2.3.6 Single Minute Exchange of Die (SMED)

SMED also known as quick changeover of tools was developed by Shingo, as a scientific strategy for reducing setup times that can be implemented in any industrial unit and by any machine. SMED was defined as the shortest amount of time required to change the type of production activity when comparing the final item produced by a prior lot to the first piece produced by the following lot. Before the creation of the SMED technique, the best strategy to reduce the cost of idle machines during setup operations was to produce large lots to achieve the lowest percentage of idle time per unit produced. When the inventory costs met the costs of idle equipment during tool changeover, the perfect amount for each manufacturing lot was attained[16].

In SMED there are two operations involved, internal setups which can only be performed when the process or machine is stopped and external setups which can be carried out while the process or machine is operating. Preliminary phases, separate internal and external setup, converting internal to external setup to avoid stopping the machine or process and standardizing all aspects of the setup are the four stages needed to make a setup reduction[16].

2.4 Ishikawa Diagram

The Ishikawa diagram, also known as a cause and effect diagram, is a tool for determining the underlying causes of quality issues. The diagram was named after Kaoru Ishikawa, a Japanese quality control statistician who used it for the first time in the 1960s[17].

This diagram is an analysis tool that provides a systematic way of looking at effects and the causes that create or contribute to those effects. It is also known as a fishbone diagram because its design is similar to the skeleton of a fish, as displayed in Figure 7. Its representation can be quite basic, with oblique line segments representing the causes that converge to a horizontal axis, the effect, illustrating the dispersion of various causes and sub-causes that generate them[18].

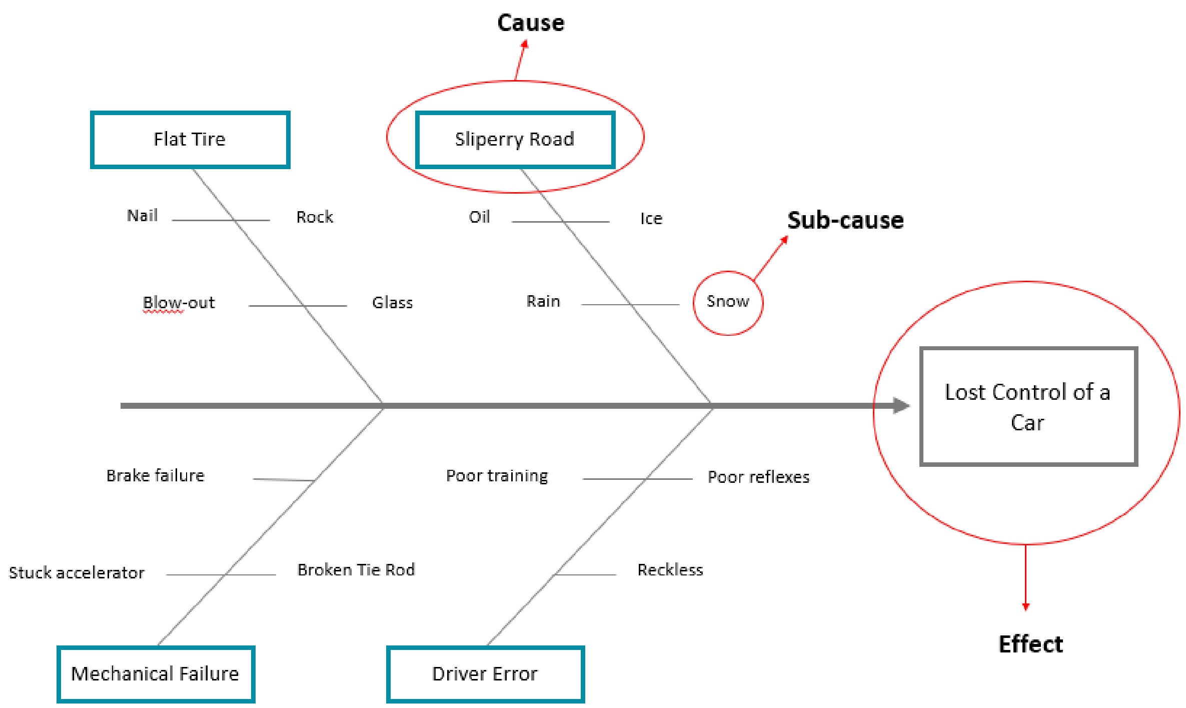


Figure 7 - Example of an Ishikawa diagram. Adapted from [18]

2.5 Spaghetti Diagram

A spaghetti diagram is a tool for viewing the movement of an object in the system using a line. The examined moving item might be a worker, material, or something else. A system in which such object moves can be a manufacturing area, a section of a facility, or a workshop[19].

Using this diagram, the movement path of products, workers and intermediate products can be easily tracked. Figure 8 represents an example of this diagram[19].

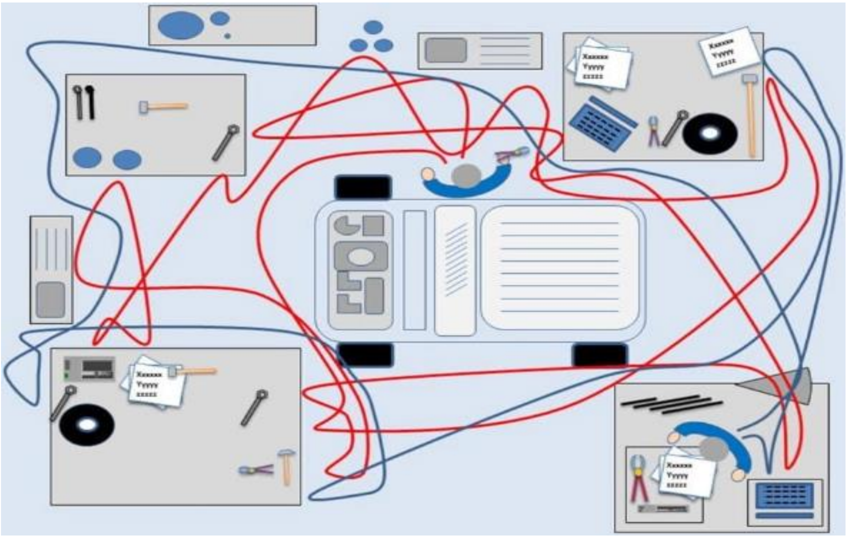


Figure 8 - Spaghetti diagram, How to create a Spaghetti diagram used within lean, by latest quality [24]

It is also useful to trace movement at different periods by using different colors for different items, workers, or technical methods. Following the study, we may determine the movement durations, the number of movements, overlapping and crossing movements, and their characteristics. Applying Spaghetti diagram results becomes easier to identify unnecessary movements and ineffective zones, reduce the number of employees, and make modifications to the work organization or workstation layout[19].

2.6 Standard Work

Standardization is the practice of defining, communicating, following and improving standards. Standards form the baseline from which all improvement activities participate in the continuous improvement process, as Mr.Taiichi Ohno said: “Where there is no standard, there cannot be improvement”[20].

Standard work is described as a group of work processes that specifies the optimal techniques and sequences for each operation and each worker. This tool, like other Lean manufacturing approaches, focuses on minimizing waste while optimizing the efficiency of each worker's tasks. It is a tool used in cellular manufacturing and pull production to keep production pace in sync with the flow of orders and to allow operators to easily shift positions within the process [20].

Standard Work is composed by the following elements[21]:

- Standard Cycle Time: The time it takes for a product to be manufactured from start to finish in order to meet market demand.

- Standard Work Sequence: Consists of a sequenced set of actions that indicate the best and safest approach to complete the assignment. Each operator performs these actions frequently and consistently over time.
- Standard Work-in-Process: Reflects the minimum amount of stock that should be kept in order to assure continuous production with no downtimes.

This approach does not require that all sorts of work must be done in the same way, but it does suggest that one type of work is always done in the same way, regardless of the operator, as a result, individual preferences are removed[21].

3 Industrial Environment

In order to contextualize the problems presented, it is necessary to introduce the real situation of the company in terms of its production processes. In this chapter, the company where this project was inserted will be described, so that it is possible to understand the whole project.

3.1 Corticeira Amorim S.G.P.S., S.A.

The Amorim group was founded in 1870, world leader in the cork sector that has operations in more than 100 countries. It has been diversifying its business into areas such as real estate, energy and the development of quality natural products, with cork remaining its core business. Its strategy has as its mission to add value to cork, in a competitive, differentiated and innovative way, in perfect harmony with nature[22].

Corticeira Amorim is organized into 5 business units:

- Raw-Materials – Amorim Florestal, S.A.
- Cork stoppers – Amorim Cork, S.A.
- Floor & Wall Coverings – Amorim Revestimentos, S.A.
- Composite Work – Amorim Cork Composites, S.A.
- Insulation Cork – Amorim Isolamentos, S.A.

At the moment, its strategic challenge is to be profitable with a sales volume of roughly 740 million euros, of which 69.8 % is achieved through the cork stoppers business unit, which sells 5.4 billion stoppers annually, and this project is inserted in the progressive rise of these numbers. The company currently has 25,000 customers, 51 distribution companies, 18 industrial units, and 12 joint ventures[22].

In terms of quality and safety, the official SYSTECODE accreditation guarantees that the company fulfills the most efficient preventive practices against the contamination of cork by undesired microorganisms. Figure 9 represents the certifications of the company: Quality Management Systems (ISO 9001), Environmental Management Systems (ISO 14001), Food Safety Management Systems (ISO 22000) and HACCP (Hazard Analysis and Critical Control Point) [22].

Figure 9 - Certification of cork stoppers by Corticeira Amorim [22]

3.2 Why Cork

Cork is the bark of the Cork Oak tree (*Quercus suber L*). It is a natural plant tissue that is biodegradable, and its unique capacity to hold CO2 makes it a champion of sustainability and a formidable ally in the fight against climate change. It is a raw material with unique qualities that give it an unrivaled character, it embraces a set of properties of various materials, and that is what makes cork so valuable[22]:

- Lightness
- Comfortable and soft to touch
- High-friction resistance
- Resistance to fire and high temperatures
- Impermeability to liquids and gases
- Thermal and acoustic insulation
- Elasticity, compressibility, and resilience
- Hypoallergenic

Cork can be removed from the tree every 9 years. The first stripping only takes place when the cork oak is 25 years old. It is called *desbóia* from which the cork has irregular structure and hardness. The second stripping known as *secundeira* has already a better structure and hardness but still not enough for the manufacture of stoppers. However, none of these corks are wasted and can be used in other applications, such as flooring, decorative items, insulation, among others. From the third stripping *amadia* (43 years old) the cork has ideal characteristics to produce natural stoppers [22].

The harvesting is done by highly specialized professionals, always between May and August, when the tree is in a more active phase of growth, and it is easier to strip without hurting the trunk. The cork oak can be stripped about 17 times during a lifetime which is, on average, 200 years. The largest areas of cork oak forest are in western Mediterranean countries, of which 55% are from Portugal [22].

3.3 Macroprocess

The Lamas Industrial Unit is Amorim Cork main factory and is in charge of producing natural cork stoppers from the raw material to the final product. The process is divided into two main phases, as represented on Figure 10.

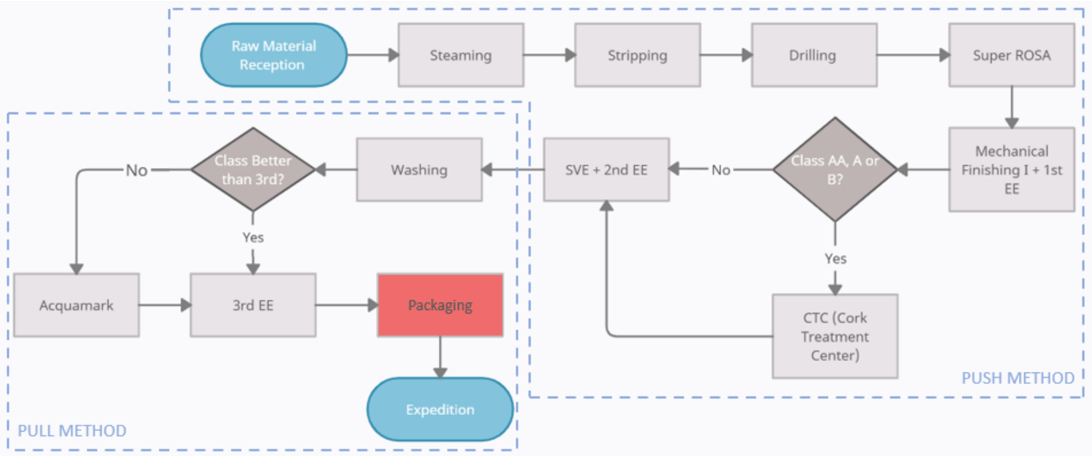


Figure 10 - Production process flowchart of Lamas industrial unit.

The first phase uses a pull type control of the material flow, which means that from the reception of the raw material to the 2nd electronic selection (EE - *Escolha Eletrónica*) the main goal is to produce as much as possible. Beyond that the material flow is controlled based on pull method, where the customization of the product according to the customer's requirements begins.

The cork arrives at the dockyard after being selected and boiled at Amorim Florestal. After being received, the planks are usually steamed for about 20 minutes to give them a smoother shape. Here, if the cork is processed immediately, it is sent for stripping. However, if it is intended to remain in stock, it needs to be dried to prevent the development of fungi, since these are directly related to the levels of TCA (2, 4, 6 Trichloroanisole). This fungus is responsible for giving the commonly called "cork taint", impairing some fundamental characteristics of the wine, such as its flavor.

In the next section, stripping, the planks are cut to obtain strips, these strips must allow the execution of holes with 0.5 mm wider and 2 mm longer than the final dimension of the stopper. There are 2 types of stripping, manual and automatic, being that the manual is used mainly for cork that is more difficult to handle.

With the strips ready they are drilled to obtain the cylindrical shape of the stopper. This sector is made up of 2 types of drills. The manual ones, which are operated by humans where the best quality stoppers are made, their experience allows them to easily identify where to drill, thus avoiding defects in the cork, and the automatic ones which uses artificial intelligence to replicate the human eyes. At the end of this sector, a separation process is done using sophisticated computers that classify the corks based on their visual quality. *Raça* are the corks that will follow the normal production process, as they do not present major defects. The corks classified as *repasse* present some defects but can still be reused. In turn, those that end up being chosen as *apara* have to be triturated due to the high number of critical defects, the grains that come from this process are reused by other companies in the group for the manufacture of technical stoppers. In Figure 11 is represented the three classifications referred.

Figure 11 - Cork stopper defined as*: Apara, Repasse* and *Raça*

After this first segregation, the stoppers of the *raça* class are transported to the Super ROSA (Rate of Optimal Steam Application) where they are submitted to three distinct factors: Wet Steam, high temperatures and ventilation. These processes have as their main function to regulate the humidity of the corks, aiming to minimize the possibilities of microbial contamination.

The next stop, mechanical finishing is responsible for polishing the body and the tops of the stoppers to the final dimensions. Besides, it is in this sector that the 1st EE is made, the stoppers arrive as *raça* and are classified in industrial classes. From best to worst we can find the following designations: AA, A, B, C and *apara*.

Classes AA, A and B are sent to the CTC (Cork Treatment Center), the most recent sector of Amorim Cork, S.A. Here, the stoppers are subjected to a treatment that aims to remove TCA, guaranteeing a very close to 100% removal rate. The ones from class C go to the importation sector.

The importation sector and the 2nd EE only differ in the industrial class of stoppers that enter the sector, both consists of two stages. The first is called SVE (Seal Verification System) and separates stoppers into seals and non-seals, with sealing being the ability of the stopper to isolate the liquid inside the bottle from the outside environment. The non-sealing ones are treated as *apara*. The stoppers classified as sealing proceed to the 2nd EE where they will be separated into commercial classes which are, from best to worst, the following: Flower, Extra, Superior, 1st, 2nd, 3rd, 4th, 5th and 6th being that from 4th the stopper is transported to a sector called acquamark that will transform these stoppers into filled stoppers. This process consists in filling the cork stoppers pores with cork powder, glue, water and some chemicals, giving the stoppers a better appearance.

From this moment on, the factory starts to work in a pull system as mentioned above. According to the orders and demands of each client, the stoppers go through a washing process in which the stoppers are cleaned and disinfected with water and chemical agents. In Figure 12 is demonstrated the several types of washing, each one gives a different visual aspect to the stoppers.

Figure 12 - Different washing colors

With the stoppers already in their final dimensions and washed, they are subjected to another electronic selection (3rd EE) in which they are again separated by classes and are also subjected to a more rigorous visual control performed by the process control team that compares the stoppers with a standard sample.

Finally, the stoppers that survive all these segregations head towards packaging sector and then shipped to customers, it is in this sector that this project is focused on.

It is important to mention that the factory uses a MES (Manufacturing Execution System) system that allows the ERP (Enterprise Resource Planning) system to be informed in real time of all the actions carried out on the different sectors of the factory.

4 Analysis and description of the Initial situation

This chapter focuses on the analysis and description of the initial situation of the packaging sector and the X-ray machine. The main problems identified from the information collected on the factory floor are presented and analyzed.

4.1 Packaging sector

This sector is responsible for packing cork stoppers in raffia bags (Figure 14). The stoppers that are packaged come from the 3 EE (previous sector) in containers (Figure 13) that carry a variable quantity of stoppers according to their caliber (Table 2).

Table 2 - Containers capacity by caliber

Caliber (mm)	Capacity (thousand)
45x24	30
45x25	27
45x26	25
49x24	27
49x25	25
49x26	23
54x24	25
54x26	21

Figure 13 - Container

Figure 14 - Raffia bag

All containers from 3EE contain three pieces of information:

- MES tag (Figure 15) that contains the lot number, Item, the quantity of stoppers, the date the tag was created, and the code that identifies it.
- Kanban that indicates which order the stoppers are intended for.
- A sheet of paper placed by the quality controllers that informs whether the lot is approved or not, the reason for rejection, and the next destination.

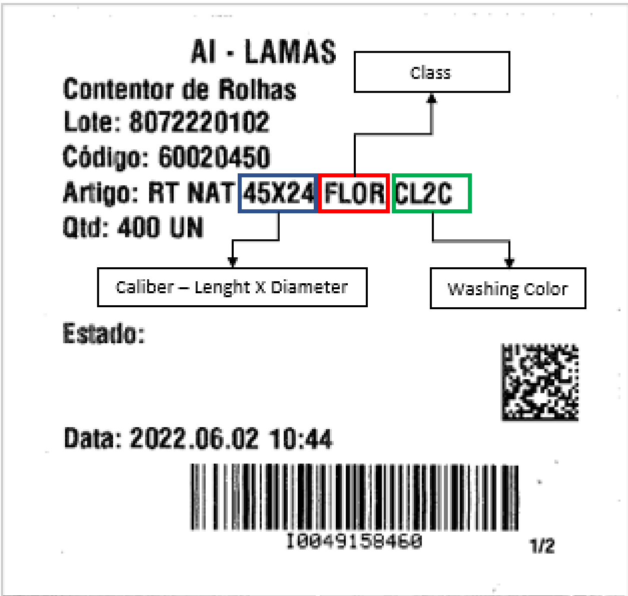


Figure 15 - MES tag

After the 3rd EE, the cork stoppers go through the process represented in Figure 16 in which the cork stoppers are controlled by highly experienced professionals. If in each sample of 100 stoppers a tabulated percentage of critical defects are identified they are forwarded to a machine that uses X-ray technology, only to remove the defects and which served as a prototype of the machine placed in the packaging sector, in other words, it is an intermediate stage for rejected lots before being packaged, after passing through this machine the lot is controlled again. The controller can also fail the corks because they are of poor quality at a visual level, i.e., the cork presents too many pores for that class, in this case, the corks are chosen again at the 3EE, lowering one class. This cycle is repeated until the correct class for the stoppers are found.

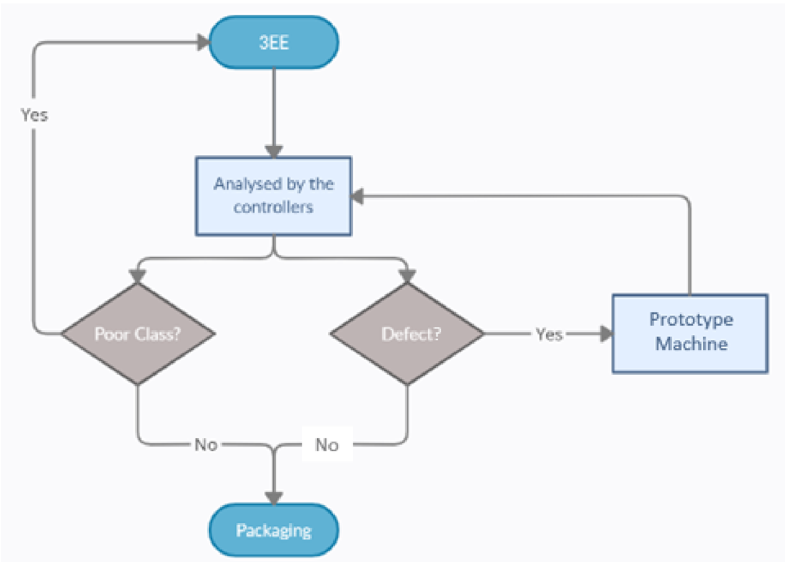


Figure 16 - Flowchart between 3rd EE and the packaging sector

After being approved, the containers are placed in the corridor where they wait to be packed. There is an order list that is updated every day, and the team leader together with the production engineer decides which containers will be packed. After the decision is made, the team leader is responsible for the transportation of the containers to the machine that will pack the cork stoppers.

The operator of each machine has the function of programming the counting machines. This programming indicates the number of stoppers that each bag must contain, normally 5000, the operator must also take into account the number of stoppers that will be removed for the sample, for this, there is a table that relates the quantity of the order with the number of stoppers that must be taken out. After the count is complete, the bags are placed open to be controlled again, and this time the control is done by comparison with an existing sample for each class and item. However, if the order is already partially packed in the warehouse, it is necessary to compare the new bags with the sample taken from the bags in the warehouse.

The approved bags are then stitched together with a tag that identifies them and sent to palletization, where the bags are placed on pallets with the help of two machines that with the help of vibrations position the bags in a more uniform way. When the pallets are complete they are filmed and sent to dispatch.

Initial Layout

The initial layout of the packaging sector is presented in Figure 17 and consists of:

- A new X-Ray machine that was added to the sector in the first week of the project.
- Three counting machines.
- As the bags have a defined quantity of stoppers, it is necessary to have a location to store the leftovers that will be used in future orders.
- An area that contains the samples taken from orders that have been partially packed before.
- Area to place the counted bags coming from each machine awaiting control.
- Three stitching machines.
- Two transport cars.
- Pallet stack to be loaded with the stitched bags.
- Pallet of new bags, where the operators pick up a set of empty bags.
- Control table used by the controller to examine the samples.
- Team leader's desk, where is consulted the order list.
- Garbage containers.

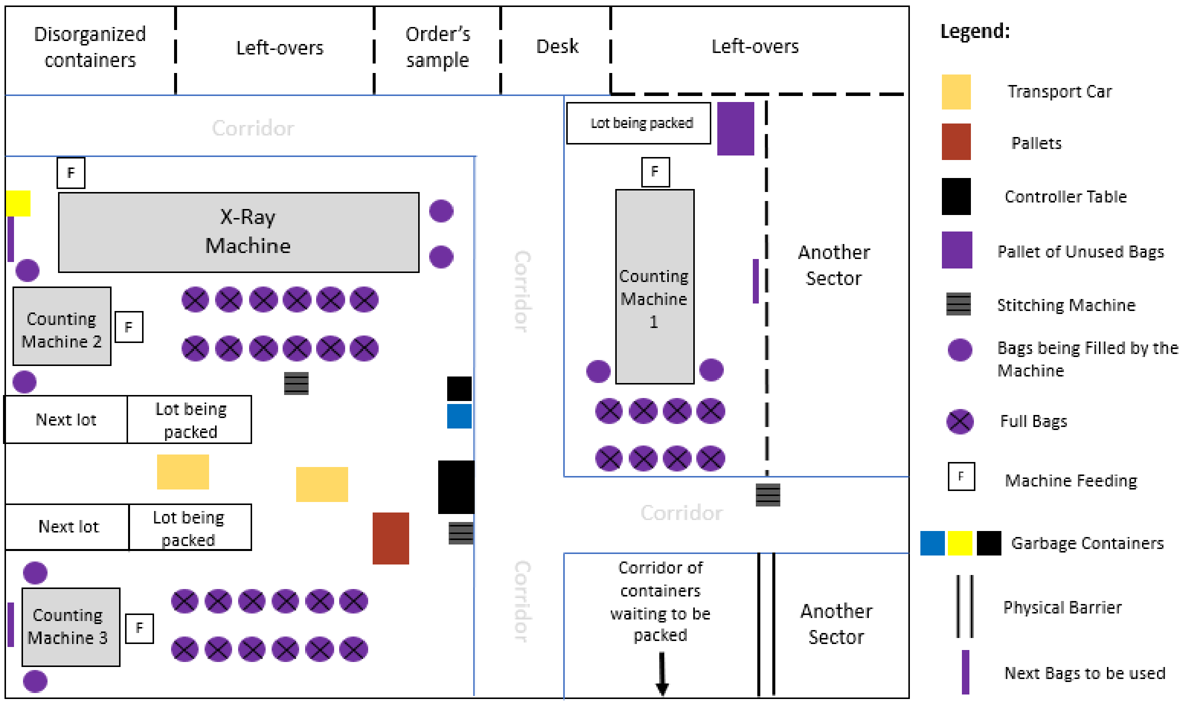


Figure 17 – Packaging sector initial layout

4.2 X-Ray Machine Overview

As previously mentioned, an X-Ray machine was added in order to improve product quality and thus increase customer satisfaction. This sub-chapter aims to describe in detail the initial situation of each sub-process that constitutes the machine, these sub-processes are represented in the diagram of Figure 18.

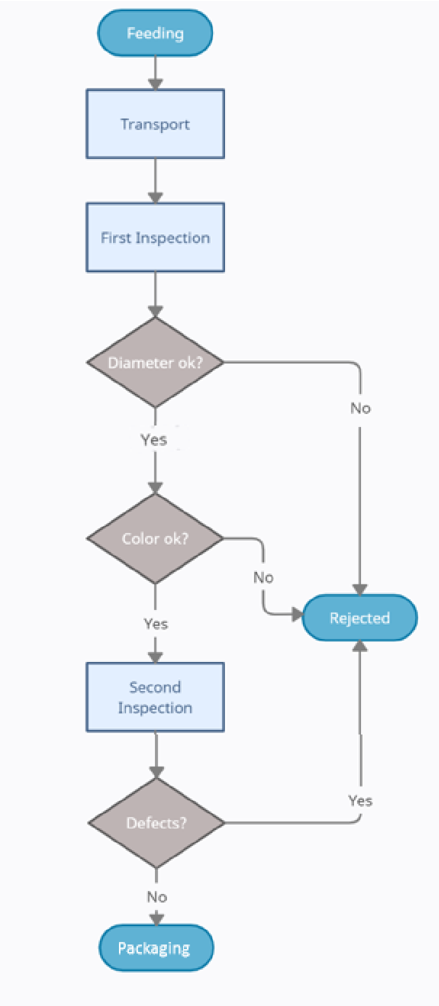


Figure 18 - Flowchart of the X-ray Machine subprocesses

4.2.1 Feeding

The cork stoppers that feed the machine come from containers that are in the corridor waiting to be packed, the operator is provided with a priority table that indicates which lots should be packed.

This planning done by the team leader only takes into consideration the orders with the closest delivery date, not taking into account the setup times associated with the change of lot.

With the chosen lot the operator pushes the container to the feeding conveyor of the machine which has the function of transporting the corks to the hopper of the machine, this equipment is represented in Figure 19.

1. Container Location
2. Conveyor Belt
3. Machine Hopper

Figure 19 - Machine feeding conveyor

The conveyor works at a constant speed feeding the hopper with 1333 stoppers per minute. In Table 3 the two modes of operation of this equipment are described, considering that it is recommended to use the automatic mode to avoid exceeding the capacity of the hopper.

Table 3 - Different modes of operating the conveyor

Operating Mode	Description	Sensors	Output
Manual	The operator can control if the conveyor is on or off	-	-
Automatic	The system is controlled depending on the level of stoppers on the machine's hopper.	Digital Capacitive Proximity Sensor	1 – Detecting stoppers - Conveyor off 0 – Not detecting stoppers – Conveyor on

4.2.2 Transport

The machine is composed of two channels that work in the same way and their cork stoppers distribution is random. After the hopper is loaded with stoppers it is necessary to transport them to the first inspection. This process consists in dividing the stoppers for each channel through an inverted V system, as represented in Figure 20.

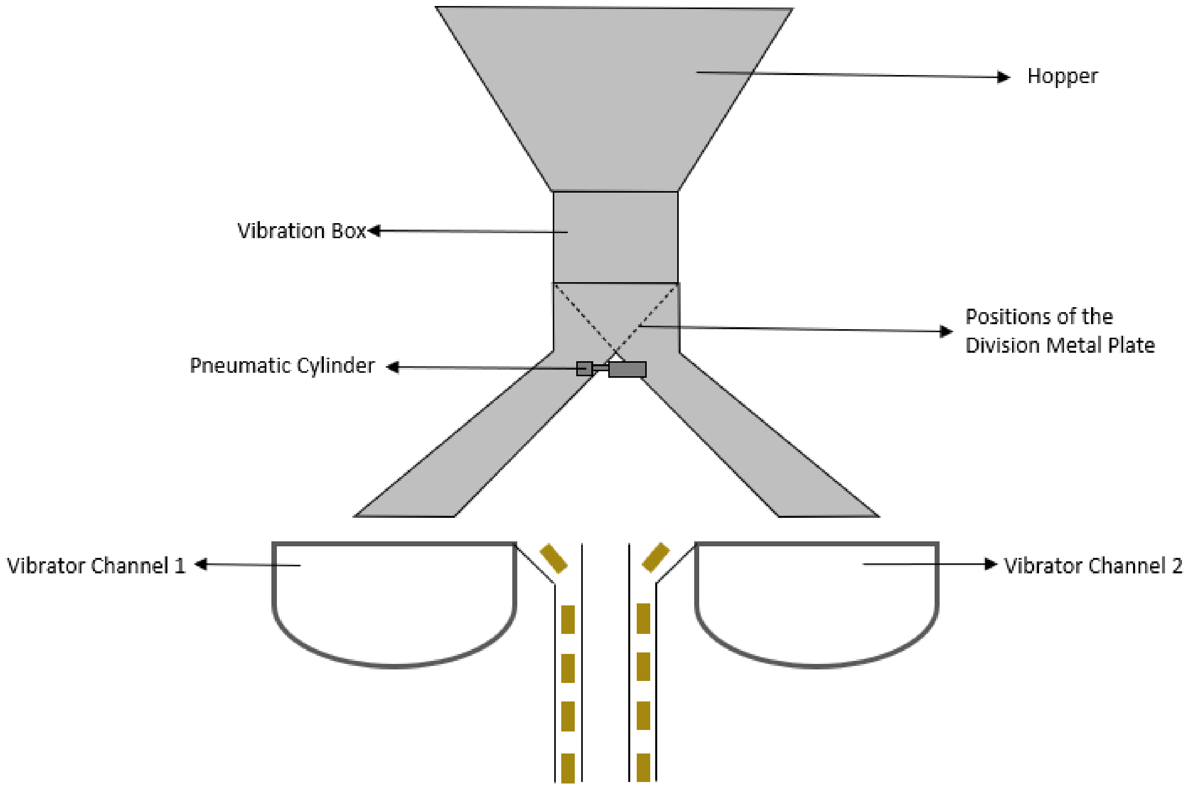


Figure 20 - Transport system illustration

When the machine is switched off, the cork stoppers do not reach the channels, this happens due to the existence of a vibration box under the hopper that prevents the cork stoppers from falling into the vibrators. Each vibrator contains an inductive proximity sensor that detects the position of the vane present in the vibrators. In Figure 21, on the left hand there are enough corks in the vibrator, so the sensor does not detect the vane. The opposite happens on the right hand, where the stoppers no longer touch the vane, which is aligned with the sensor.

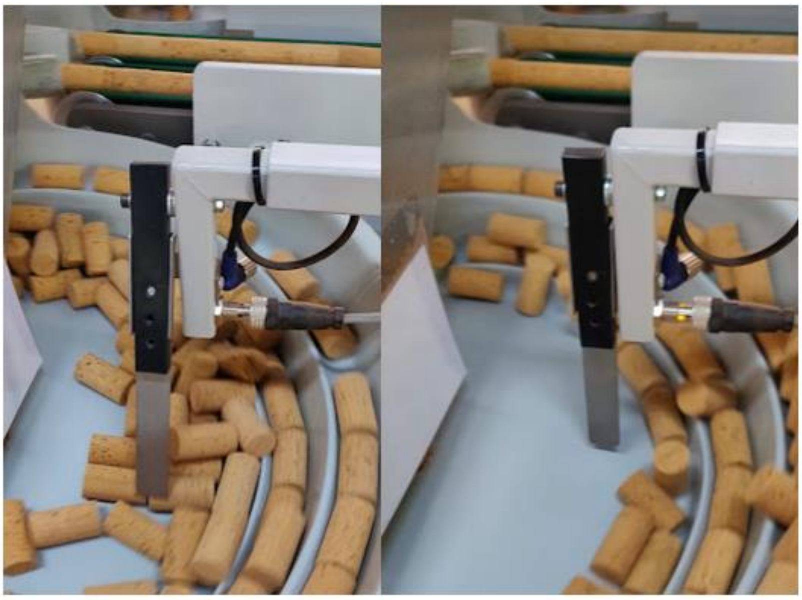


Figure 21 - The two positions of the vane

This sensor provides information to the following actuators in the system:

- Vibration box - Using vibration, it moves the corks to the inverted V system.
- Pneumatic cylinder – It is responsible for switching the metal plate between the two positions represented in Figure 20, in order to feed the vibrator that is requesting stoppers.

The vibrators are responsible for moving the stoppers to the lines of the respective channel, aligning and placing it in the correct position so that their inspection can be done without any problem. The operator can adjust the vibration intensity, the higher this value, more distance the cork stopper will cover.

4.2.3 First Inspection

One of the advantages of including this type of machine in the packaging sector is related to its capacity to remove stoppers of a different caliber and color from the item being packed, in other words, to prevent mixtures from reaching the customer.

This first inspection has as its main objective to avoid this from happening. The analysis of the stopper is done using two sensors in each channel, an RGB color sensor (Figure 22), and a laser beam sensor.

The color sensor allows the detection and classification of the cork stopper based on its color, its characteristics are presented in Table 4.

Table 4 - RGB color sensor specifications. Adapted from [25]

Sensing Distance	Light Source	Response Time	Adjustment
12 ±2 mm	White LED	50 µs	Teaching Method

Figure 22 - RGB color sensor. Adapted from [25]

This sensor has the capacity to memorize two colors, so whenever the lot changes to a different color lot the operator is forced to teach the sensor showing the stopper that must continue the process and the stopper that should be rejected.

The laser beam sensor aims to reject stoppers of different diameter from the item to being packed, this is achieved through a fork-shaped sensor that emits a laser beam, Figure 23, which contains on one side the emitter and on the other side the receiver. If the stopper when passing interrupts the beam, the output of the receiver will be different. Its characteristics are shown in Table 5.

Table 5 - Laser beam sensor specifications. Adapted from [26]

Resolution	Reproducibility	Adjustable Switching Frequency	Sensor Modes
Ø 0.05 mm	0.01 mm	5000 Hz	Standard – General applications; High Resolution – For detection of the smallest objects; Power – Increased function reserve; Speed – Safe detection of fast-moving parts;

Figure 23 - Fork barrier laser beam sensor. Adapt from [26]

The height calibration of this sensor for different diameters is done by the operator through the knobs represented in Figure 24, in this figure it is also possible to observe the color sensor of channel 1.

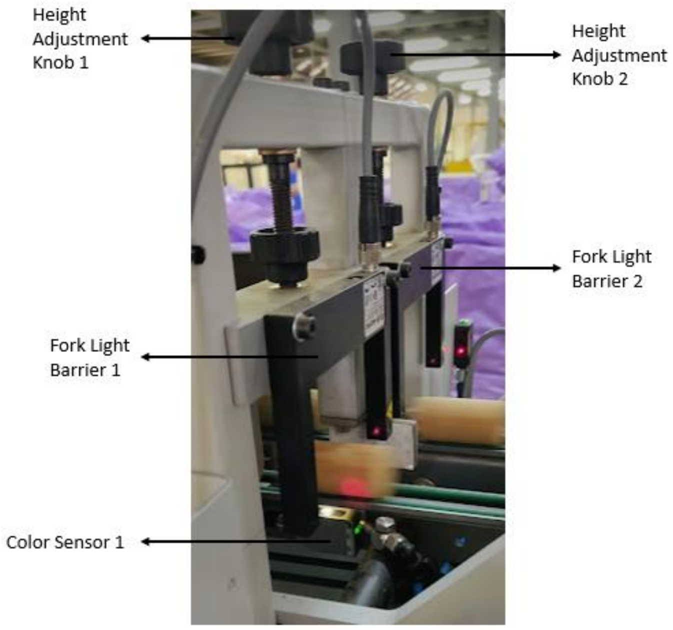


Figure 24 - Sensor's calibration system

The calibration of both sensors is done independently, meaning that whenever the next lot is of another caliber or another color, the operator has to calibrate four sensors (two for color and two for diameter).

4.2.4 Second Inspection

The second inspection is where the stoppers are submitted to an X-ray analysis. The general description of the process can be seen in Figure 25.

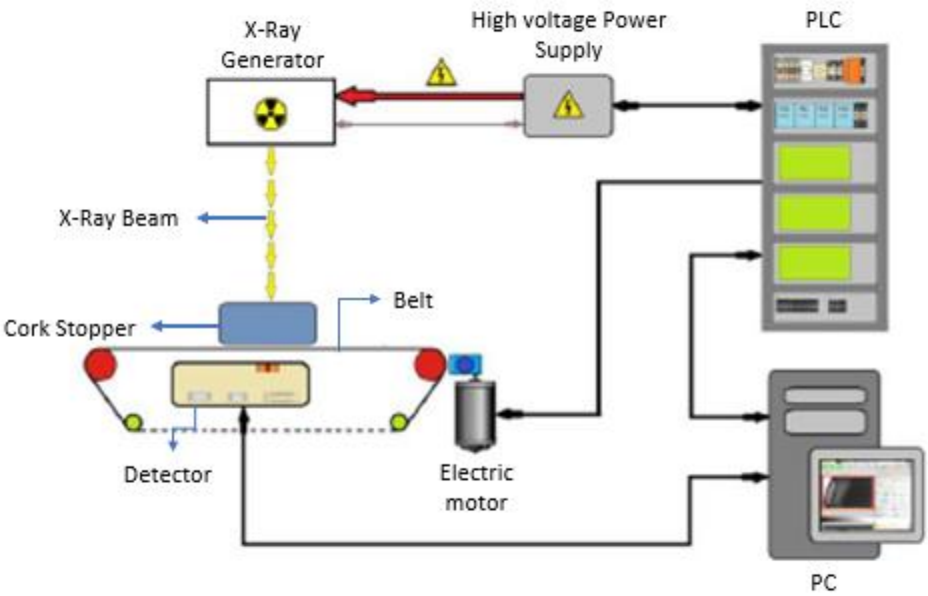


Figure 25 - X-ray machine diagram. Adapted from [23]

The operation of this system can be divided into three stages, the emission of X-rays, the control of that same emitter, and the detection of X-rays[23].

The X-ray emitter is a metal and lead box where the X-ray tube is installed. It is made to minimize the dangers of emitting radiation to the outside. The X-Rays are emitted with the same intensity in all directions, but only those that pass through the collimator are useful.

The X-Ray generator control module is responsible for controlling several essential factors to obtain a sharp image in order to facilitate the implementation of the image analysis algorithms, such as the power supplied to the emitter and the speed of the belt [23].

The most important factor is the power supplied to the X-ray emitter, this value determines the image contrast and can be modified by changing the working voltage and current. The higher the working voltage, the higher the beam penetration power, and the higher the working current value, a higher number of photons will be produced increasing the illumination of the captured image [23].

The third and last stage, X-ray detection, is achieved through a detector consisting of a line of silicon diodes, illustrated in Figure 26, which are coated with a material that converts the X-ray power into light. This detector goes through a calibration phase before being able to receive the product, in the first phase the X-rays are turned off so that the detector recognizes the signals from each diode establishing that value as zero, that is, the darker the image can be since no X-rays are reaching the detector and the diodes emit their minimum light. In the second phase, X-rays are turned on and the detector recognizes the signals from the diodes and establishes that signal as the maximum level of light that can be emitted by the diodes. This scale between the darkest tone (black) and the lightest tone (white) is divided into 256 parts, so when the product passes it is possible to know how much energy was absorbed by it. For example, if the product absorbs half of the radiation, the other half will reach the diodes which will produce a signal equivalent to the value of 128 (middle tone in grey). This detector is synchronized with the conveyor speed set at 30 meters per minute [23].

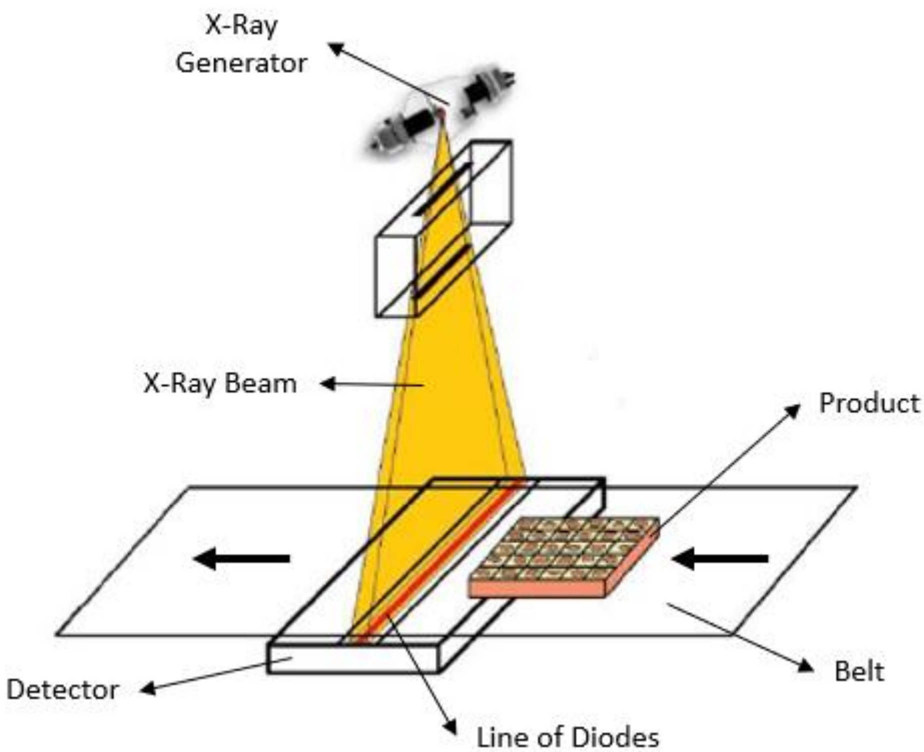


Figure 26 - Product detection illustration. Adapted from [23]

The image capture is taken line by line by the detector, which are then joined together to form the complete and final image of the product, as shown in Figure 27.

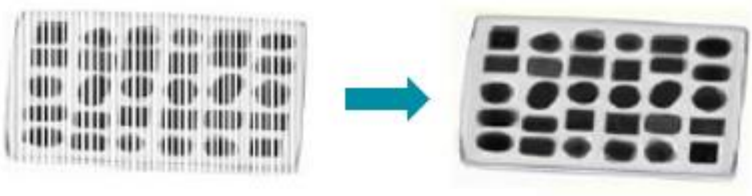


Figure 27 - Image composition method. Adapted from [23]

After obtaining the final image, the value of the color scale is given to each pixel, Figure 28, thus forming a data matrix that will allow the application of the algorithm and the detection of anomalies in the analyzed product [23].

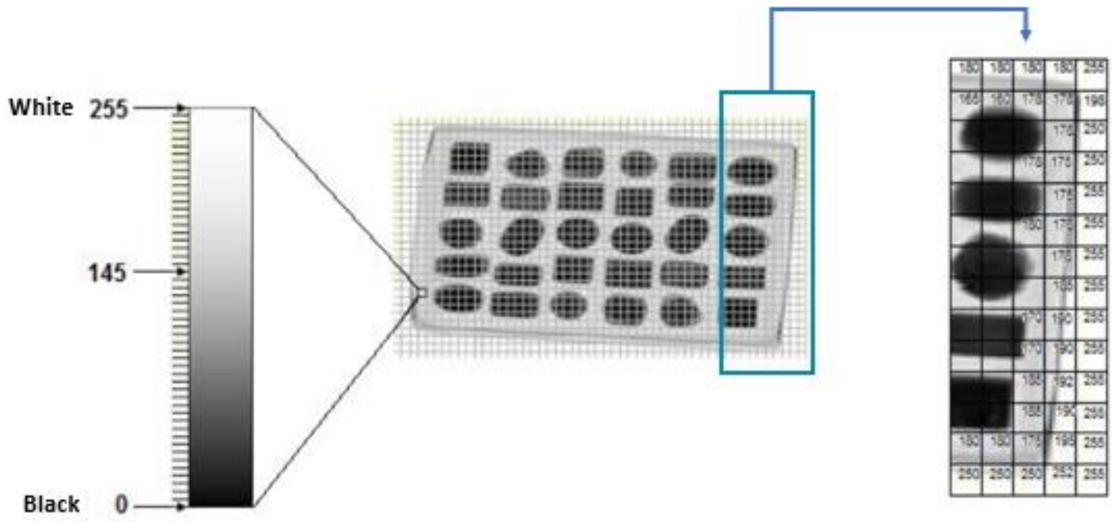


Figure 28 - Formation of the data matrix. Adapt from [23]

Through the data matrix, the histogram is obtained, this histogram is a graphic representation of how many times each value of the black and white scale is repeated. This graphic allows the verification of whether the energy set is appropriate for the product under analysis. In Figure 29 two examples of histograms are given, one of them in which the energy is too high, where the radiation easily crosses the product, generating a histogram very deviated to the right (light), and in the other is too low, where exactly the opposite happens (dark) [23].

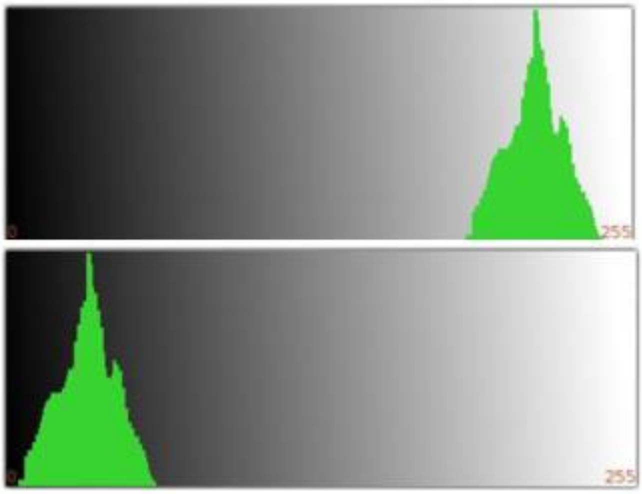


Figure 29 - High and low energy histogram. Adapted from [23]

In Figure 30 is represented an X-ray image of a cork stopper analyzed by the machine with its respective histogram, the energy supplied to the X-ray generator is adequate since the histogram is in the center of the scale [23].

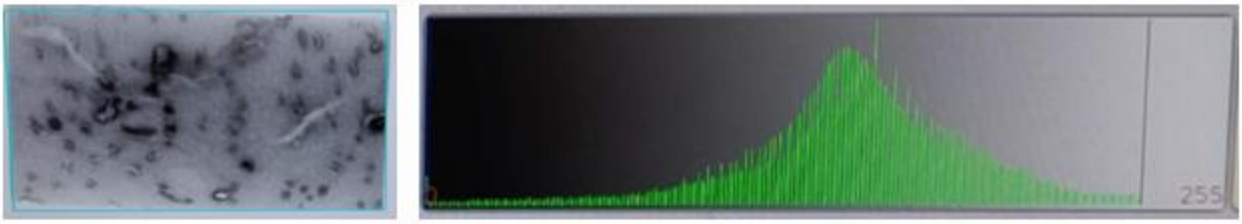


Figure 30 - Stopper X-ray image and respective histogram.

The voltage and current values used are shown in Table 6.

Table 6 – Working voltage and current

Voltage	Current
20 kV	2 mA

The function of this inspection is to eliminate the following natural cork defects:

- Flathead Oak Borer (BH)
- Nail
- Clay

Flathead Oak Borer larvae feed off cork, developing galleries in it and leaving behind their excrements, covering the walls. When examined on an X-ray image, these excrements increase the density of the stopper and appear as darker regions, as illustrated on Figure 31.

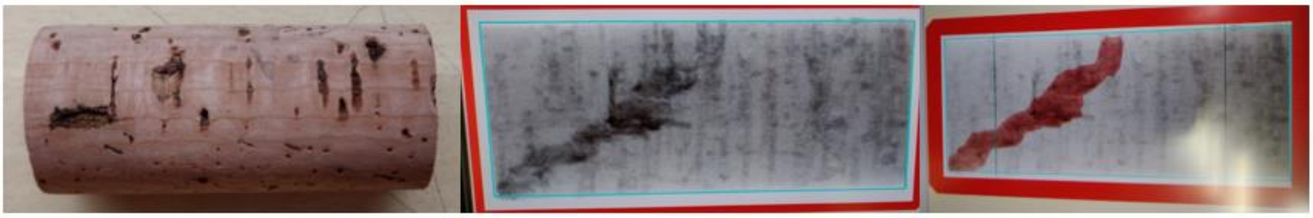


Figure 31 – Cork stopper with BH and respective X-ray image

Occasionally, small segments of the cork's exterior layer, known as coast, become enclosed in the inner layers, resulting in a phenomenon known as nail, Figure 32. This type of defect also increases the density of the stopper.

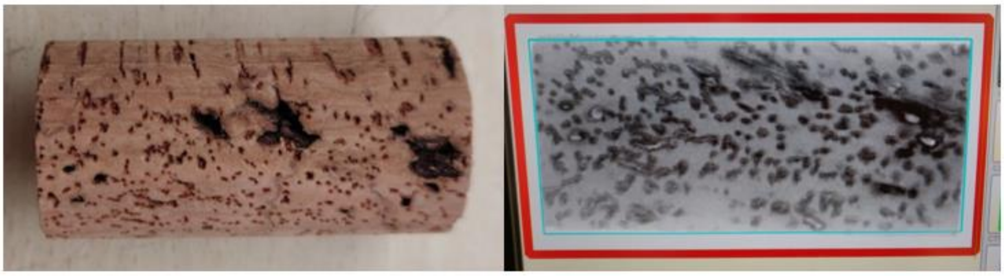


Figure 32 - Cork stopper with nail and respective X-ray image

Lastly, clay (Figure 33) is another defect that also confers higher density to the stopper, appearing more frequently along the body than the previous defects presented.

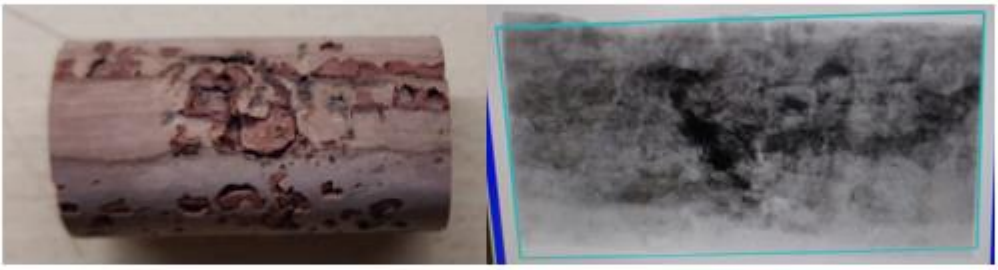


Figure 33 - Cork stopper with clay and respective X-ray image

Since all these defects have the effect of increasing the density of the stopper, it is up to the applied algorithm to distinguish between them through parameters such as area, tilt, length, and width.

In addition to defects, this inspection is also able to detect short and long stoppers, thus completing its capacity to avoid mixtures, as stoppers of different diameters and colors are removed in the first inspection.

4.2.5 Packaging

After the second inspection, the stoppers are divided into five out of the six existing outlets in each channel, with the first destined for short or long stoppers, the second for stoppers with nail, the third for stoppers with clay, the fourth for stoppers that present BH and finally, the fifth, which receives the stoppers considered good.

Outputs 5 and 6 are assigned to a dual-channel conveyor, one channel for each output. This equipment, represented in Figure 34, is responsible for transporting the stoppers to the bags. At the beginning of the project, only output 5 was functional, which means that only one channel of each conveyor was being used.

Figure 34 - Conveyor responsible to transport the stoppers to the bags

4.3 Inicial Indicators

In this phase, the state of the indicators at the beginning of the project will be presented. The most relevant indicators are the OEE, the percentage of lots with mixtures, and the lead-time between the 3rd EE and the packaging sector for rejected lots after the 3rd EE.

4.3.1 OEE

This indicator takes into account all losses that have a direct impact on the efficiency and effectiveness of the machine. In the theoretical context of OEE, the first step is to identify the planned stops, but in this case, the planned stops will be included in the unplanned stops since at the end of the project it is intended that the machine will continue to work during the lunch and snack break.

Thus, Planned Production Time will match Shift Time.

$$Planned\ Production\ Time = Shift\ Time = 8\ h$$

For the calculation of the 3 categories of this indicator, the six big losses presented in section 2.3.5 (page 14) were taken into consideration and the unplanned stoppage time was identified and measured. This data was collected by monitoring an entire 8 hour shift. Tables 7 and 8 present the unplanned stoppages, as well as their duration.

Table 7 - Unplanned Stops

Unplanned Stops		
Index	Stop	Description
1	Full Bag	When a Bag in each channel gets full, the machine stops and only gets back working when the operator removes the bag and turns the machine on.
2	Stuck Stopper	Stoppers get stuck at the entrance of the X-Ray Box.
3	Color and Diameter Sensor Calibration	Stop due to the calibration of the color and diameter sensor. Mean of 3 calibrations/shift
4	Cleaning for next Lot	Preparing the machine to receive the next lot. Can't remain any stopper from the previous lot on the machine. Mean of 3 lots/shift
5	Lunch	When the operator leaves to have lunch and the machine keeps working until the first bag gets full this stop takes into account the period between the moment when the first bag is full and the moment the operator return from the 30 min break and turns on the machine.
6	Snack break	When the operator leaves to have a snack and the machine keeps working until the first bag gets full this stop takes into account the period between the moment when the first bag is full and the moment the operator return from the 10 min break and turns on the machine.

Table 8 - Unplanned stops duration

Measurement of unplanned stops						
Number of occurrences	Stop 1 (s)	Stop 2 (s)	Stop 3 (s)	Stop 4 (s)	Stop 5 (s)	Stop 6 (s)
1	23	32	228	279	1020	331
2	36	41	257	301		
3	38	25	225	295		
4	42	22				
5	21	26				
6	25	35				
7	29	27				
8	28	30				
9	39	32				
10	41	40				
11	32	21				
12	25	23				
13	24	39				
14	21	38				
15	36	24				
16	37					
17	22					
18	19					
19	29					
20	37					
21	35					
22	32					
23	31					
24	25					
25	40					
26	29					
27	35					
28	21					
29	31					
30	29					
SubTotal (s)	912	455	710	875	1020	331
Total (s)	4303 = 1,20h					

By subtracting the duration of the unplanned stops from the Planned Production Time we obtain the Run Time.

$$Run\ Time = 8\ h - 1.20\ h = 6.8\ h$$

After obtaining the values of Run Time and Planned Production Time, using equation 2 presented in section 2.3.5.1 it is possible to calculate the first category of OEE, the machine availability.

$$Availability\ (A) = \frac{6.8}{8} \times 100 = 85.00\ \%$$

In this research shift, the machine production was 150 thousand stoppers in a working time of 6.8 h. Taking into account that the ideal cycle time is 35 thousand stoppers per hour, value established by the machine manufacturer. From equation 3 the second category, performance efficiency, was calculated.

$$Performance\ Efficiency\ (P) = \frac{0.103\ \times 150000}{6.8 \times 3600} \times 100 = 63.11\ \%$$

To obtain the last performance category, quality, as this machine is an inspection machine and not a product manufacturing machine, equation 4 (section 2.3.5, page 13) would lead to an error in the calculation of this category, as if a lot with 50% of stoppers with BH entered the machine and the machine removed those 50%, it would have a quality of 50% while it did an excellent job, removing all the cork stoppers requested.

In short, it will be analyzed if the stoppers that the machine rejects are well rejected and if the stoppers that the machine does not reject are approved to be sent to the client. The following four factors were established:

1. Ratio of cork stoppers rejected that actually contain BH.
2. Ratio of false rejections (rejected cork stoppers that do not contain BH).
3. Ratio of total cork stoppers rejected from the lot.
4. Ratio of approved lots in the visual control done after going through the machine.

Therefore, the third category is calculated using the following equation:

$$Rate\ of\ quality\ (Q) = (1 - Factor\ 1 \times Factor\ 2 \times Factor\ 3) \times (1 - Factor\ 2 \times Factor\ 3) \times Factor\ 4 \quad (5)$$

The first three factors were calculated using the data presented in Table 10, where a sample of 1100 stoppers with 50 BH (Table 9) stoppers was analyzed in the machine three times.

Table 9 - Sample constitution

Sample	
Total Stoppers	BH
1100	50

Table 10 - Experience results

Rejected Stoppers				
	1st analysis	2nd analysis	3rd analysis	Average
BH	37	36	38	37
False Rejections	7	4	12	8
Total Rejections	44	40	50	45

Using the data in Table 10 and the following equation the first factor can be calculated.

$$Factor\ 1\ = \frac{BH\ Rejected}{BH\ Sample} \times 100 \tag{6}$$

Given the equation 6:

$$Factor\ 1\ = \frac{37}{50} \times 100 = 74.00\ \%$$

The second factor is calculated according to the following equation:

$$Factor\ 2 = \frac{False\ Rejections}{Total\ Rejections} \times 100 \tag{7}$$

Where the numerator represents the stoppers that were rejected and did not contain BH and the denominator represents the total number of stoppers that were rejected.

Thus, using the equation 7:

$$Factor\ 2 = \frac{8}{45} \times 100 = 17.78\ \%$$

The third factor is calculated by dividing the number of rejected stoppers by the total number of stoppers in the sample. This calculation is done through the following equation:

$$Factor\ 3 = \frac{Total\ rejections}{Sample\ Total\ stoppers} \tag{8}$$

So, throught the equation 8:

$$Factor\ 3 = \frac{45}{1100} = 4.09\ \%$$

Finally, the fourth factor is obtained by dividing the number of lots approved during the bag-to-bag control carried out by the quality controller by the total number of lots controlled. This factor allows the quality of the stoppers considered good to be evaluated. The value can be calculated by the following equation:

$$Factor\ 4\ = \frac{Approved\ Lots}{Total\ Lots} \times 100 \tag{9}$$

Using equation 9:

$$Factor\ 4\ = \frac{184}{200} \times 100 = 92.00\ \%$$

Having said this, the Rate of Quality was calculated using equation 5:

$$Rate\ of\ Quality\ (Q) = (100 - 74.00 \times 17.78 \times 4.09) \times (100 - 4.09 \times 17.78) \times 92.00 = 90.83\ \%$$

In conclusion, the equation 1 was used to determine the efficiency of the machine.

$$OEE = \ 85.00\ \times 63.11\ \times 90.83 = 48.72\ \%$$

4.3.2 Mixture Ratio

This is an indicator that allows the quality of the product to be evaluated by measuring the percentage of lots that were detected with mixture. The graph shown in Figure 35 shows the percentage of lots with mixture before the integration of the X-ray machine.

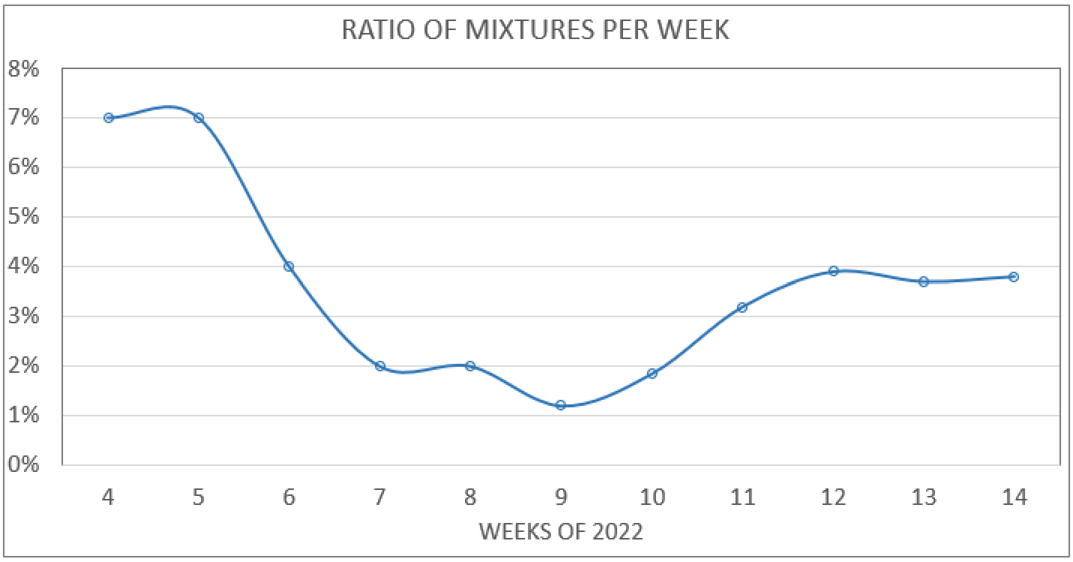


Figure 35 - Ratio of mixtures per week

The only way to detect mixtures until the installation of the machine was during the visual control that is done bag by bag by the quality controller. A mixture is a lot that contains one or more stoppers of a different caliber or color from the item of the order. For example, the order is 45x24 stoppers and a 45x25 stopper is found.

A single cork with a different caliber in an order of 100 thousand corks may generate a complaint from the client, as if the mixed cork presents a larger diameter, it will certainly break the bottle during bottling, causing an unexpected loss to the client. If the cork presents a different color, at a visual level, it will not allow the client to sell the bottle. Due to these factors, this is an indicator highly valued by the company.

During weeks 4 to 14 of 2022 on average 3.6% of the lots had mixture and it is expected that after the integration of the X-ray machine there will be a reduction of at least 30 %.

4.3.3 Leadtime for rejected Lots

Leadtime of a rejected lot between 3rd EE and packaging before the implementation of the X-Ray machine was 36 hours as represented in Figure 36.

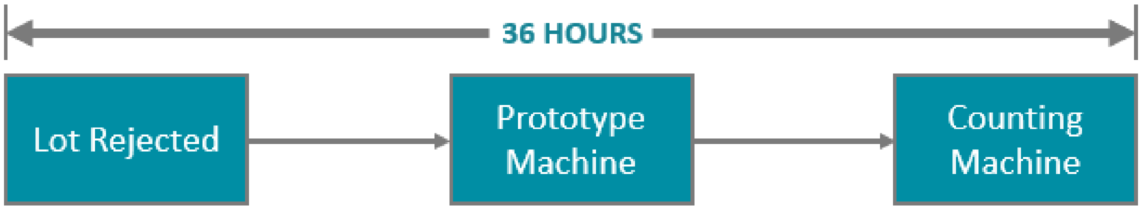


Figure 36 - Lead time diagram

The collection of this data was done by following rejected lots with destination to the prototype machine from the moment they left the 3rd EE until they were packed in the counting machine. This follow-up was done with the help of the MES software that records the date and time of the movements of all containers. At the end of the project, it is intended that this indicator shows a 30% reduction.

4.4 Problems Identified

Table 11 presents a summary of the problems identified, to which more relevance will be given in this dissertation. These problems are divided into three categories: Sector, Machine, and Management.

Table 11 - List of problems identified

	PROBLEMS	DESCRIPTION
SECTOR	Sector organization	No identification of the sector's components; Lack of places to store equipment and materials; Unnecessary distanced covered by the operators; Unnecessary distanced covered by the controller.
MACHINE	Only one output for the approved Stoppers	There is only one output working of two available for the approved stoppers.
	Continuous feeding of the vibrator even when it is turned off	The feeding system keep feeding the vibrator that is off, causing the system to get clogged and not letting the metal plate to move.
	Problems with the pneumatic blow	When the sensor informs the system that the stopper must be rejected by the diameter or color the pneumatic blow that reject the stopper causes the movement of the belts derailing stoppers and lifting the previous ones provoking false rejection on the diameter sensor.
	Conveyor cracking stoppers	The conveyor that is responsible to transport the stoppers to the bag was cracking stoppers.
	Ditch under the conveyor accumulating stoppers	The conveyor grab stoppers from previous lots that accumulate in the ditch causing mixtures.
	Diameter's sensor is only capable to reject diameters above or below the correct diameter	Sensor is not capable of rejecting stoppers with the diameter 26mm and 24 mm when the correct diameter is 25. The operator has to decide which one wants to reject.
MANAGEMENT	High Setup Time	Not planning the next lot in order to reduce setup times; Long diameter's sensor setup.
	Standard work	Inexistence of a work standard; Lack of operator training; Missing information due to shift work;

5 Development and implementation of proposed improvements

In this chapter, the development of each improvement action is presented in detail, with the aim of eliminating the waste linked to the problems described above.

5.1 Sector

At the beginning of the project, the packaging sector presented a lot of disorganization, without defined locations for the components used in the sector. This sub-chapter explains all the actions carried out to organize and optimize the areas of the packaging sector, in order to reduce as much as possible the distances covered by the quality controller and the operator. For this purpose, it was used the 5S tools and the spaghetti diagram to detect the unnecessary movement of employees.

The spaghetti diagram, represented in Figure 37, shows two movements made by the operators and one movement made by the controller at the beginning of the project.

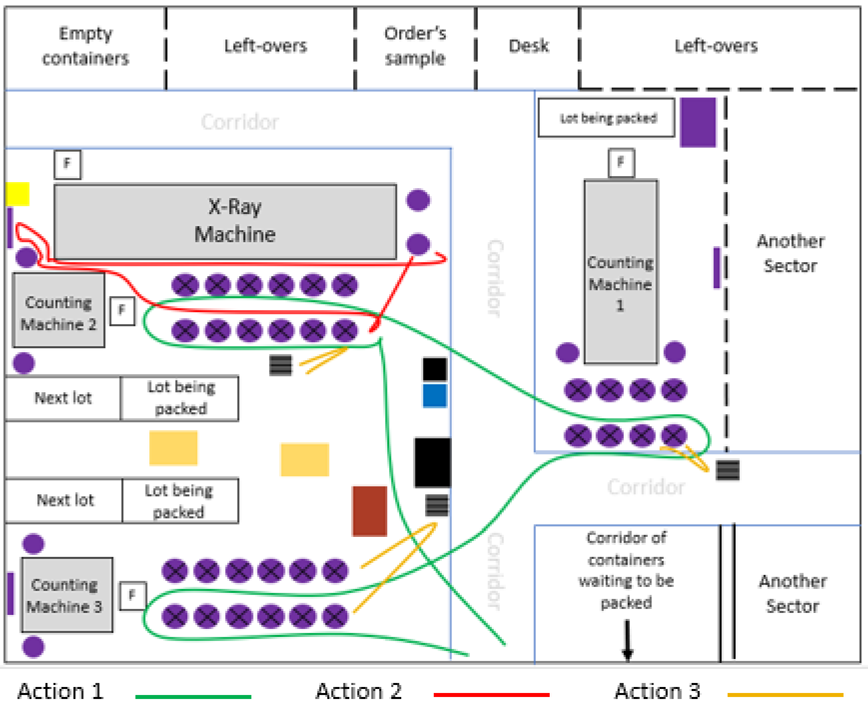


Figure 37 - Initial layout spaghetti diagram

Action 1: Movement made by the quality controller to control all the bags that exist in the sector.

Action 2: The movement made by the X-ray operator when it is necessary to remove the full bag, fetch the empty bag, and place it in the holder.

Action 3: The movement made by the operator of each machine to stitch the bags. The operator drags bag by bag to the respective stitching machine.

Therefore, the first phase consisted of the identification of all the items present in the area that were not being used and did not add value to the actions carried out by the employees in the sector.

With the addition of the X-Ray machine, counting machines 1 and 2 were no longer used. Machine 1 was very old and was very susceptible to getting stoppers stuck and causing mixtures, so it was completely removed from the sector. Machine 2 could not be used at the same time as the X-ray as there was no space to place the bags produced by both machines. The empty containers area was also removed because there was already an area for empty containers, they were only there because the other area was full. Figure 38 graphically represents what was removed from the sector throughout the project.

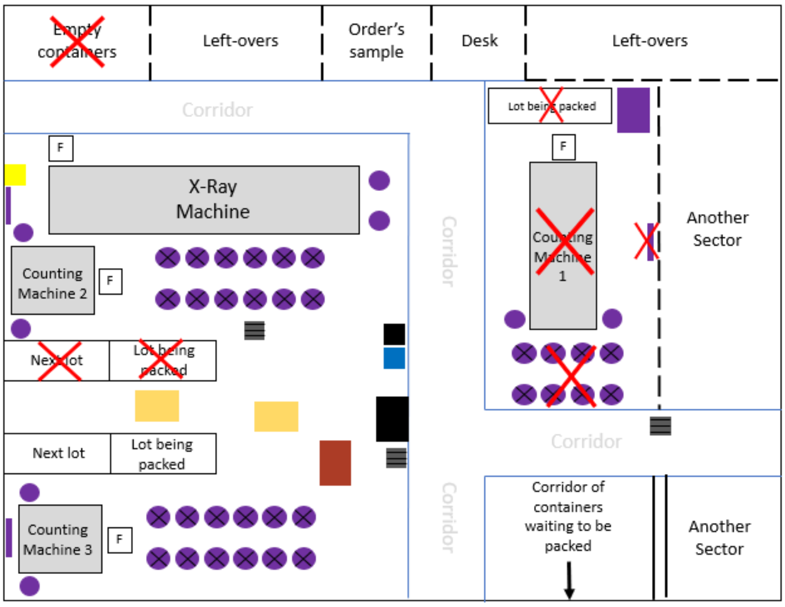
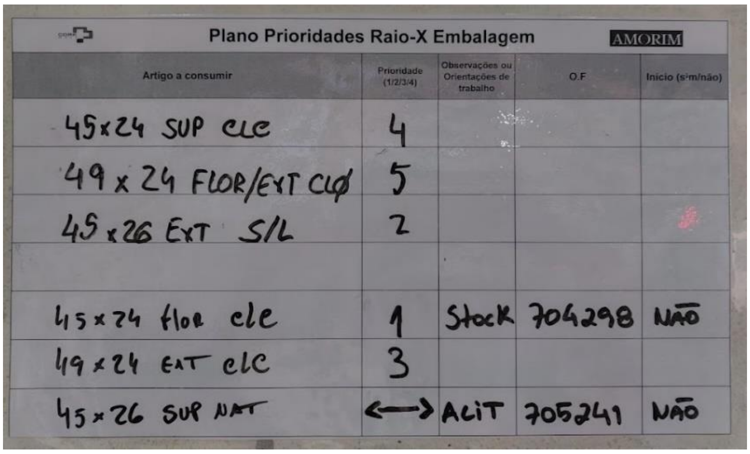


Figure 38 - Components removed from the sector

After identifying what was necessary to remove, a list of essential equipment, materials and tools for the X-ray machine was created. This includes:

- <u>Caliper</u>: For the operator to measure the stoppers to verify the existence of mixtures.
- <u>Production planning Sheet</u>: For the operator to know which lot is entering next, the sheet is filled by the production planner (Figure 39).



Plano Prioridades Raio-X Embalagem AMORIM

Artigo a consumir	Prioridade (1/2/3/4)	Observações ou Orientações de trabalho	O.F	Inicio (s/m/não)
45x24 SUP CLC	4			
49 x 24 FLOR/EXT CLØ	5			
45x26 EXT S/L	2			
45x24 flor clc	1	Stock	704298	NÃO
49x24 EXT clc	3			
45x26 SUP NAT	⟷	ACIT	705241	NÃO

Figure 39 – Production planning sheet

- Detected mixtures sheet: For the operator to fill when a mixture is detected (Figure 40).

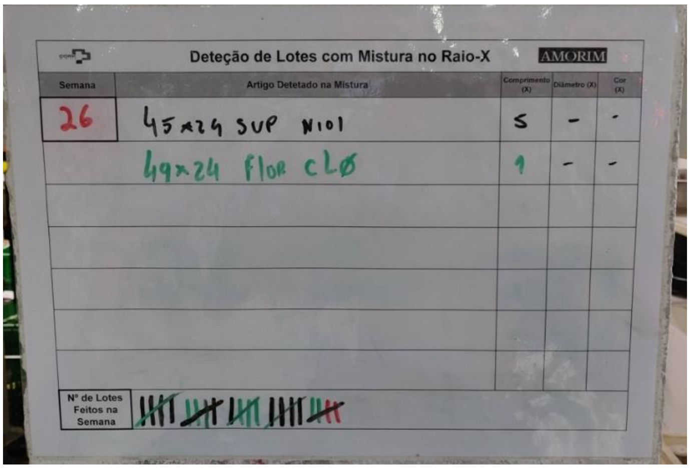


Figure 40 - Detected mixtures sheet

- Cleaning Cloths: For Cleaning the machine and erase what is necessary on the sheets.
- Sensor Calibration and test Stoppers: Stoppers to calibrate and then test if the sensors are well calibrated.
- Color sensor calibrations tool: Tool for the calibration of the color's sensor.
- Markers: Fill the sheets.

It was necessary to create a location to store all these materials and identify them with labels, a shelf was made and fixed to the wall next to the machine, represented in Figure 41.

Figure 41 - Shelf to store the equipment, materials and tools

With all the equipment available for the continuous operation of the machine, the sector was organized and locations were defined and identified for all the components in order to standardize the movement of the employees. In Figure 42 it is represented the final layout of the sector.

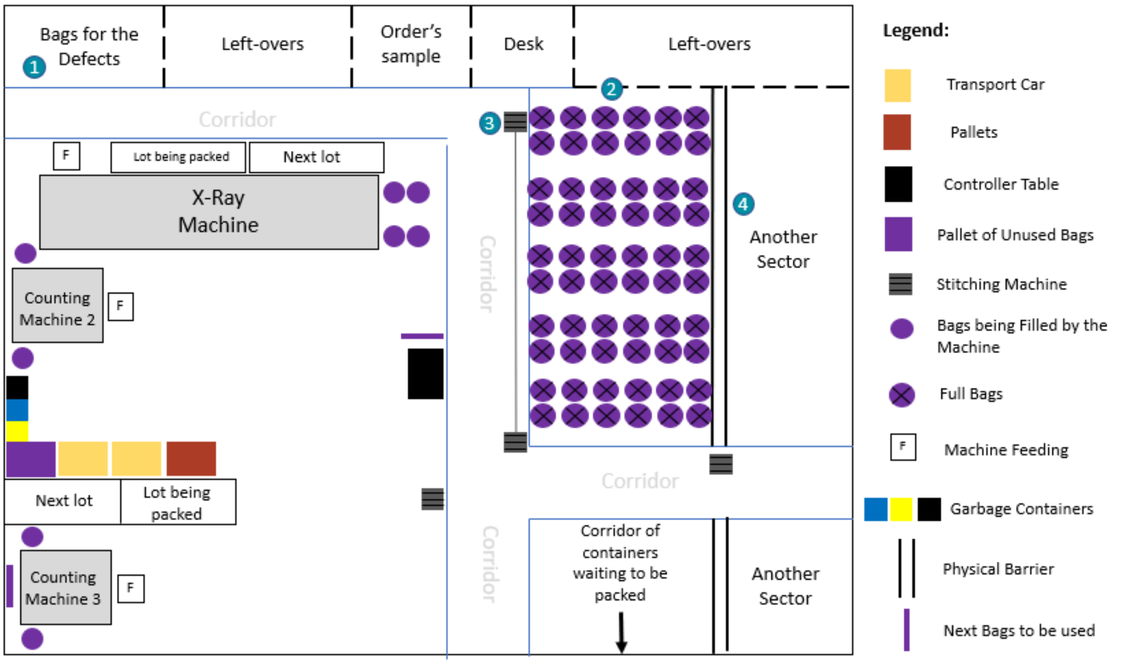


Figure 42 - Sector's final layout

Comparing this layout with the initial layout it is possible to notice four main differences, numerated in Figure 42:

1. <u>Bags for defects</u>

As previously mentioned, in the packaging sector stoppers were only counted, meaning that all stoppers were packed. The addition of this machine requires reserving an area to place the defective stoppers rejected by the machine. Figure 43 shows this area of the sector and the information plates placed in each bag.

Figure 43 - Zone for the defective stoppers and plate example

To simplify the operator's action, the bags have different colors, where the orange ones are for stoppers 49 mm long and the green ones for stoppers with a length of 45 mm. In addition, several calibers, defects, and washings are grouped in the same bag, thus reducing the total number of bags and reducing the chances of cork stoppers being inserted in the wrong one. The plate also contains the destination that has to be given to that bag after being completed.

2. <u>Only one place for the full bags</u>

The space made available by the removal of the counting machine 1, was used to place all the full bags of both machines (Figure 44) facilitating the work of the quality controller. In this way, the area around the machines is also ampler giving the operator greater freedom of movement and whenever the team's leader decides to use the counting machine 2 there is already space available.

Figure 44 - Full organized on the defined location

3. <u>Rail guided Stitching machine</u>

A stitching machine was inserted in a guide (Figure 45) that allows the operator to move the stitching machine along the entire space destined for the full bags, in this way the machine is moved to the bags and not the other way around, thus reducing the load moved by the operators.

Figure 45 – Rail guided stitching machine

4. <u>Physical Barrier</u>

The physical barrier (Figure 46) placed is due to the fact that in the sector adjacent, cork stoppers are dumped into containers right beside the full bags, and the possibility of cork stoppers falling into the bags is very high, causing mixtures even before the bags are stitched.

Figure 46 - Physical barrier separating the bags from cointainers from the other sector

Also, in Figure 42 it is shown that the already existing components have been organized. Figure 47 shows the sector organized as suggested in the final layout.

Figure 47 - Each component on its identified location

Finally, with the sector in its final state, a spaghetti diagram was again drawn up to check the movements after the layout changes. In the diagram of Figure 48, the same actions previously referred are represented.

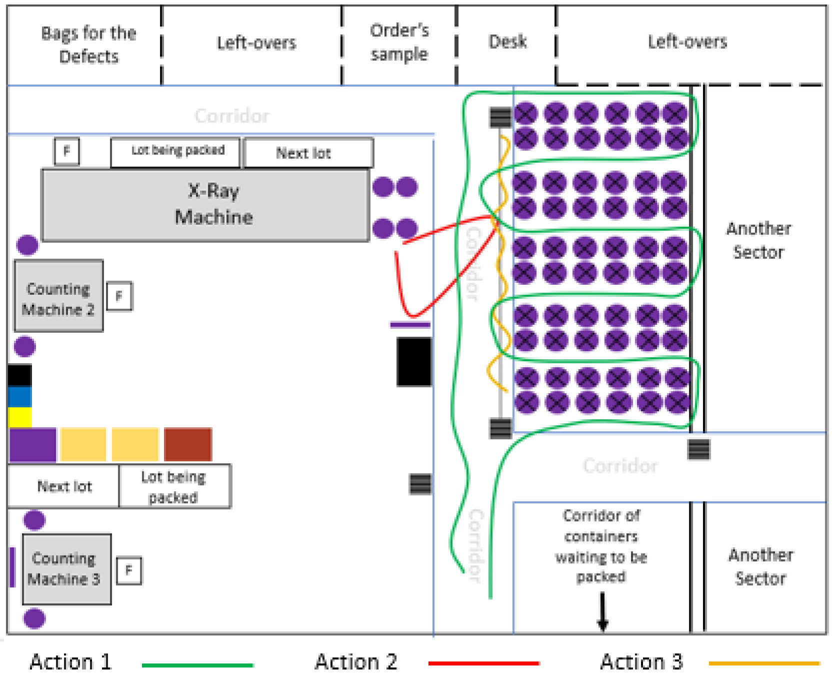


Figure 48 - Final layout spaghetti diagram

Analyzing the two spaghetti diagrams, it is concluded that the distance traveled in actions 2 and 3 are smaller in the final diagram thus reducing the time to complete the action. Regarding action 1, it is the action that presents more gain in space made available in the sector, and the distance covered between lots by the controller was substantially reduced.

5.2 Machine

In this subchapter, all the implementations and improvements proposed to the problems found in the machine operation will be presented. These problems are associated with the unplanned losses presented above and the small stoppages that are solved by the operator that have an influence on the performance category in the OEE calculation.

5.2.1 One output available for the approved stoppers

As mentioned before, the approved stoppers are expelled from the machine through outputs 5 and 6. However, output 6 was not working until halfway through the project. Together with the company responsible for the PLC programming it was proposed to find a viable solution to this problem that stops the machine at each full bag. According to Table 8 (section 4.3.1), there are three unplanned stops (1, 5, and 6) associated with the filling of the bags, and two of them are the ones that take more working time from the machine.

It is intended that when filling a bag at output 5 the machine switches to output 6 and while output 6 fills another bag the operator has already removed the full bag from output 5 informing the machine that output 5 is available again, this way the machine never stops working.

The feeding and transport system to the first inspection described in sections 4.2.1 and 4.2.2 is controlled by a PLC distinct from the one controlling the rest of the machine. The communication between the two PLCs at the start of the project is shown in the diagram in Figure 49.

Figure 49 - Initial communication diagram

Using a real situation to describe the diagram, when the count reaches a defined value, usually 5000, the PC gives the information to the PLC that controls the X-Ray through an RS-232 type connection to turn off the X-Ray system, which communicates through electrical impulses with the feeding PLC, which means a digital signal is transmitted, when the signal is 0 the feeding system is off and when it is 1 the feeding system is on. The machine only starts working again when the operator removes the bag, clears the output count through the HMI (Human Machine Interface), and turns on the X-Ray, which would send a signal 1 to the feeding system that turns on and feeds the machine again.

The X-ray PLC is considered a critical component and should not be modified according to the machine manufacturer orders, due to this hindrance a solution was developed to overcome this problem and to allow the feeding system to be informed about which channel it should put to work depending on which bags are full and which full bags have already been removed by the operator. The solution developed was to make the feeding PLC communicate with the machine PC through a Modbus communication protocol (Figure 50).

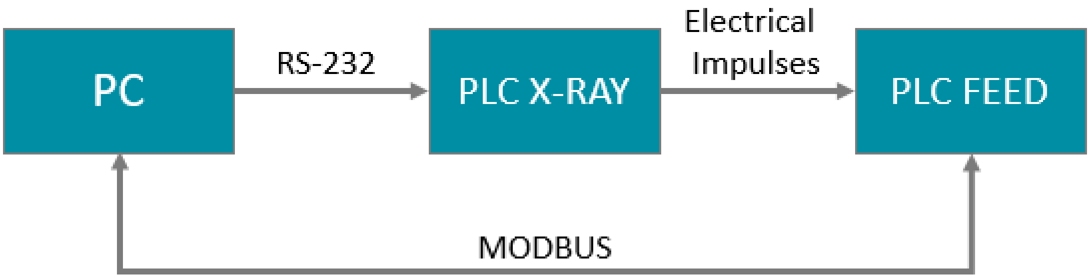


Figure 50 - Final communication diagram

With this additional connection the X-ray system only stops working when the operator turns off the machine, since with this solution the information that there are not supposed to have any stoppers in the channels is given directly to the feeding system and not through the X-ray PLC. Besides the implementation of the solution, four illuminated pushbuttons were integrated (Figure 51) that inform the operator when the bag is full.

Figure 51 - Operator pressing the illuminated pushbutton installed

Returning to the real situation, when the count reaches the value defined at output 5 the PC informs the X-ray system to switch to output 6 and also informs the feeding system to turn on the illuminated pushbutton linked to that bag, when the operator removes the bag and presses the pushbutton the feeding system informs the PC that the full bag has already been removed which informs the X-ray system that output 5 is available again and so on.

That being said, this solution allows the machine to only stop when all four bags are full whereas before it stopped when one bag was full.

5.2.2 Feeding the wrong vibrator

After solving the previous problem when one of the vibrators is switched off for any reason and at that moment the vane is in the position of requesting stoppers, the vibration box continues to vibrate feeding the vibrator continuously causing the inverted V system to get clogged (Figure 52) blocking the plate that allows changing the feeding to the other vibrator.

Figure 52 - Inverted V system clogged

The part of the PLC programming involving the actuation of the vibration box relay was analysed, shown in Figure 53.

Figure 53 - Vibration box control program

Variable Q:100.00 corresponds to the output programmed to actuate the vibration box, and the problem lies in not being able to set it to 0 when one of the vibrators is switched off. Lines 38 and 39 are the ones that set the variable to 1, which means they switch on the actuator. The variable remains at 1 until one of the actions in lines 40, 41, and 42 occurs. These lines of code are explained below.

- Line 38: The channel 1 vibrator is switched on (variable I: 0.00) and when the set time (T0030) is reached, the counting of this time starts from the moment the vane of channel 1 requests stoppers.
- Line 39: The channel 2 vibrator is switched on (variable I: 0.05) and when the set time (T0040) is reached, the counting of this time starts from the moment the vane of channel 2 requests stoppers.
- Line 40: The time (T0011) set as sufficient to feed the vibrator of channel 1 is reached, the count is started when the vane of channel 1 leaves the position of requesting stoppers.
- Line 41: The time (T0021) set as sufficient to feed the vibrator of channel 2 is reached, the count is started when the vane of channel 1 leaves the position of requesting stoppers.

- Line 42: Both vibrators are switched off.

Having said this, describing a real situation when the channel 1 vibrator switches off while it is being loaded, meaning that the first line has already been executed, but as the vibrator is switched off the corks cannot remove the vane from the stopper request position, so the T0011 time does not start and the vibration box remains switched on and continues to load the vibrator. The solution to this problem is to ensure that switching off the vibrator stops the vibration box immediately. The code after the change is shown in Figure 54.

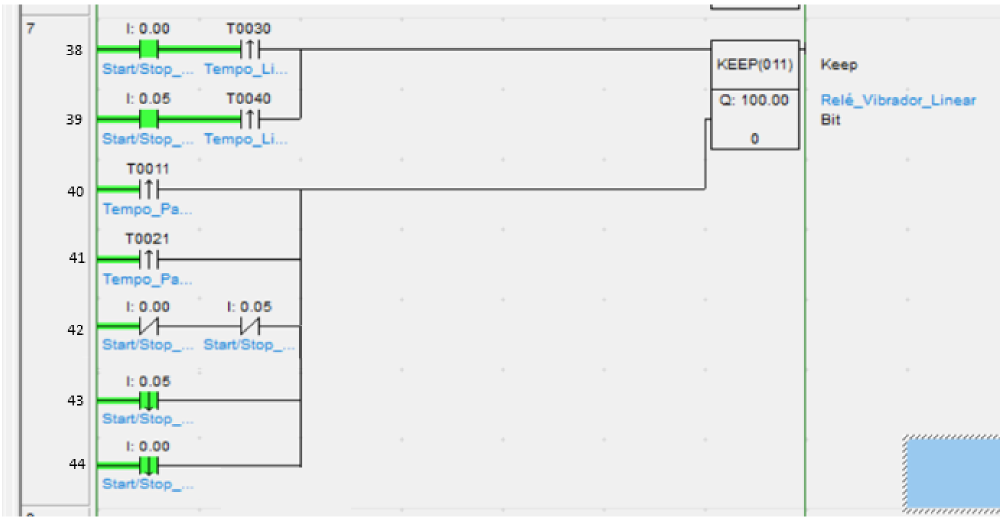


Figure 54 - Vibration box control program after the modifications.

Lines 43 and 44 were then added that set the variable to 0 when the vibrator is switched off. This means that line 38 or 39 has to happen again for the vibration box to work, but as one of the vibrators is switched off only one of them can occur.

5.2.3 Pneumatic blow derailing stoppers

The blowing that rejects stoppers with the wrong diameter and color was causing derailment and false rejections of previous stoppers. Figure 55 shows four images of this process.

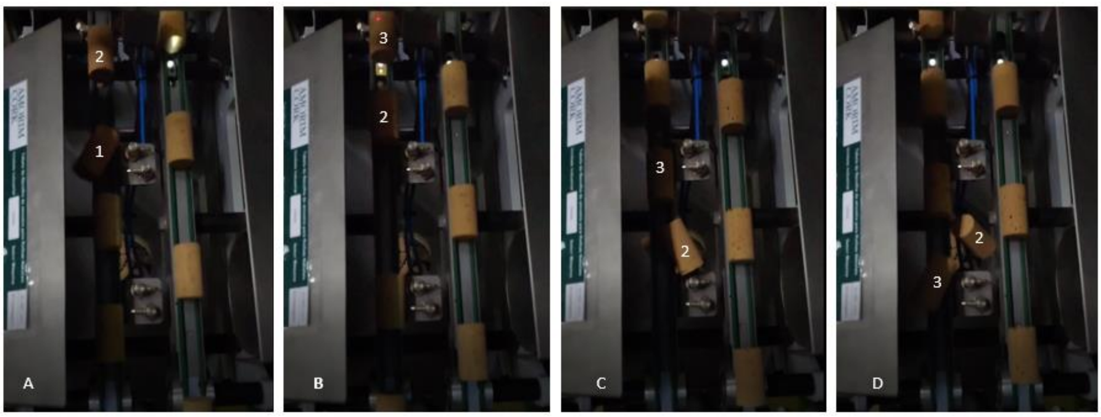


Figure 55 - Sequence of images of the oscillating belt causing derailing and false rejections.

Analyzing the figure, in image A the cork stopper 1 is rejected by the pneumatic blow, this blow causes the belts to oscillate, due to the movement of the belts the cork stopper 3 rises being detected by the laser beam of the height sensor (image B) and the cork stopper 2 derails hitting the support of the blows (image C). In image D can be seen cork 3 being incorrectly rejected. Many times this oscillation of the cords caused stoppers to get stuck on the X-ray chamber inlet (Figure 56).

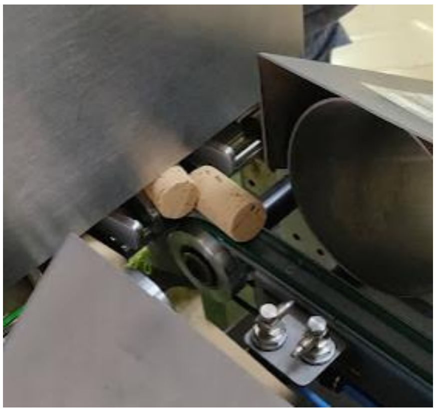


Figure 56 - Stoppers stuck in the entrance of x-ray chamber

When analyzing the situation, it was concluded that the oscillation of the strings was caused by the blowing being too strong or too low, as it was simpler to correct the height of the blowing, opting to follow this solution. This way the blowing reaches the upper part of the stopper and does not move the belts as much. Thus, it was possible to reduce the obstructions at the entrance of the X-ray (unplanned stop number 2).

5.2.4 Conveyor cracking stoppers

Before using output 6 of each channel, it was necessary to confirm that it was suitable to transport the stoppers to the bag. For this test, a sample of 200 stoppers of a different length from the one that was being packed was used and the machine was programmed to remove the stoppers of the wrong length through output 6. Before these stoppers were placed in the machine, they were analyzed by the quality controller to detect the existence of any defects, in order to understand if the imperfections that the stoppers presented after going through the equipment already existed before.

After passing through the machine, numerous cork stoppers with cracks were detected, as shown in Figure 57.

Figure 57 - Cracked stoppers

These cracks were made in one channel of the channel 1 conveyor, due to a protruding plate that trapped the cork stoppers. A failure of this type in the sector that precedes the dispatch of the product to the client is worrying, so it was necessary to find the most immediate solution possible. In this sense, the two conveyors were replaced in order to completely eradicate this type of failure.

5.2.5 Ditch accumulating stoppers

The base of the conveyor structure that transports the stoppers to the hopper of the machine rests on a ditch to be lower than the ground level allowing the stoppers to fall by the action of gravity when the operator places the container. The major problem with the ditch is that it accumulates the stoppers that the conveyor belt drops (Figure 58).

Figure 58 - Conveyor ditch full of stoppers

When a considerable number of stoppers accumulates after several lots, they can be collected again by the conveyor belt causing mixtures in the current lot. The cadence of stoppers that fall into the ditch is reduced, four stoppers on average appear per shift. One of the causes of this problem is that the plate between the linear belt and the vertical belt is fixed and does not touch the belt teeth (Figure 59), allowing the stoppers to pass between the plate and the edge of the belt teeth. The proposed solution would be for the plate to be movable (Figure 60) and to rest on the tooth of the vertical conveyor, as already exists in some conveyors, thus making it impossible for the stopper to pass between the plate and the edge.

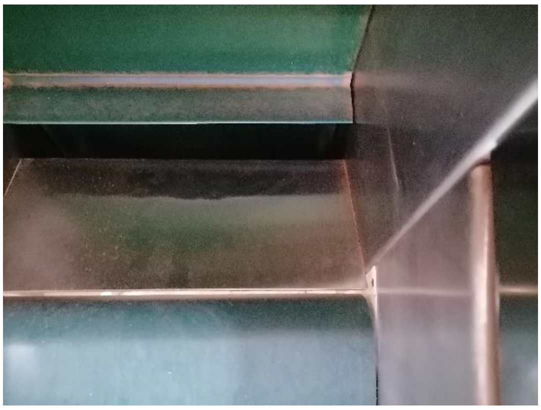


Figure 59 - Fixed plate


Figure 60 - Movable plate

This solution was not implemented until the end of the project, so a precautionary measure was taken whereby the cleaning of the ditch is done daily by the operator to avoid the accumulation of cork stoppers.

5.2.6 Efficiency of the diameter sensor

As already mentioned, the height of the diameter sensor is calibrated by the operator. There are three standard diameter stoppers which are 24 mm, 25 mm, and 26 mm. During calibration, it is up to the operator to decide, through a selector, whether to reject the stoppers that interrupt the laser beam or reject the stoppers that do not interrupt. For instance, if the stoppers being packed are 24 mm the sensor must reject the stoppers that interrupt the laser beam, meaning the sensor is calibrated for a height slightly above 24 mm so that the stopper of 24 mm does not interrupt the laser beam if a stopper of 25 mm or 26 mm goes through, the laser is interrupted informing the system that the stopper must be rejected. The opposite happens if the stoppers being packed are 26 mm. Figure 61 represents the two calibration modes when the diameter being packed is 25 mm.

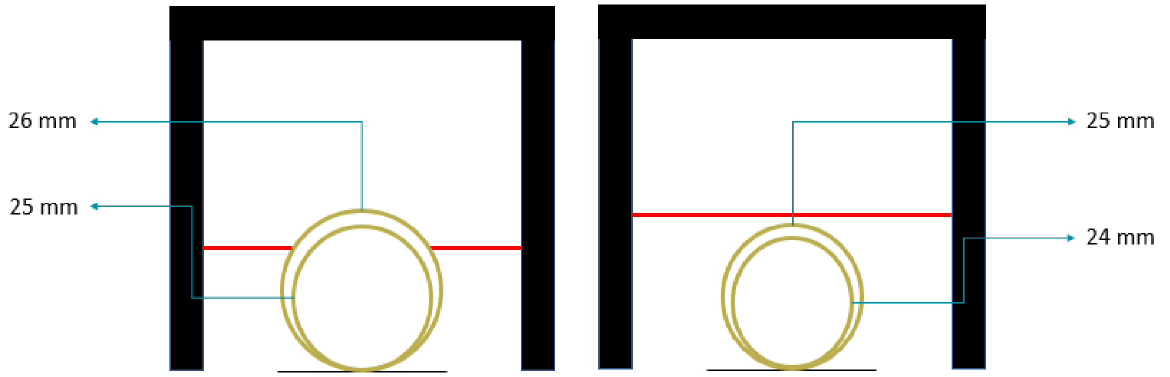


Figure 61 - Two modes of calibrating the laser beam sensor.

In the left-hand illustration, the sensor was calibrated to reject the stoppers that do not interrupt the laser beam, so the 25 mm stopper must interrupt the laser beam, however, the 26 mm stopper will also interrupt, rejecting only the 24 mm stoppers. In the diagram on the right, it has been calibrated to reject the stoppers that interrupt the laser beam, this time the 25 mm stopper cannot interrupt the beam, likewise the 24 mm stopper does not interrupt either, in this case, the 26 mm stopper is the only one that is rejected. This type of sensor does not allow maximum efficiency in the combat of mixtures.

Having said that, a proximity laser sensor was installed (Figure 62). Its technical specifications are presented in Table 12.

Table 12 - Proximity sensor specifications. Adapted from [27]

Measurement Range	Resolution	Minimum Response Time	Sensing Mode
25-100 mm	± 0.02 mm	1.5 ms	Proximity

Figure 62 - Proximity laser sensor. Adapted from [27]

This sensor allows rejecting any diameter, as it measures the distance to each stopper analyzed. It is possible to define a range that includes the measured distance to the correct stopper and all stoppers outside this range are rejected.

5.3 Management

This section presents the development of the improvement suggestions related to the management of time, people, and work methods in order to ensure maximum efficiency of all available resources.

5.3.1 High Setup Time

The setup time is measured from the last produced stopper of the current lot until the first stopper of the next lot is produced. In the first phase, the lean manufacturing tool, SMED, was applied to analyze which actions are done by the operator during this time, which ones can be done with the machine working (external setup), and which ones have to be done with the machine stopped (internal setup). The identified actions are the following:

1. Sensor's calibrations (Internal)

The calibration of the sensors consists in calibrating the color and diameter sensors as previously mentioned, with the new diameter sensor the operator does not need to calibrate it, because the sensor calibrates itself automatically, whenever the lot is changed the sensor memorizes the first 20 stoppers that pass through the sensor establishing a range between the smallest and largest diameter stoppers. The stoppers that are out of this range are rejected. Thus the calibration time of the diameter sensor is reduced from approximately three to zero minutes.

2. Ensure that there are no stoppers from the previous lot in the machine (internal)

Before placing the next lot the operator has to verify and remove all cork stoppers that are in critical places of the machine, illuminated pushbuttons were placed in these critical locations (Figure 63) in order to guarantee the verification of the existence of stoppers, the machine only starts working when the operator has pressed all the pushbuttons. This implementation does not bring gains to the setup time because this action was already done before, it was only not required to press the pushbuttons.

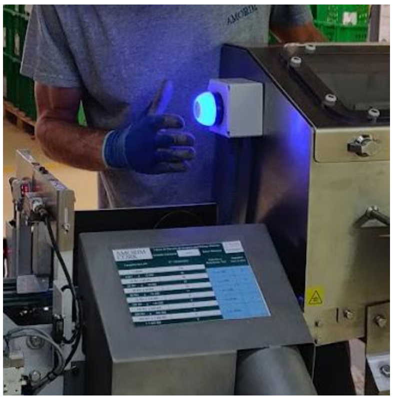


Figure 63 – Operator checking critical locations

3. Choose the next lot (external)

The existing counting machines in the packaging sector did not need to be calibrated for each lot, therefore no importance was given to the order of the lots that would be packed subsequently. In the X-Ray machine, lot planning is crucial to reduce setup time between lots, the following two examples (Figure 64) demonstrate the difference in setup time.

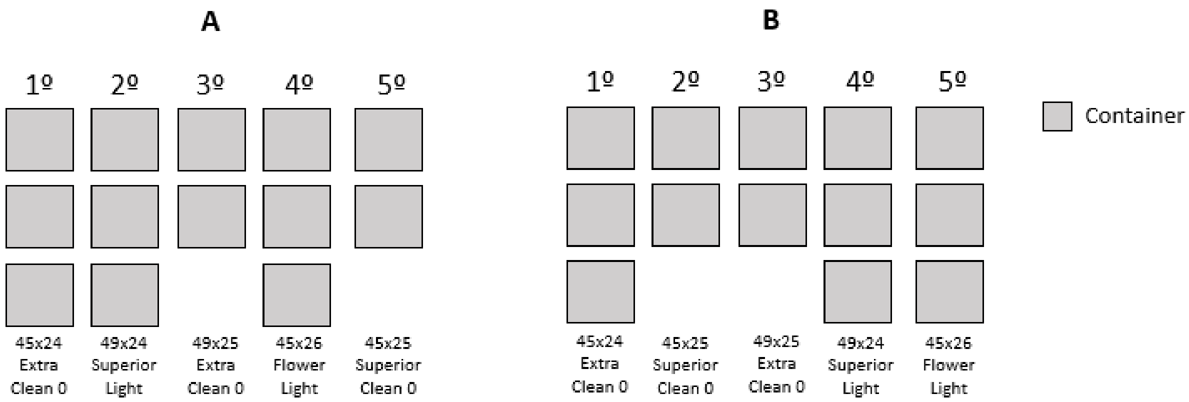


Figure 64 - Example of two ways of ordering the available lots

Supposing that the next lots to enter the machine are the five represented in the Figure 64, three of these lots are stoppers with the Clean 0 washing, and the other two are stoppers with the

Light washing. These two washings provide different colors to the stoppers, and it is necessary to calibrate the color sensor every time a lot is changed from one to another.

In example A the stipulated order demands four calibrations of the color sensor, from Clean 0 to light then back to Clean 0, and so on. Assuming an average duration of the color sensor calibration is 1 minute, the operator would spend 4 minutes on setup in the production of these 4 lots.

On example B, it is only necessary to calibrate once, from the third to the fourth lot, which only takes one minute off the operator's time. Correct lot planning at the end of many lots allows a considerable gain.

5.3.2 Inexistence of a Standard work

The packaging sector works 24 hours, divided into three shifts of 8 hours, this working method has many disadvantages. There is a lot of information lost between shifts, and the sector is never the same since a shift ends and re-started the next day, unlike what would happen in a normal job, in which the worker always finds the workspace as it was left the day before. At the start of the project, the night shift, in particular, had a very different way of working from the other two shifts, making it difficult to transmit information between shifts.

In order to reduce and simplify as much as possible the information needed to be transmitted to the next shift, it is crucial that all shifts follow the same working method and that all operators are trained based on the same principles.

Since the X-ray machine was a new equipment, one of the project's actions consisted of providing 7 days training to each operator of the packaging sector that would operate the machine. A list of actions was created in which the operator would only be able to operate the machine when all the points on this list were fulfilled (Appendix A).

In addition to training, a standard work was created in the sector (Appendix B) to standardize the actions performed by the operators of the different shifts. This standard contains all the information that the operator must transmit to his colleague during the shift, as well as all the actions that must be carried out by the operator at the beginning, during, and at the end of each lot.

6 Analysis and discussion of results

This chapter aims to discuss and analyze the results obtained with the implementation of the improvements presented in the previous chapter, as well as their impact on the defined indicators. The monetary gains associated with the project are also included in this section.

6.1 OEE

After the implementation of the improvements, another full shift was monitored to register the unplanned stops and the production of the machine. Table 13 shows the time that the machine was stopped due to the same unplanned stops presented in table 8 (section 4.3.1).

Table 13 - Unplanned stops after implemented improvements

Measurement of unplanned stops						
Number of occurrences	Stop 1 (s)	Stop 2 (s)	Stop 3 (s)	Stop 4 (s)	Stop 5 (s)	Stop 6 (s)
1	23	25	74	288	120	0
2	29	37	69	310		
3		24	57	287		
4		17				
5		20				
6		22				
SubTotal (s)	52	145	200	885	120	0
Total (s)	885 = 0,25h					

For the Run Time calculation only stops longer than 5 minutes are considered, analyzing the table the only stop that this occurs is stop 4, which refers to the checking of cork stoppers in critical locations before the next lot. The final Run Time can then be calculated through the following equation.

$$Run\ Time = 8h - 0.25h = 7.75h$$

Thus, the Availability is obtained from the equation 2:

$$Availability\ (A) = \frac{7.75}{8} \times 100 = 96.88\ \%$$

The remaining stops will be considered small stops, becoming part of the performance losses which do not let the machine work in its ideal cycle time. Table 14 shows the gains and losses in each stop at the end of the project.

Table 14 – Gains and losses on the duration of each stop

Stop	Before	After	Gains/Losses
1	912	52	-94%
2	455	145	-68%
3	710	200	-72%
4	875	885	+1%
5	1020	120	-88%
6	331	0	-100%

Stop 1 is related to stop 5, as it was due to the time when the operator was on the lunch break and then when came back the machine had already filled the four bags two minutes ago, and the two bags considered in stop 1 are two of those bags. Stop 6 was eliminated because the machine does not stop during the operator's snack break. Concerning stop 3 there was a reduction of 72% due to the need of the operator to calibrate the color sensor only. The only stop that remained almost the same, increasing only 1%, was stop 4 which does not present much room for improvement.

In terms of machine production, the improvements implemented had a considerable impact. In the shift in which the data was collected the number of cork stoppers produced was 240 thousand. Thus, through equation 3 it can be calculated the performance after the resolution of the problems.

$$Performance\ Efficiency\ (P) = \frac{0.103\ \times 240000}{7.75 \times 3600} \times 100 = 88.60\ \%$$

As for the last indicator that makes up the OEE, the rate of quality, since there were no changes in the algorithm, nor in the X-ray analysis parameters, the value remained practically unchanged. Factor 4 is the only factor that had an increase of 2%, from 92% of lots approved in the visual control to 94% resulting in a rate of quality value:

$$Rate\ of\ Quality\ (Q) = (100 - 74{,}00 \times 17{,}78 \times 4{,}09) \times (100 - 4{,}09 \times 17{,}78) \times 94{,}00 = 92{,}81\ \%$$

With the three parameters calculated, it can be obtained a final OEE of:

$$OEE = \ 96.88\ \times 88.60\ \times 92.81 = 79.66\ \%$$

The graphic represented in figure 65 shows a summary of the gains obtained in the equipment's efficiency.

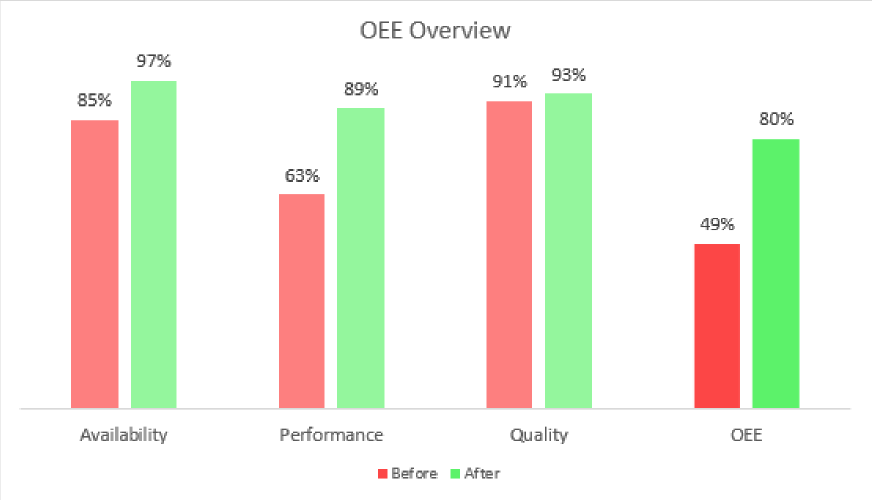


Figure 65 - Evolution overview of OEE

The graph shows that the improvements developed and implemented led to an increase of 12% in the equipment availability time, 26% in the machine's ability to match the ideal cycle time throughout the shift, and 2% in the machine quality index. The increase of these indicators led to a final OEE value of 80%, a 63% increase over the value calculated at the beginning of the project.

6.2 Mixture Ratio

Mixtures, as already mentioned, are a quality factor of considerable value and one of the main reasons for the acquisition of the X-ray machine. In the packaging sector, before the acquisition of the machine, the only way to detect mixtures was during the visual control made by the controllers that only analyze a small percentage of each bag, with the risk of some mixture escaping. The graph in Figure 66 shows the percentage of lots detected as mixtures by the machine from week 14 to the end of the project.

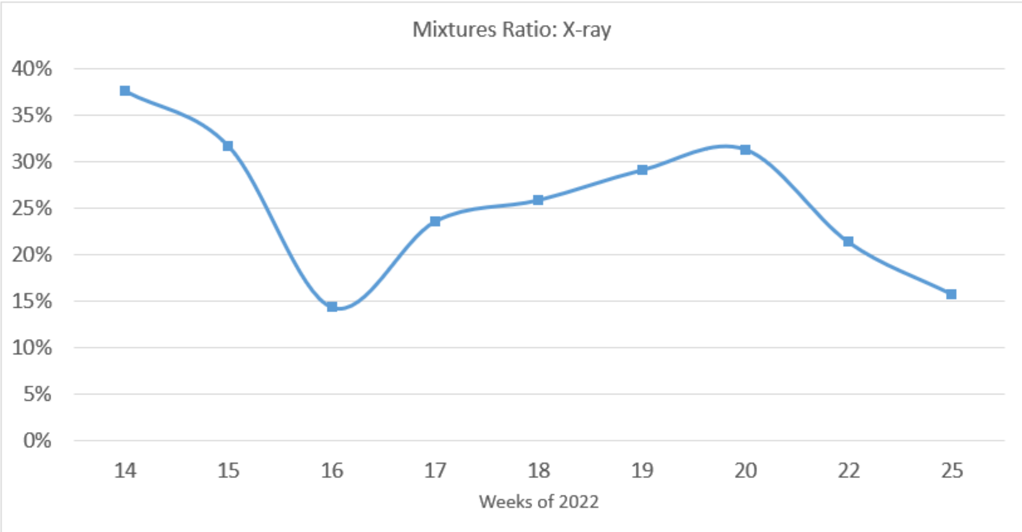


Figure 66 - Mixtures ratio detected by the X-ray machine

As it is possible to note from the graph, during most of the weeks of the project, the machine on average detected a mixture in 25% of the lots. Therefore, the integration of the machine has proven that the 3.6% detected by the controllers is in reality a misleading percentage, with a considerable quantity of lots that were not detected by the controller. Without this machine, these detected lots would be packed as if they had no mixture and most of them would probably not be detected.

The graphic represented on Figure 67 shows the percentage of lots identified with mixture by the controller before and after the X-ray machine was placed.

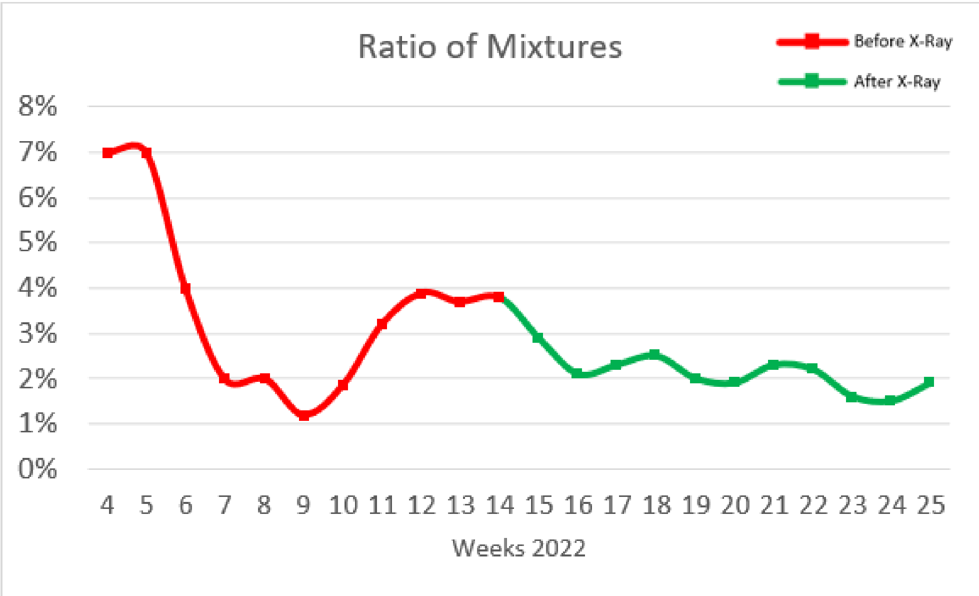


Figure 67 - Mixtures ratio detected on the visual control before and after the X-ray machine.

After the integration of the X-ray machine, the percentage of mixtures detected presents an average value of 2.1%, presenting a reduction of 41% from the 3.6% that was obtained in the beginning of the project.

There are two reasons why this value is not closer to zero, one of them is that during the project the X-ray machine was not the only machine packing cork stoppers in the sector, the counting machine 3 was also operational, considering that the analysis of this indicator includes both pieces of equipment, one of which is only counting, it is expected that the value could be lower if only the X-ray was taken into account.

The second obstacle comes from the fact that the color sensor is not 100% effective because there are very similar washings and most of the time it is unknown which washing will appear mixed. When calibrating the color sensor, the operator must show the cork to be packed and the cork to be rejected. The choice of this cork has to guarantee a fair trade-off between effectiveness and false rejections. Therefore, a standard calibration was created that consists of showing the lightest wash when the darkest colored corks are being packed and vice-versa. Table 15 shows the tone that each washing gives to the cork stopper, where 0 is the lightest tone and 10 is the darkest tone, and which washing is used to calibrate the sensor.

Table 15 - Tone given to the stopper by each washing

Washing	Tone	Standard Calibration
Clean 0	10	Light
S/L	10	Light
N101	6	Light
Nature	8	Light
Clean C	7	Light
Clean 2000	2	S/L
Light	0	S/L

In three lots with the following washings, Clean 0, N101, and Light were added 30 stoppers of all washes and it was registered how many stoppers are effectively rejected by the sensor with the standard calibration. Table 16 shows the results obtained.

Table 16 - Efficiency results of the color sensor

		Washing of the intruder						
		Clean 0	S/L	N101	Nature	Clean C	Clean 2000	Light
Washing Being Packed	Clean0	-	0,0%	33,3%	26,7%	53,3%	93,3%	100,0%
	N101	0,0%	0,0%	-	0,0%	0,0%	23,3%	100,0%
	Light	100,0%	100,0%	53,3%	70,0%	40,0%	0,0%	-

Analyzing the results, it is possible to draw several conclusions, the sensor is 100% effective if the intrusive wash is used to calibrate, for example in the case of light that is calibrated with S/L (10 on the scale) rejected the 30 corks from this wash as well as those from the Clean 0 wash (10 on the scale). N101 is the most critical, since it presents a medium tone, in this case, it could also be calibrated with the S/L and would present a higher efficiency in dark washes, but there would be a considerable increase in false rejections since this washing is a more similar to the S/L stopper than the Light one.

In conclusion, not knowing the intruder the X-ray machine is not 100% effective in combating mixtures. The company intends that by 2023 the packaging sector will consist only of X-ray machines, ensuring a substantial reduction of this indicator, but very unlikely to be null.

6.3 Lead time reduction

The X-ray machine adds the possibility to the sector to pack rejected lots in the 3rd EE that before would go to the prototype machine and only afterward could be packed. This functionality allows skipping a step in the production flow between the 3rd EE and the packaging sector, in other words, the x-ray machine can perform the function of the prototype machine and the counting machine, thus reducing the lead-time. The diagram of figure 68 shows the average lead time of a rejected lot until it is packed after the integration of the X-ray machine.

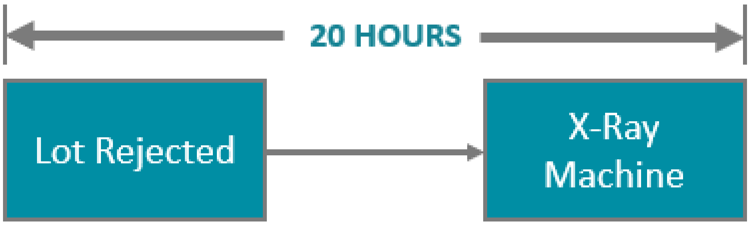


Figure 68 - Final lead time diagram

The lead time was reduced by 44%, from 36 to 20 hours. This reduction not only allows faster packaging of an order but also relieves the load of lots destinated to the prototype machine, thus creating availability to execute other types of lots that may be needed, which reduces inventory as well.

6.4 Production

This project also had a priority to verify the maximum production capacity of the machine, the target set was 250,000 stoppers per shift. Before most of the improvements were implemented the machine was capable of producing 150,000 stoppers per shift. By 2023 the factory anticipates a maximum packaging requirement of 1,800,000 stoppers per day and as already mentioned intends that the packaging sector will be operated by X-ray machines.

Thus, with the initial productions a machine was capable of producing 150,000 x 3 shifts per day, which gives a total of 450,000 stoppers, so to satisfy the need would be necessary 4 X-ray machines. The graphic represented in figure 69 shows the evolution of the X-ray machine production along the project

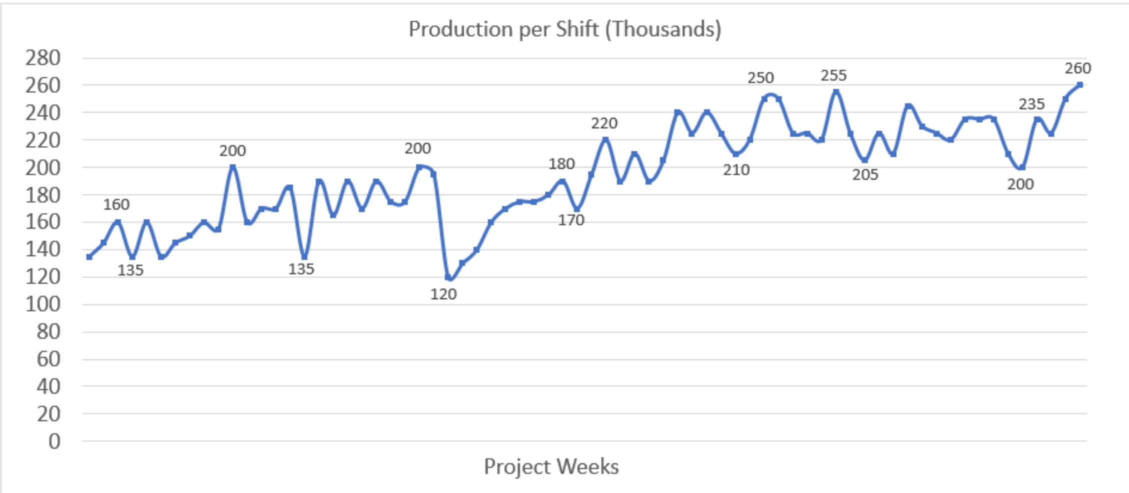


Figure 69 – X-ray machine production per shift during the project

From the graph, it can be seen that there was an increase in the production of the equipment reaching the objective several times. At the end of the project, it can be assumed that the machine produces 240,000 cork stoppers per shift with some consistency. Using this value, the machine produces 720,000 stoppers per day, needing only 3 machines, where one of them only needs to produce half of its full capacity (360,000) to satisfy the sector's needs.

In conclusion, this project will allow the company to invest in three machines instead of four which brings a monetary gain of 150,000 euros. Given that three operators would be needed, one per shift, and that the annual cost of an operator is approximately 15,000 euros, making a total of 45,000 euros per year.

7 Conclusions and Future Work

This chapter presents the main conclusions to be drawn from the dissertation project and proposals for future work are recommended.

7.1 Conclusion

Most of the existing equipment for detecting defects in cork stoppers is based only on the analysis of the surface of the stopper, not guaranteeing the quality of the product in its interior. As such, an investment was made in an X-ray machine that enables the inspection of the inside of the cork stopper, resulting in an improvement in the quality of the inspection of the product.

This project consisted of the consolidation of the investment made by the company, the machine was added to the packaging sector of the factory, this being the last stage before the product reaches the client's hands. This equipment was completely new, which required remodeling the sector since, before, all the stoppers that arrived at the packaging sector were packed without carrying out any inspection. The objectives of this project coincided with the objectives that the company set for the machine itself, the following results were obtained.

- Increased the machine productivity in 60%.
- Reduction of 41% of lots detected with mixtures.
- 63% increase on OEE.
- Reduction of 44% on the lead time between sectors.

These goals were achieved by increasing the operational time in the sector with training given to the operators so that they understood the defined objectives and the functioning of the sector with this new machine, and also the resolution of problems that did not allow the optimal use of the machine capacity, mainly through lean manufacturing tools.

Having said this, the results obtained in this project demonstrate the great potential of this type of analysis, justifying the continuation of the investment to always achieve the most important objective, which is to increase customer satisfaction.

7.2 Future work

The future proposals include the further consolidation of this type of machine in relation to the machines that previously existed in the sector through the analysis of small cracks in the cork stoppers after they have passed through each of the machines. This analysis consists of using two samples (1 and 2) with various stoppers of the same article. The samples are previously seen by the controllers in order to know how many corks of each sample already have cracks, and those that present cracks are marked, then sample 1 goes through the X-ray and sample 2 the counting machine, after this process, the corks are returned to the controllers to be seen again and to perceive if there was an increase of stoppers with cracks in each sample. The values of the two machines can be compared, allowing the conclusion to be drawn as to which machine causes the least amount of cracks in the cork stoppers. This quality evaluation was already started during this project, but not enough data was obtained to be able to reach a definitive conclusion.

As the X-ray machine allows the detection of defects, another future proposal is to try to relieve the demand of the previous machines of the packaging sector, that is, as before the packaging sector only counted the stoppers, these had to reach the sector already ready to be sent to the client, making the machines of the previous sectors have no margin for error, requiring high accuracy in this equipment to avoid defective stoppers continuing in the process, thus causing a high number of false rejections. The X-ray machine has increased the flexibility of the previous equipment, as defective stoppers not detected by these machines can be detected later by the new X-ray machine. In this way it is possible to maintain the same efficiency, reducing false rejections.

Finally, it is recommended to continue to supervise the working method of the three shifts in order to standardize as much as possible the actions defined.

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Appendix

A: Training plan to operate the X-ray machine

Plano de formação operador de embalagem do raio x						
Etapa	Detalhes	Duração	Validação			
			Operador 1	Operador 2	Operador 3	Operador 4
Operar com a máquina	Saber ligar/desligar a máquina, escolher o programa, zerar a contagem, desencravar a máquina, desligar e ligar sensores.	7 dias				
Sensores de cor e diâmetro	Saber calibrar os sensores					
	Saber que rolhas deve escolher para calibrar e testar o correcto funcionamento					
	Saber distinguir as lavações existentes					
	Saber o que é considerado uma mistura e utilizar o paquímetro para deteta-la.					
Utilizar as sobras	saber estimar qual a quantidade de sobra necessária para concluir o ultimo saco, com base na % de rejeitados da encomenda em					
	Verificação de sobras logo no início do lote					
Etiquetas MÊS	Saber agregar/desagregar e movimentar					
amostra para o laboratório	Saber qual a quantidade de rolhas que deve tirar de cada saco para o laboratório					
Encomendas com Controlo saco a saco	Colocar os sacos abertos para controlo					
	Retirar os "echapes" de cada saco - max 5					
	Se for continuação , localizar a contra-amostra. Prencher o formulário para o controlo do processo para controlarem saco a saco					
	se o lote foi rejeitado na 3ªEE deve chamar a controladora no inicio do lote para averiguar da conformindade do lote					
Encomendas sem controlo saco a saco mas rejeitadas na 3ªEE	Saber escolher o programa (começa por R)					
	chamar a controladora no inicio do lote-primeiros sacos					
	Em caso de aprovação, começar a cozer os					
Controlo de contagem	Fazer controlo de contagem 1000 rolhas					

B: Standard work

AMORIM CORK

NORMA - Metódo de trabalho RAIO-X

CORK MAIS

Unidade Industrial	UI LAMAS	Setor/ Máquina	RAIO X EMBALAGEM	IT.AL.IND.172

Passagem de turno (Duração 2 min):

Informar se o que já está em sacos está aprovado ou não.

Informar o que está a seguir e onde estão os contentores.

Informar se a máquina trabalhou bem ou se surgiu algum problema.

Início de lote:

No inicio do lote fazer o teste de diâmetro, cor e comprimento a ver se está tudo como esperado.

Ver se há sobras logo no inicio do lote e junta-las para evitar a heterogeneidade.

Atualizar a tabela de prioridades.

Durante o lote:

Agregar as etiquetas MES do lote atual e desagregar e movimentar os defeitos do lote anterior sem depender do chefe de equipa.

Colocar os defeitos do lote anterior nos sacos corretos de acordo com as placas.

Lotes reprovados chamar sempre a controladora nos dois primeiros sacos para verificar se está a retirar o defeito do lote. Colocar Kanban e folha vermelha nos sacos.

Luz vermelha indica que o saco está cheio. Pressionar ao retirar o saco.

Perguntar ao chefe de equipa a quantidade da encomenda e se está a começar ou não. Se não estiver buscar a contra-amostra.

Informar o chefe de equipa de quantos sacos irão sair e pedir para preencher o papel para controladora.

Em todos sacos retirar as rolhas mais fracas "Échapés" (Máximo 5 rolhas por saco)

Lotes aprovados WPK podem ser colocados logo no carrinho e enviados para cima.

Lotes aprovados e de classe 1º ou abaixo não é necessário controlar e podem ser logo cozidos.

Garantir que o lote seguinte já está perto da moega.

Fim de lote:

Verificar se há misturas ou rolhas deformadas no cestos de rejeitos de diâmetro e cor (utilizar paquímetro). Se houver retirar, registar no quadro e voltar a passar as restantes.

Limpar a máquina e verificar os sitios críticos, identificados com luz azul.

Se para o lote seguinte não for preciso fazer a calibração de cor a troca tem que demorar 2 MIN.