# Productivity Enhancement through Lean Practices in a Paper-to-Cardboard Company


*Francisco José Teixeira Castro*


**Masters Dissertation**

Orientador na FEUP: Prof. Jonas André Rodrigues Henriques de Lima


U. PORTO

FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO


**Master in Mechanical Engineering**

2024-06-27

*To my family.*

## Resumo

Esta dissertação aborda um projeto de otimização numa fábrica dedicada à transformação de papel em cartão canelado. O principal objetivo foi aumentar a produção da caneladora para 16.000 m²/h. Para alcançar este objetivo, identifiquei e abordei três problemas principais: alta percentagem de paragens não planeadas, elevado número de reclamações sobre a qualidade do produto e falta de processos padronizados. Estabeleci metas específicas para direcionar o trabalho: atingir uma velocidade média de 135 m/min; reduzir as paragens não planeadas para 10%; diminuir as reclamações em 20%; e padronizar os processos.

Nos primeiros dias na empresa, familiarizei-me com os postos de trabalho, proporcionando uma compreensão detalhada do funcionamento da fábrica. Participei numa formação de Six Sigma White Belt oferecida pela empresa, essencial para a aplicação de metodologias de melhoria contínua. Posteriormente, foquei-me no funcionamento da caneladora, recolhendo dados detalhados sobre o processo produtivo.

A análise centrou-se principalmente nas paragens não planeadas e na qualidade da produção, áreas críticas para a produtividade. Trabalhei em estreita colaboração com os departamentos de produção, manutenção e qualidade, utilizando ferramentas Lean e o software da empresa para recolher e analisar dados. Este processo envolveu reuniões e sessões de brainstorming, resultando na criação de um plano de ação para resolver os principais problemas identificados.

As ações de melhoria implementadas foram monitorizadas através de auditorias regulares para garantir a sua eficácia. Este trabalho resultou num aumento significativo na produtividade da caneladora, uma redução notável no número de reclamações dos clientes e uma diminuição substancial das paragens não planeadas. Além disso, a padronização dos processos contribuiu para a uniformidade e eficiência das operações.

Em resumo, este projeto demonstrou a eficácia de uma abordagem estruturada para a resolução de problemas e melhoria contínua, proporcionando resultados tangíveis e sustentáveis para a fábrica.

## Productivity Enhancement through Lean Practices in a Paper-to-Cardboard Company


### Abstract

This dissertation deals with an optimization project at a plant dedicated to converting paper into corrugated cardboard. The main objective was to increase the production of the corrugator to 16,000 m²/h. To achieve this goal, I identified and addressed three main problems: a high percentage of unplanned stoppages, a high number of complaints about product quality and a lack of standardized processes. I set specific targets to direct the work: achieve an average speed of 135 m/min; reduce unplanned stops to 10%; reduce complaints by 20%; and standardize processes.

During my first few days at the company, I familiarized myself with the workstations, giving me a detailed understanding of how the factory works. I took part in Six Sigma White Belt training offered by the company, which is essential for applying continuous improvement methodologies. Afterwards, I focused on the operation of the fluting machine, gathering detailed data on the production process.

The analysis focused mainly on unplanned stoppages and production quality, critical areas for productivity. I worked closely with the production, maintenance and quality departments, using Lean tools and the company's software to collect and analyze data. This process involved meetings and brainstorming sessions, resulting in the creation of an action plan to solve the main problems identified.

The improvement actions implemented were monitored through regular audits to ensure their effectiveness. This work resulted in a significant increase in the productivity of the fluting machine, a notable reduction in the number of customer complaints and a substantial decrease in unplanned downtime. In addition, the standardization of processes has contributed to the uniformity and efficiency of operations.

In short, this project demonstrated the effectiveness of a structured approach to problem-solving and continuous improvement, delivering tangible and sustainable results for the factory.

# Acknowledgements

I would like to extend my sincere gratitude to the several individuals who helped make this work successful during its duration.

To engineers Ana Sousa and Carlos Varandas, for their unwavering support, insightful counsel, and continuous availability during the project. This work would not have been feasible without this support.

To Professor Jonas Lima, thank you for all of your help, availability, and advice with the dissertation. His counsel and recommendations were crucial to finishing this work.

Additionally, I want to express my gratitude to the entire staff at International Paper for always being available and cooperating when needed.

My sincere gratitude is extended to everyone of my family and friends for their unwavering support and encouragement along the way, especially to my parents, whose tolerance and support have served as a continual source of inspiration.

Thank you for my deepest gratitude.

# Contents

## Acronyms and Symbols

ECT – Edge Crush Test

IP – International Paper

JIT – Just-in-Time

KPI – Key Process Indicator

QMS – Quality Management System

WIP – Work in Progress

## List of Figures

## List of Tables

# 1 Introduction

As part of the MSc project of the 2nd semester of Mechanical Engineering at the Faculty of Engineering of the University of Porto, this project was carried out in collaboration with International Papel Cartovar, as part of the curricular unit "Dissertation", with a duration of approximately 5 months. The topic of the project is "Productivity Enhancement through Lean Practices in a Paper-to-Cardboard Company". In this sense, this chapter describes the structure of the dissertation and aims to make known the company as well as the objective of the work and the methods used to carry it out.

## 1.1 Company Presentation

International Paper Cartovar, S.A. was founded in 1987 under the name Fábrica de Papel do Ave and was intended to produce corrugated board and packaging. Its main suppliers were the paper mill in Vila do Conde and the Spanish company Europa&c, which acquired it in 2000, with the Ovar unit becoming part of the Europac Group (Papeles y Cartones de Europa, S.A). However, its original name remained until the end of 2010, when, in order to establish a brand concept, Europa&c changed its name from Fábrica de Papel do Ave to Europa&c Cartão Ovar (Ovar, 2018).

Figure 1.1 - Internation Paper´s facilities

The Europac Group (Papeles y Cartones de Europa, S.A) was set up in 1995 and within three years it had entered the Portuguese and French markets by listing on the stock exchange. Until 2018, the company owned 27 industrial facilities and 8500 hectares of forestry in countries such as France, Portugal (located in Viana do Castelo, Ovar, Leiria, Sintra and Vila do Conde) and Spain, dedicated to paper production, corrugated cardboard production, energy production, forestry and waste management. At the beginning of 2019, British paper and packaging group DS Smith bought Europa&c for 1.9 billion euros, agreeing with the European Commission to sell three mills, one of which is the Ovar plant and the other facilities are located in France. The sale of these 3 plants, suggested by DS Smith, was based on accommodating the European Commission's conditions for maintaining competition in the market for the production of board, as well as in the production of corrugated cardboard packaging in Portugal and France. In April 2019, DS Smith announced the sale of the Ovar and Northwest France mills to International Paper for 63 million euros in order to comply with the agreement with the European Commission.

The Ovar plant currently covers an area of 30,096 m2, with 13,000 m2 of built area. It has an installed capacity of around 61.2 million m2 of cardboard per year, in three work shifts, and has around 60% of its sales volume in the cardboard and reseller market, with EBIT of approximately 4.4 million euros in 2023.

## 1.2 Project Scope and Objetives

International Paper Cartovar, S.A. is a company that is constantly evolving and is strongly committed to implementing Lean methodologies, with the aim of improving the entire value chain, making the corrugated board and packaging production processes more efficient and effective. IP offers a wide variety of products, and its production process consists of two distinct phases: board production and packaging production.

Board production is carried out according to the customer's order, either for direct sale or for subsequent processing into packaging. The cut corrugated board is kept in temporary intermediate storage areas while waiting for the processing machines to be programmed. Once the machines have been programmed, the corrugated boards, together with the cutting tools, printing tools and packaging and production consumables, are supplied to the processing lines to be packaged according to the customer's specifications. (Ovar, 2018).

This project stems from the company's need to improve the productivity of the "mother" machine, the corrugator, responsible for transforming paper into cardboard. As a result of the competitiveness and demands of the market, this project aims to:

- Increase the productivity of the Corrugator machine:
    - Increase production to 16.000m2/h
    - Increase the average speed to 135m/min
    - Reduce unplanned downtime to 10%
- Reduce cardboard quality claims by 20%
- Create process and work standardization

To sum up, this project is a proactive reaction to the market demands and competitive environment. We seek to position the business for long-term success in a changing industry environment by focusing on particular goals pertaining to process standardization, quality improvement, and productivity enhancement.

## 1.3 Methodology followed in the project

The methodology followed in this dissertation is based on Kurt Lewin's Action-Research philosophy. This plan was implemented in several stages, each of which was done carefully:

• Problem identification: The obstacles and issues the Production and Quality Department faced were thoroughly examined. A review of the literature was part of the study, which provided a full understanding of the circumstances and the difficulties faced.

• Data Analysis: Statistical data on the company's entire production process was analyzed and the opinions of the workers were heard. This analysis made it possible to gather valuable information and gain a better understanding of possible shortcomings in the company.

• Planning: A complete action plan with the intended results was created using the PDCA (Plan-Do-Check-Act) technique.

• Development and implementation of the solutions: By analyzing the data collected and based on the available literature and the practical experience of all the company employees involved, solutions were suggested for the problems identified. These solutions were implemented progressively, allowing the business environment to adapt.

• Evaluation of results: Analyses were done to evaluate the solutions' impact and efficacy once they were put into practice.

• Reflection: Continuous reflections were carried out throughout the procedure to assess the success of the measures made, define lessons discovered, and encourage additional advancements. This thoughtful approach improved the solutions that were put into practice and advanced practical knowledge in the field of mechanical repair.

Essentially, this strategy comprised methodically addressing issues in the Production and Quality Department, which resulted in observable gains in operational effectiveness and understanding of mechanical repair by meticulous examination and incremental improvements.

## 1.4 Thesis Structure

The company is introduced, its operations are discussed, and the proposed project is presented in Chapter 1. This chapter outlines the project's overall goals and presents the approach that has been used throughout the project's path.

Going on to Chapter 2, which provides a foundational framework for project creation, a thorough assessment of relevant literature is given. This examination of the literature promotes a comprehensive awareness of the project landscape by shedding light on the solutions that have been put in place in addition to helping to comprehend the current issues.

Chapter 3 provides a detailed account of the company's operations and current state, which goes right to the core of the issue. This section clarifies the current state of affairs within the company, setting the stage for further investigations and actions.

In Chapter 4, the emphasis is on explaining the solutions that have been developed to deal with the problems that have been recognized. This chapter begins with a thorough explanation of the tactics used and ends with a presentation of the outcomes that were ultimately attained as a result of these efforts.

Chapter 5 summarizes the final conclusions derived from the project's findings and acts as the epilogue to this story. Furthermore, it delineates pathways for subsequent pursuits, opening doors for sustained expansion and enhancement of the organizational environment.

# 2 Literature Review

The primary focus of this chapter is on theoretical ideas that serve as the foundation for the dissertation. It helps to improve comprehension of the applicable concepts, hence it plays a significant role.

## 2.1 Toyota Lean System

Henry Ford, the company's founder, invented a mass production system that, when applied to his business, helped establish Ford Motor Company's reputation as a leader in the automotive sector globally. Large-scale production, product standardization, and assembly line utilization served as the foundation for this system. Customers' choices, however, shifted as the industry developed. When the Second World War broke out, there was a higher need for product diversity, which presented a challenge for this kind of system due to resource constraint. Because of this, businesses faced a shortage of material, human, and financial resources toward the close of World War II, which gave rise to the Toyota Production System (TPS) (Fritze, 2021).

TPS was viewed by many as an industrial revolution. Under the shadow of competition from Japanese manufacturers who were outpacing American producers in terms of output, Taiichi Ohno, Shigeo Shingo, and Kiichiro Toyoda, the president of Toyota Motor Company, developed a system that was centered on identifying and getting rid of processes that led to waste. These adjustments would enable continuous production, increased adaptability to demand variations, and—above all—a decrease in expenses as superfluous steps and components of the process would be removed (Monden, 2011).

Fujio Cho created the TPS house as a more simple and straightforward approach to illustrate this technique in order to streamline its presentation. In the manufacturing sector, this graphic has grown to be one of the most frequently encountered symbols. The home shape was justified by the fact that a strong roof, when combined with sturdy pillars and a base, results in a robust structure. Every component of the house is critical on its own; the existence of a weaker part undermines the entire structure and may cause it to collapse (Liker and Hoseus, 2008).

Regardless of the various iterations of TPS house we may encounter, the main goals are higher quality, lower lead times and costs, increased safety, and increased happiness with the workstations that will hence constitute the roof portion of the house.

The exterior pillars are predicated on the following policy (Womack, 2003):

- Just-in-Time (JIT), it relates to TPS's most noticeable aspect and aims to eliminate as much stock as feasible that is utilized to protect operations from potential production-related issues;

- Jidoka, it focuses on the notion of never allowing a fault to continue to the next stage of the manufacturing process and minimizing human interaction with the machines in order to encourage automation.

The first principle is a theory that guides an organization toward a common goal based on 14 distinct concepts that have a purpose beyond financial gain. The second focuses on easy tasks that are meant to be completed by every employee. The primary goal of the third is to reduce waste and faults by standardizing all operations. Lastly, the notion of Heijunka, which illustrates the leveling of production and the decrease of stocks, is used to solve problems (Lander and Liker - 2007).

The foundation of the home is stability, which calls for heijunka—which enables leveling out the production schedule in terms of volume and diversity and therefore supports stability and minimum stock—and standardised, stable, and dependable processes.

People are the center of the organization because only through constant improvement can operations achieve the required stability. They must receive training to be able to analyze waste and determine the root cause of issues when they are in direct contact with the shop floor, rather than learning about them from others (Carpenter, 2007).


Figure 2.1 - The lean house (Liker, 2004)

## 2.2 Lean Thinking

*Muda*, which translates as "waste", refers to any human action that consumes resources without providing value, such as needless processing processes. The concept of Lean Thinking arises from the very presence of the word *muda*. It offers a mechanism to define value, align value-creating operations in the appropriate order, and carry out these tasks continuously and more successfully as needed (Melton, 2005) (Pinto, 2018).

There are seven categories into which waste (*muda*) falls (Melton- 2005):

1. Defects: One crucial factor to take into account is the end product's quality. Errors and flaws that occur during the production process can cause major issues, delivery delays, and extra expenses.
2. Over Production: Waste has the biggest impact on the organization in terms of consequences. It's linked to the creation of goods or production techniques that don't provide value, which builds up inventories and raises needless expenses;

3. Waiting Time: It is typically linked to issues with the flow of production, which results in a significant volume of work-in-progress being held back in the manufacturing process. connected to operator or machine downtime brought on by waiting for the next action to be taken;
4. Transport: The factory floor's layout and this waste are tightly related. This means that its disarray results in needless product movement, time loss, and occasionally product damage. Transportation that does not improve the finished product's worth;
5. Inventory: The needless expenses resulting from overproduction are caused by the excessive storage of raw materials and products at the middle and end of the production process. Overproduction is often the cause of these expenses;
6. Over Processing: This occurs when a process is completed or completed longer than anticipated without adding value to the finished product;
7. Motion: Staff members frequently move excessively in the facilities, which does not improve the output.

The reason this way of thinking is dubbed lean is because it may give the consumer exactly what they want with less time, money, resources, and human labor. More gratifyingly, the idea of Muda can be quickly translated into value by offering prompt feedback on the efforts made. This way of thinking is also related to the fact that, as a result of businesses' ongoing technological advancements, job elimination is becoming more commonplace. As a result, businesses are turning to this way of thinking rather than just considering job elimination because new jobs are more adaptable to changing business needs and are less efficient (Melton, 2005) (Deshmukh, 2022).

There are 5 fundamental principles of lean thinking (Womack, 2003):

1. **Value**: Viewpoint of the client. It reflects the price a buyer plans to spend for a certain good that satisfies his needs;
2. **Value Chain**: Focuses mainly on the order of procedures that adds value for the client and on the non-value-adding activities, since it is our goal to discover and then remove waste in these operations;
3. **Flow**: The primary goal of this principle is to ensure continuous flow throughout all value chains, as this is the only method to reduce waiting times and needless stoppages while increasing response time and delivery to the client;
4. **Pull**: Only what is required to satisfy client demand is produced, and production orders are derived from customer orders;
5. **Perfection**: Its foundation is ongoing analysis and enhancement of the previously stated ideas. As a result, it starts the process of getting rid of wasteful and unvalued operations in the pursuit of excellence.

### 2.2.1 Kaizen

Kaizen is the Japanese term for constant improvement. It literally translates to change (kai) and good (zen), without any further meaning. It might be interpreted as a comprehensive philosophy that aims for excellence. It is the process of eliminating anything that adds no value while making tiny, gradual improvements along the way (Imai, 1986).

Through this methodology, you can learn and gain skills such as problem-solving, process improvement, data collection and analysis, self-management within a group, and working efficiently in small groups. Employees take on greater responsibilities. Through direct discussion and collective consensus, the group's decision-making starts to become their own (Macpherson, 2015).

The Kaizen strategy states that improvements should be implemented in the firm no more than once every day. Since improvement is universal, good in and of itself, and by definition, it is irrefutable. There will always be business improvements in the areas of productivity and quality. But in order for an improvement to be acknowledged, a problem must first be identified; otherwise, an improvement will never be required. This leads us to the conclusion that Kaizen draws attention to issues and offers solutions. Standardizing the improvement will allow the problem to be solved. To sum up, kaizen is a general idea that may be used in a variety of contexts (Imai, 1986) (Macpherson, 2015).

### 2.2.2 PDCA Cycle

Creating a solution was never an easy effort, and there was never a single approach that could be applied to all projects, whether it was in traditional project management or Lean methodology. At that point, Edwards Deming and Walter Andrew Shewart made the decision to create a straightforward technique that required little practice or discussion for a team to comprehend how to apply it (Imai, 1986).

This process, which has four improvement steps, is now known as the PDCA cycle:

1. **Plan:** Analyzing the starting point, spotting a chance, and creating a plan for change;
2. **Do:** The change's execution;
3. **Check:** Evaluate the strategy, evaluate the findings, and make conclusions;
4. **Act:** Repeat the cycle if the modification is unsuccessful. If the modification is successful, carry it out more broadly and keep an eye on the outcomes all the time.

### 2.2.3 ABC Analysis – Pareto's Law

In the 1800s, an Italian economist named Vilfredo Pareto created Pareto's law. This study, frequently referred to as the 80/20 rule, is a theory that suggests that a small percentage of sources—roughly 20%—usually account for the majority of problems—roughly 80% of them. When using this notion, one thing to keep in mind is that the 80/20 ratio should not be interpreted literally; rather, it is merely a sign that a minority of inputs often yield the majority of the results (Powell and Sammut-Bonnici, 2015).

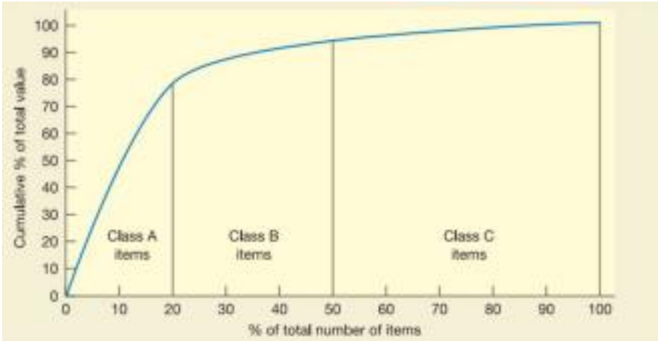



Figure 2.2 - Pareto curve and ABC analysis (Slack, Chambers and Johnson, 2010)

Based on the Pareto Law, ABC analysis is a classification technique that groups products into three classes (A, B, and C). This law is comparable to the ABC analysis, which states that 80% of the total demand is represented by a small percentage of products—roughly 20% of the population of products. These are the most significant products, and they are in Class A. Then, about 30% of the products and 15% of the total demand are in Class B, or intermediate importance products. Lastly, Class C includes the remaining 50% of products that are considered of low importance because their share of the market is only 5% (Muller, 2003).

### 2.2.4 Ishikawa Diagram

The Ishikawa diagram, also known as the Fishbone diagram, was developed in 1950 by Kaoru Ishikawa and is currently used in many industries. It is also known as a cause-and-effect diagram because it is an effective visual aid for determining the fundamental factors influencing an organization's and a team's performance. (Watson, 2004).

A cause-and-effect diagram may be used to determine the causes of a particular effect, benefit from group brainstorming and process expertise, graphically and rapidly visualize the process, pinpoint areas that require additional analysis, sort and identify relationships between the effect's causes, and analyze them to accurately eliminate them (Scorecard, 1996).

This diagram resembles the skeleton of a fish. The fish's head represents the central issue, while the skeleton's bones represent the roots. The main causes are represented by the ribs that branch off the back, while the root causes are represented by the sub-branches. These elements are similar to the bony structure of the fish skeleton. In order to determine the underlying causes of the problem, the Fishbone diagram can branch out into as many levels as needed (Trout, 2020).

The force-field analysis is the Fishbone diagram's progression. It essentially refers to those as restraints and should include all of the causes that the Fishbone diagram indicated. The circumstances and events that exacerbate the issue are known as restraining forces. These have the opposite effect of driving forces, which are beneficial impacts meant to offset the restraints (Juran and Godfrey, 1999).

### 2.2.5 Process Mapping

Process mapping is a crucial strategy for process optimization that makes processes easier to comprehend. To find inefficiencies and places for improvement, it entails putting the steps in a process into a visual representation that shows the process from beginning to end. This strategy has been widely used in many different industries to increase output, cut waste, and improve overall performance (Bowles, J. B., & Gardiner, L. R., 2018).

Process mapping usually entails several important steps. Clearly defining the process that is being mapped is the first step. This entails determining the process's inputs, outputs, and important actions. The procedure is then divided into discrete parts, and a flowchart, swimlane diagram, or value stream map are used to generate a visual depiction of the process. This aids in determining how information, resources, and actions move through the process (Martin, M. J., & Osterling, M. 2014).

Once the map is constructed, it is examined to find any inefficiencies, bottlenecks, and potential improvement areas. Finding non-value-added tasks, pointless procedures, and areas that can be automated or streamlined is part of this process. Adjustments are made to the process in order to make it better based on the analysis. To increase efficiency, this may entail rearranging workflows, getting rid of pointless stages, or introducing new technology (Bowles, J. B., & Gardiner, L. R., 2018).

Numerous advantages of process mapping for industrial productivity have been demonstrated, including more transparency, better communication, and increased efficiency. Process mapping can help cut waste and raise production levels by locating and removing inefficiencies. It is simpler to find opportunities for improvement because the process's visual depiction makes it evident how the procedure operates (Bowles, J. B., & Gardiner, L. R. 2018).

### 2.2.6 Standard Work

The simplest, safest, and most efficient approach to do a task is through standardization. Standard work is constantly evolving at Toyota because its goal is to lay the groundwork for future improvements. A process can be developed, verified, and improved with the use of standardized work. A series of actions with a known outcome is called a process (Dennis, 2015).

The following is a list and explanation of Dennis (2015) seven main advantages for implementing Standardized Work:

- **Process Stability:** Stability makes it possible to repeatedly achieve the targeted results in terms of lead time, cost, quality, and productivity, among other things;
- **Clear Stop and Start Points for Each Process:** These Takt Time knowledge-related points make it simpler to visualize how the production process works;
- **Organizational Learnings:** Standard work guarantees the retention of knowledge even in the event that more seasoned operators go;
- **Audit and Problem Solving:** Standard work enables you to evaluate the existing state of affairs and identify weaknesses;
- **Employee Involvement:** As a result, the operators who contribute to the standard work's development can spot opportunities for improvement to reduce errors;
- **Kaizen:** Standard work serves as the basis for continuous improvement;
- **Training:** Operator learning and training are based on standardized work.

Three charts—the Production Capacity Chart, the Standardized Work Combination Table, and the Standardized Work Analysis Chart—can be used as instruments to analyze, define, and quantify process improvements. These charts are examined below (Dennis, 2015).

**Standardized Work Combination Table**

The Standardized Work Combination Table lists all process aspects along with how long they take to complete, how much time is spent on each, how much time operators spend with machines, and how operators interact with one another or with the machine (Dennis, 2015).

**Standardized Work Analysis Chart**

The Standardized Work Analysis Chart, which includes the work layout and process steps together with their timings, enables you to analyze ways to optimize the layout and teach the operators (Dennis, 2015).

### 2.2.7 RACI

The RACI (Responsibility Assignment Matrix) is a powerful tool used to define and communicate roles and responsibilities within a project or process. It is a matrix that ensures that each task is given to the right person or team by listing the tasks, activities, or deliverables against the roles or individuals involved. By ensuring that all parties involved are aware of their duties and responsibilities, this framework helps to avoid misunderstandings and confusion (Scorecard, 1996).

A typical RACI matrix consists of four quadrants (Scorecard, 1996):

- **R (Responsible):** The person or team responsible for completing the task or delivering the output;
- **A (Accountable):** The person or team accountable for the outcome of the task or deliverable;
- **C (Consulted):** The person or team consulted during the task or deliverable, providing input and expertise;
- **I (Informed):** The person or team informed of the progress and outcome of the task or deliverable.

## 2.3 Quality Control

The idea of quality is crucial to the company's capacity to succeed in the face of intense competition in the market. Quality is about the wants and expectations (voice) of the customer, whether they are external or internal to the business and across different divisions. It extends beyond simply adhering to product standards (i.e., no defects); businesses also need to have a quality control program that guarantees adherence to these requirements, whether explicit or implicit. The term "quality" can therefore be employed as an attribute, denoting a feature inherent in the good or service, or as an adjective, signifying weak, good, or exceptional.

### 2.3.1 History of Quality

Frederick Winslow Taylor developed a novel method of manufacturing management in the United States at the beginning of the 20th century, which he named scientific management. Inspection departments were established in order to prevent defective products from reaching customers; the outcome was prioritized over the manufacturing process. Thus, the American System began to incorporate the assessment of production processes.

Subsequently, statistical techniques for analyzing and managing quality differences in the product manufacturing process emerged in Germany and America. A method called statistical quality control was created by Walter A. Shewhart. They began utilizing sample acceptance with H.F. Dodge and H.G. Romig, discarding the concept of comprehensive product quality inspection. The most well-known proponent of statistical quality control and quality management, William Edwars Deming, started instructing employees of enterprises engaged in wartime manufacturing at the start of World War II. With Deming's help, The American Society Quality Control was founded in 1946 (Hoover, 2012).

Japan suffered significantly from the war, and products with the "Made in Japan" label were often of low quality. The idea of "zero defect," which defines quality as compliance with standards, was first introduced by quality expert Philip Crosby in the 1970s and 1980s. America reacted to this new Japanese approach with Total Quality Management (TQM), and the first International Organization for Standardization (ISO) 9000 quality management standards were published in 1987, marking a significant advancement in the global evolution of the concept of quality. Versions of the ISO 9000 standards for quality management that are industry-specific have been added (Hoover, 2012).

### 2.3.2 Cost of Quality

First off, as per Crosby of Crosby and Associates, the price of quality is: “Quality is free; it´s non-conformance that costs!” (Campbell, 1995).

A company's quality cost is the sum of its expenses incurred from low quality and its efforts to achieve high quality. is the total of four categories (Campbell 1995):

- **Prevention** - costs to avoid quality issues before they arise. Examples: quality planning, quality control systems, among others;
- **Appraisal** - expenses incurred by the company to ensure that its goods and services adhere to quality standards. Examples: materials inspections, calibrations, testing, among others;
- **Internal Failure** - are faulty goods that were identified prior to production leaving the factory. Examples: bottlenecking, rework, downtime, scrap;
- **External Failure** - goods that are rejected but defects weren't found at the time they were taken from the factory. Examples: claims, loss of customers, warranty (replacement and repairs) and lawsuits.

### 2.3.3 ISO9001

An organization can use the ISO family of standards as a guide for implementing a system of quality management. The following are a few documents that belong to this family (Srđan Medić, 2016):

- ISO 9000 – fundamentals and vocabulary;
- ISO 9001 - which specifies requirements.

In 1987, the International Organization for Standardization produced a family tree. The standard states that "non-conformity" is the non-fulfillment of a condition, and "conformity" is the satisfaction of a requirement.

**Preventive action:** action taken (used to prevent occurrences) to remove the source of a prospective nonconformity or another potentially undesirable condition;

**Corrective action:** action taken with the intention of preventing recurrences to eliminate the cause of a detected nonconformity or another undesirable situation.

The current version of ISO 9001:2015 was released in September 2015.

Companies put the standard's standards into practice to show that they can reliably deliver goods and services that satisfy both legal and customer needs. This standard requires businesses to establish and record quality management systems, and then to confirm compliance with the standards through audits conducted by outside organizations certified for this purpose (Srđan Medić, 2016).

The basic principles of quality management:

- Costumer focus;
- Leadership;
- People commitment;
- Process approach;
- Improvement;
- Evidence-based decision making;
- Relationship management.

Compared to the 2008 revision, the most recent version from 2015 has more significant changes. The primary shifts in the comprehension of quality are related to leadership, knowledge as a resource, risk-based thinking, and organizational environment.

The primary modifications are:

**Context of the organization** – The confluence of both internal and external elements that may impact an organization's strategy regarding its investments, services, and products. Thus, the context of a company will affect how its quality management system is implemented;

**Risk based thinking –** It was included in its specifications for the creation, execution, upkeep, and ongoing enhancement of the quality management system. Risk is associated with possible events and is usually defined by the probability and impact of those events.

**Knowledge like a resource –** Knowledge is now a vital component and resource for projects that succeed and for the growth of businesses. the expertise required to complete the task in accordance with the QMS. Knowledge needs to be managed, including the risk of not acquiring it in a timely manner, and it must be preserved, safeguarded, and made available when needed.

**Leadership –** Top managers and company executives must be more involved in overseeing the quality management system. Promoting integration and alignment with company plans and processes is the aim.

The ISO 9000 standard states that (Priede, 2012):

- Conformity product: the state at which a prerequisite is met;
- Non-conformity product: is one that does not meet a criteria;
- Preventive action: (taken with the objective of preventing recurrences) activity to eliminate the cause of a detected non-conformity or another unpleasant circumstance;
- Corrective action: it can be implemented concurrently with a preventive action in order to eradicate a discovered non-conformity.

The ISO 9001 certification process involves a certification company that is qualified and independent of the organization to certify the certificate in accordance with the standard.

# 3 IP Activity and Analysis of the Initial Situation

The objective of this chapter is to present a thorough synopsis of the business's operations, emphasizing the production process and the starting situation noted. I tried to pinpoint crucial areas that require improvement through in-depth study to maximize production quality and efficiency.

First, the production process used by the company will be examined, outlining each step of the manufacturing process at the plant. To comprehend how each stage, from raw materials to the finished product, contributes to the result, an exhaustive procedure mapping is essential.

It will be shown then a process map that was created to graphically depict the factory's workflow. In addition to making the entire production chain easier to grasp, this mapping points up potential bottlenecks and places for development.

An additional crucial component of this chapter is the examination of unscheduled stoppages. Utilizing several analytical instruments, it was examined the origins of unexpected breakdowns in manufacturing. The development of solutions to lower downtime and, as a result, boost operational efficiency depends heavily on this analysis.

Furthermore, a thorough examination of the business's quality division will be conducted. This section will examine the department's procedures, the kinds of tests that are conducted, and an evaluation of the test findings. It is feasible to specify particular steps to raise the quality of the finished product when one is aware of the quality methods and the difficulties encountered.

Through performing this, it is hopes to have a comprehensive understanding of the company's current situation, highlighting its advantages and areas in need of improvement. This comprehensive understanding forms the foundation for creating the enhancements that are suggested in the upcoming chapter, which aims to raise the output and caliber of the made goods.

## 3.1 Productive Process

As the "heart" of the plant, the corrugator is the machine that produces corrugated board and is regarded as the most crucial piece of equipment to run. This machine, which has a length of 100 meters, is operated by seven people: the machine manager, exit operator, a palletizer operator, 3 operators of the machines and one forklift driver who helps load and unload materials from the machine. The corrugator is made up of two SF machines (BHS and Medesa), which comprise the area of the machine where the single-sided cards are produced (two splicers in each), one gluing machine (one splicer), a drying table, a single cutter, a creasing cutter, a double cutter, two output areas (lower and upper), a palletizer and a pallet conveyor with built-in pallet storage at the end of the output line.

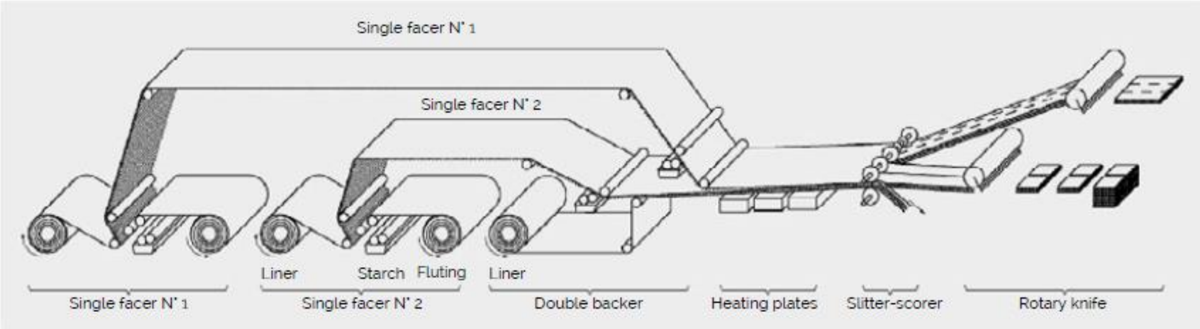



Figure 3.1 - Sketch of the corrugator machine (Ovar, 2018)

In the corrugator process, two names are used for the function of the paper: fluting and liner. The fluting represents the corrugated paper layer and the liner the paper layers below and on top of the fluting. Table 3.1 describes the types of paper used by International Paper and the characteristics that define them:

Table 3.1 - Types of paper used in the production of cardboards

| Function | Type | Characteristics |
|---|---|---|
| Liner | Kraft | is a paper with a high resistance to traction, tearing, and moisture that is mostly constructed of virgin fibers. Because of these characteristics, it is perfect for producing packaging with more intricate structures that call for higher resilience. |
| | Tesliner | is a paper that is made of a blend of recycled and virgin fibers, with white or brown fibers making up the top layer. Compared to kraft paper, it has less resilience to rupturing and varies in accordance with the percentage of virgin fibers in its composition. |
| Fluting | Semi-chemical | is a semi-chemically produced paper composed of 80% hardwood fibers and 20% resinous wood fibers. It has an intermediate level of resistance to breakage and humidity. |
| | Testliner | is a paper that is made of a blend of recycled and virgin fibers, with white or brown fibers making up the top layer. Compared to kraft paper, it has less resilience to rupturing and varies in accordance with the percentage of virgin fibers in its composition. |

There are numerous sizes and forms available for corrugated cardboard. The most popular is simple cardboard, which is created by combining an outer liner and an inner liner on a single face.

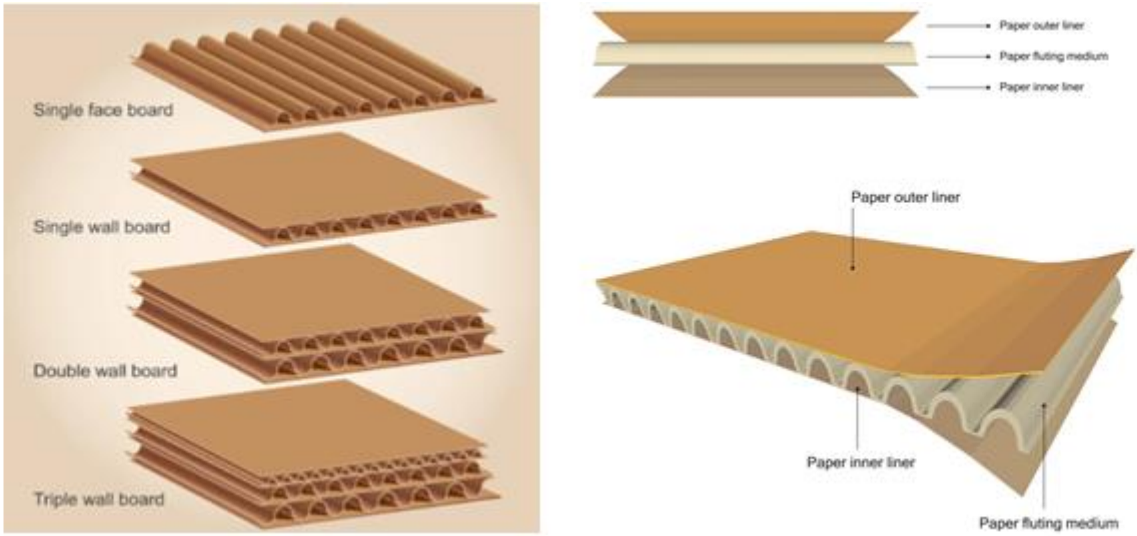



Figure 3.2 - Cardboards categories (Ovar, 2018)

Table 3.2 - Types of cardboards producted at IP

| Reference | Title | Thickness (mm) |
|---|---|---|
| E | Micro | 1.5 |
| B | Slim | 3 |
| C | Large | 4 |
| EB | Double Micro | 5 |
| BC | Double | 7 |

The process begins on the SF corrugator machines with the introduction of the paper reels for the program to be executed. To ensure uninterrupted production, the reels are fed into the two-reel splicer group, Figure 3.3. This allows for the replacement of paper when the splicers need to execute different programs.


Figure 3.3 - Spliced reel

The papers came from the warehouse and are sent to the SF machine where they are first heated by clamping them in the preheating rollers to make them easier to handle. Once the fluting paper is passed between the fluting rollers to take on its wavy form, glue is applied to the paper's wave peaks to enable the joining of the fluting to the inner liner and the formation of the single-sided paper. This is shipped to the corrugator bridge, where it is gradually moved to the gluer to allow it to cool and guarantee proper glue adhesion. The gluer unites the single face with the outer liner, which is subsequently transported by a synthetic blanket through the drying table.

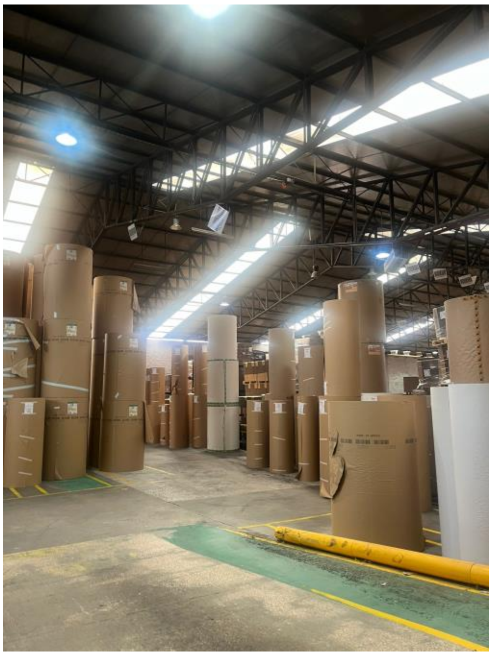


Figure 3.4 - Company warehouse

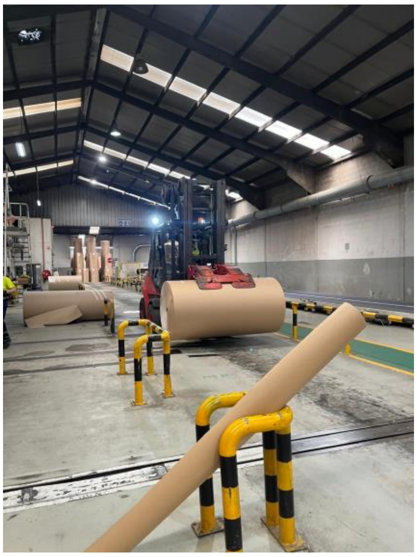


Figure 3.5 - Supply of reels by forklift

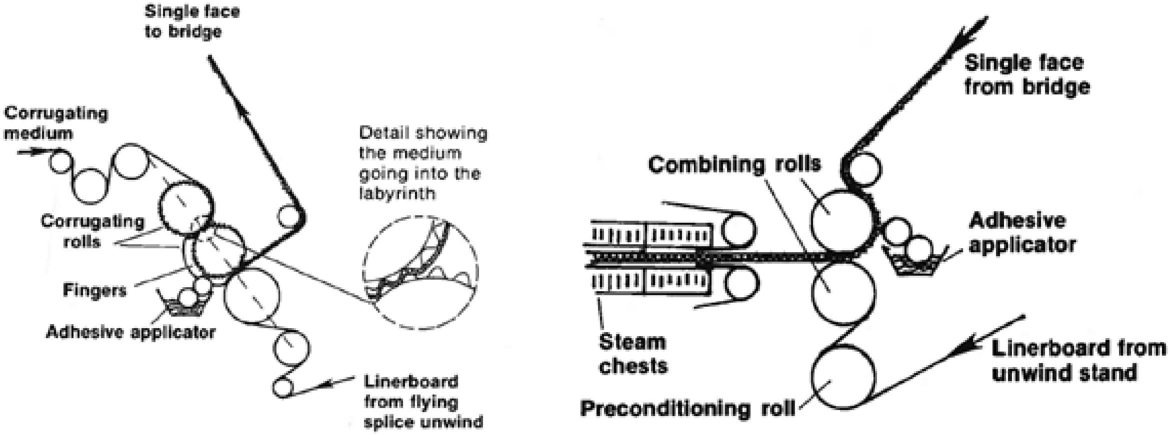



Figure 3.6 - Cardboard production process

The drying table is constructed with heating plates spaced along its length to allow the glue to reach its gel point and the cardboard to release any remaining moisture. The Simple Cutter, located at the drying table's exit, is equipped with a transverse blade that cuts the first meters of cardboard from each program (which is deemed waste), i.e., when there are modifications to the board's width, the fluting, or the way the papers are framed. Because the first meters of cardboard generated following a machine stoppage have been exposed to greater temperatures and so lost the qualities that characterize cardboard of the desired quality, it is also employed for this purpose.

The boards with the required dimensions are cut on the double cutter and the creasing cutter, respectively. To determine the width of the boards, the first cutter produces longitudinal cuts. It also trims waste, which takes the shape of side chips, and separates the boards if the program has two outs. The second cutter contains two blades, one for each output, and makes the transversal cuts that determine the length of the boards.

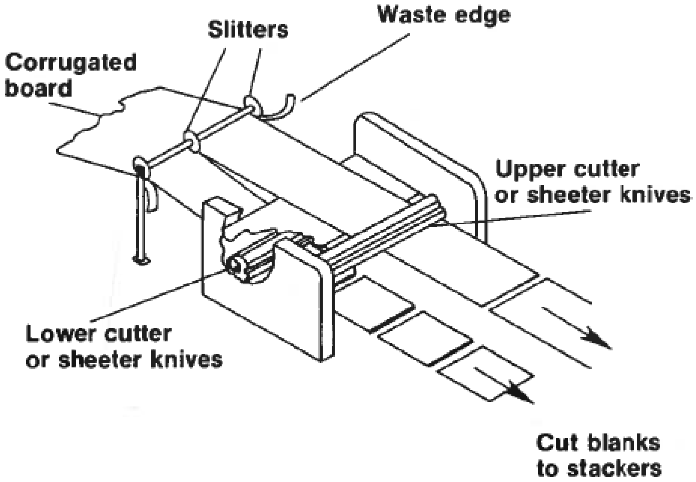



Figure 3.7 - Cutting process

Once the cardboard production process has been completed on the corrugating machine, the cardboard is subsequently stacked on boards. These can follow two different paths:

- Shipped directly to the customer without undergoing any further processing in the company;
- Stored in the WIP area for supply to the transformation lines in order to carry out the process of transforming corrugated cardboard into packaging.

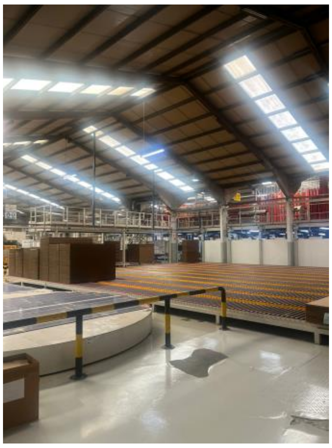


Figure 3.8 - WIP area

Following palletizing, the operator attaches the identification label to the pallet, which includes the following information: the customer's information, the type of cardboard, the order number, the card's measurements, and the date and time of manufacture.

## 3.2 Process Mapping

Process mapping is an essential tool for examining and enhancing industrial processes, particularly in settings where corrugated cardboard is produced. A thorough diagram of the corrugator's production process is displayed in Figure 3.9. The mapping's objective is to present a thorough and lucid picture of every phase of the procedure, highlighting important moments, equipment interactions, processes, and possible areas for development.

It is feasible to spot inefficiencies, bottlenecks, and areas for optimization by graphically recording every stage of the production process, from the receipt of raw materials to the shipping of completed goods. In keeping with the company's strategic goals, which include raising output, enhancing quality, and decreasing unscheduled downtime, this mapping provides a strong foundation for the implementation of continuous improvement projects.

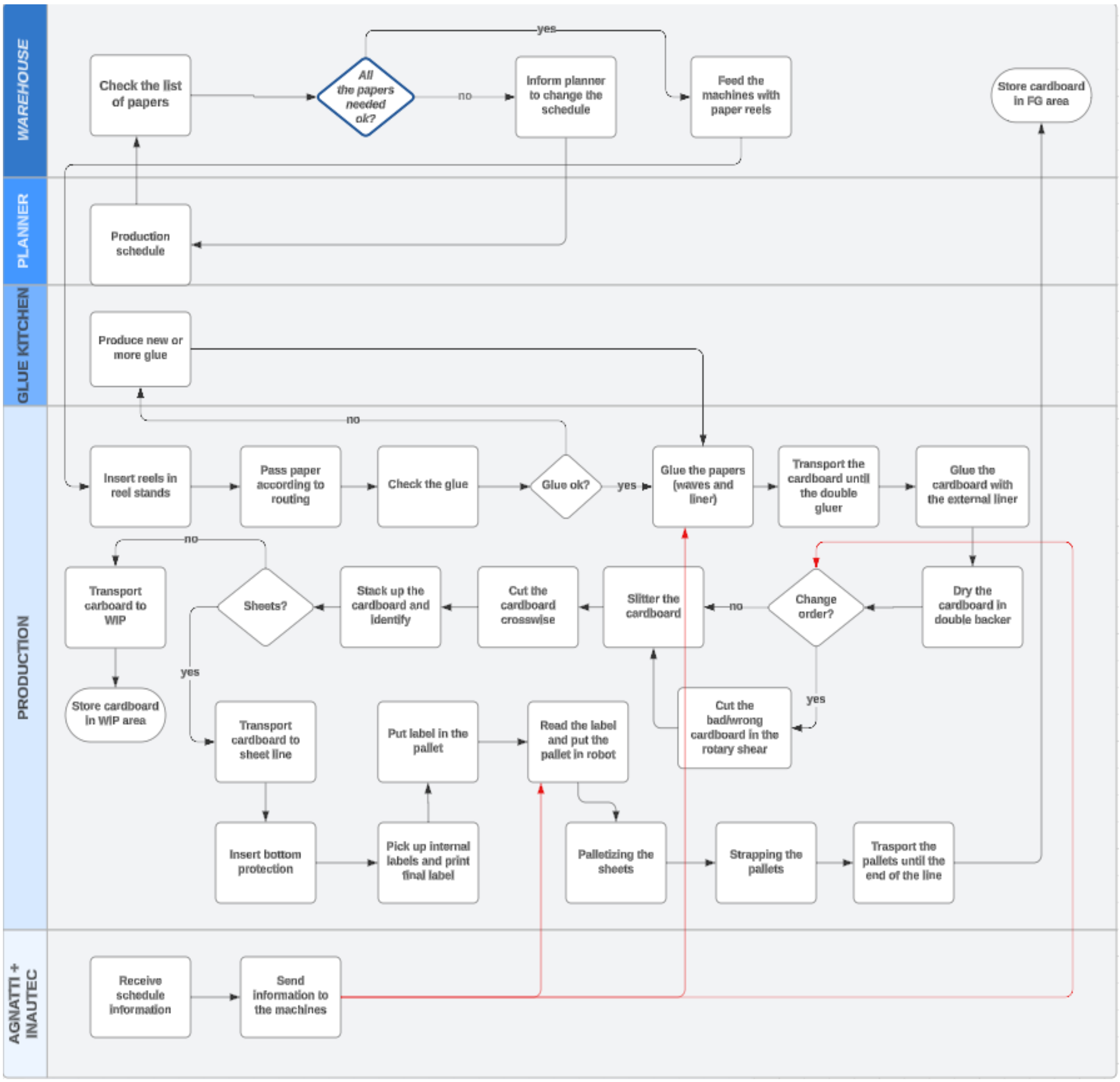



Figure 3.9 - Process mapping of corrugator machine

The process mapping that was done provided several insightful observations about the corrugated cardboard production processes. It was feasible to pinpoint crucial moments that have a direct bearing on the effectiveness and caliber of the finished product by thoroughly describing each step of the production process. This mapping not only offers a more thorough comprehension of day-to-day operations, but it also identifies certain areas where enhancements and interventions can be applied more successfully.

## 3.3 Unplanned Downtime

In manufacturing facilities, unplanned downtime, also known as PNP (Paragens Não Planeadas, in Portuguese), is a crucial indicator that has a direct effect on efficiency and production. This section examines the corrugator machine's unplanned downtime analysis with the goal of determining its root causes and opening the door for focused improvement initiatives.

The objective of this section is to identify the main causes of the Corrugator machine's unscheduled stoppage. Operational, mechanical, planning, specification, material, and tooling represent the six possible causes that were taken into attention. I applied Pareto's principle to construct this analysis. The data for the analysis in this section was collected using company software.

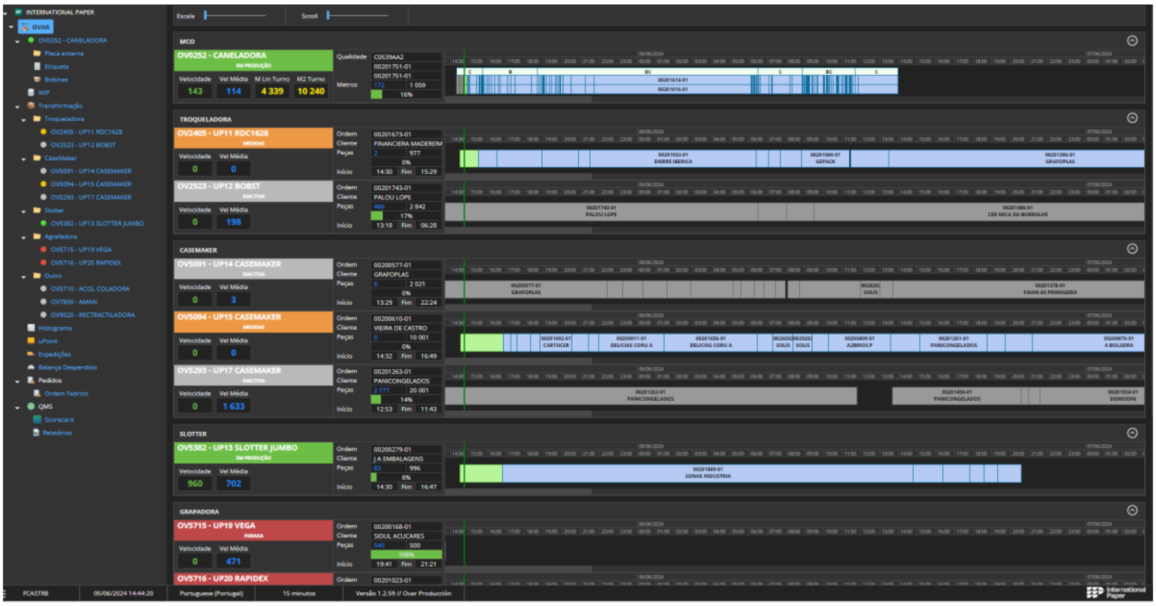


Figure 3.10 - Data system of IP

### 3.3.1 First level of Pareto

Firstly, all unscheduled downtime incidents that occurred in the first quarter of 2024 were carefully recorded. After conducting a thorough investigation using the Pareto principle, it was determined that operational and mechanical failures accounted for 80% of the cases of unscheduled downtime.

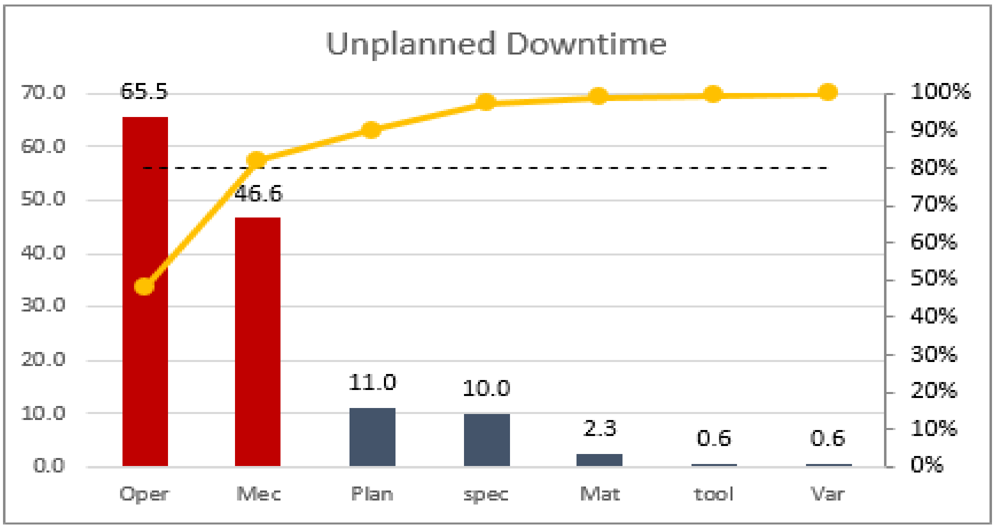



Figure 3.11- Main causes of unplanned downtime graph

There were important revelations on the underlying causes of unscheduled downtime from the Pareto analysis. Operational failures—which include problems with human error, process deviations, and poor practices—came to be the main cause and accounted for a significant percentage of the downtime incidents. The difficulties with downtime were further compounded by mechanical failures, which connected to equipment malfunctions, breakdowns, and maintenance-related problems.

The results highlight how crucial it is to fix mechanical and operational flaws in order to successfully reduce unscheduled downtime. In order to address these underlying reasons and ensure further productivity gains for the corrugator machine, focused interventions and improvement projects will be created and put into action going forward.

This analysis sets the stage for proactive measures aimed at minimizing unplanned downtime, optimizing machine performance, and bolstering overall manufacturing efficiency within the paper-to-cardboard conversion facility.

### 3.3.2 Second level of Pareto

After carrying out a Pareto analysis to identify the main contributors to unplanned downtime, a more in-depth investigation was carried out focusing on the two main causes: operational failures and mechanical failures through a second level of Pareto analysis.

Within the category of Operational causes, further analysis revealed that 80% of the unplanned downtime instances were attributed to three main factors: splice failure, jams, and cleaning issues.

In the same way, an analysis of the Mechanical category's unplanned downtime cases showed that 80 percent of them were caused by malfunctions in particular machinery parts, such as the Medesa and BHS machines channels, the upper output, and the slitter-scorer machine.

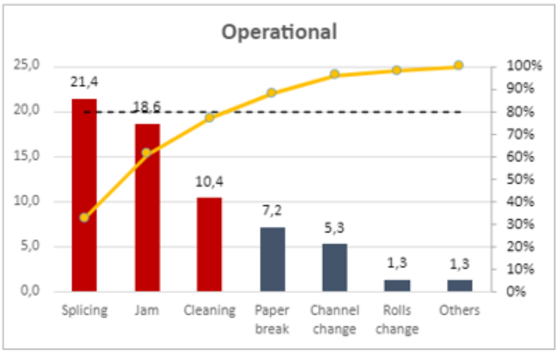



Figure 3.12 - Operational downtime graph

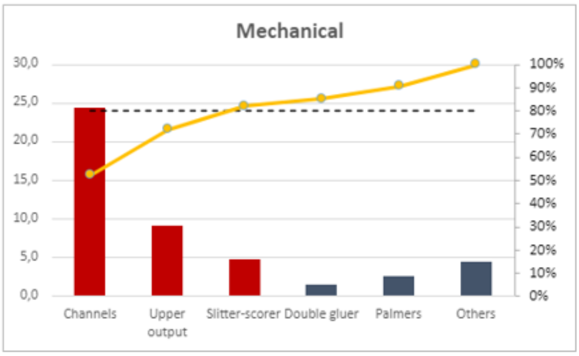



Figure 3.13 - Mechanical downtime graph

### 3.3.3 Individual Analysis

In order to carry out an even more in-depth analysis and see which is the biggest cause within each cause discovered, several meetings with the head of the corrugator were helded, talked to several corrugator operators to get even more information. Instruments like the Ishikawa diagram was used to properly arrange the data and it was employed the five whys technique in meetings to obtain more details and greater accuracy.

**Splicing**

Regarding unplanned stoppages related to splicing failures, further analysis revealed that the most critical failure occurs at reel holder 10. Splicing is a crucial process that involves hooking one reel onto the end of another, allowing continuous production with a minimal reduction in speed. The splicing process consists of the operator placing a strip of glue across the bar that will be applied to the initial part of the paper reel, which will continue when the reel is finished running. This stage is essential to avoid significant interruptions in production.


Figure 3.14 - Splicing failure

In order to identify and make clear all the causes of this problem, I met with the head of the fluting machine, spoke to the operators on the shop floor, had meetings with the maintenance department and, using an Ishikawa diagram, I gathered all the causes of this problem.

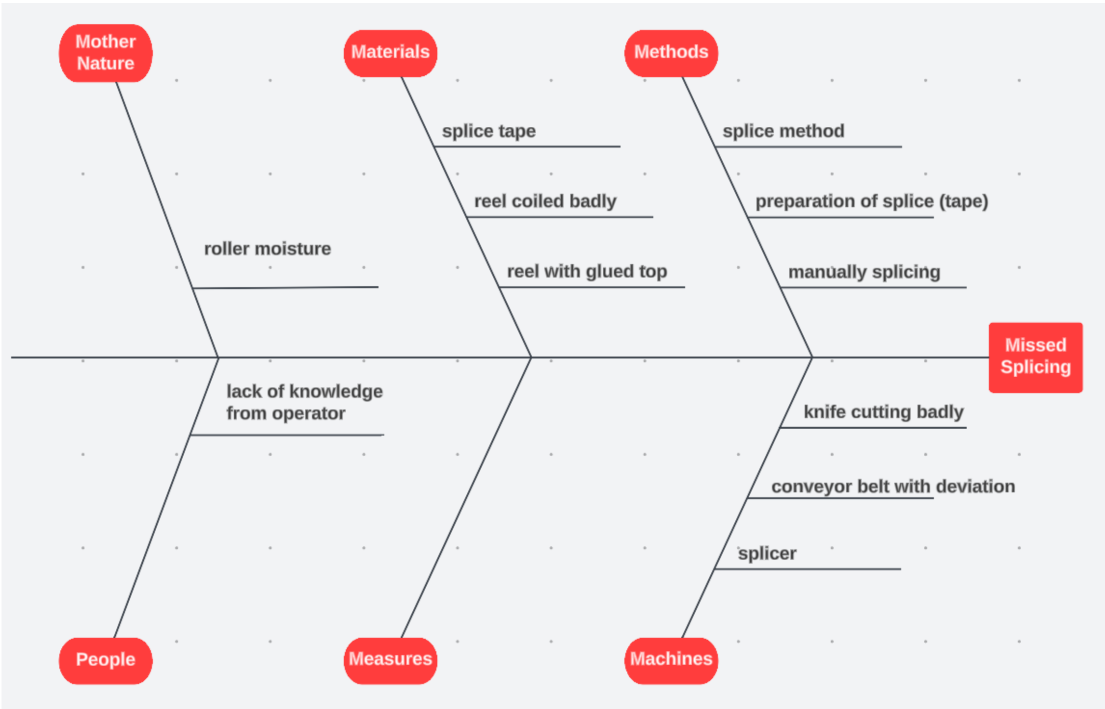



Figure 3.15 - Ishikawa diagram of missed splicing

After individually analyzing each cause for the splicer failure effect, there was a focus on the causes with the highest incidences “reel with glued top” and “splicer”. To do this, it was used the 5 whys, which is an iterative technique used to explore the cause and effect relationships underlying these specific problems.

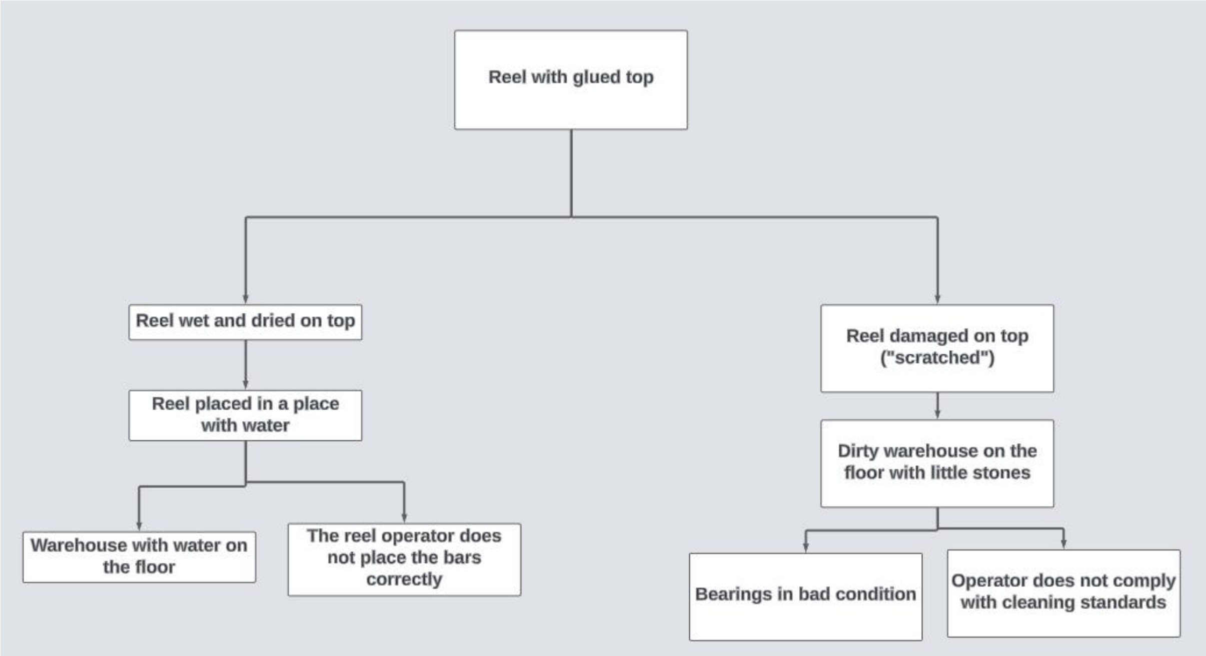



Figure 3.16 - 5 why´s analysis of reel with glued top

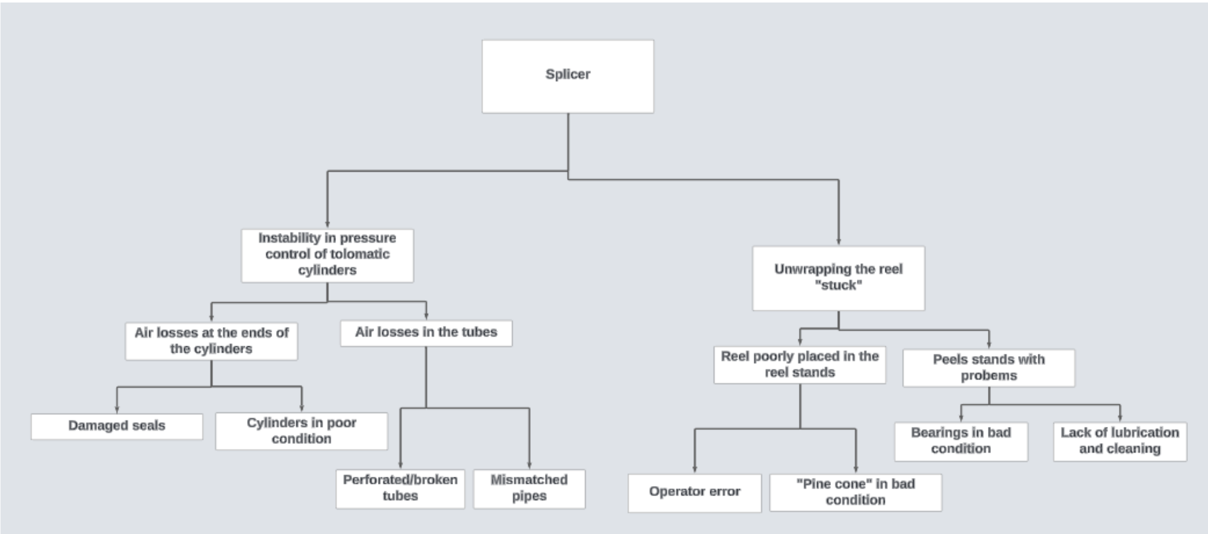



Figure 3.17 - 5 why´s analysis of splicer

## Jams

The second unplanned stoppage analyzed is jamming and the biggest cause of jams is located in the lower cutter. This critical component is located at the end of the corrugator line, after the paper has been transformed into cardboard. Its main function is to cut the sides of the board, which is being transported on the lower tray. It is important to note that the presence of two trays, lower and upper, at the final stage of production allows two orders to be prepared simultaneously, increasing the operational efficiency of the production line.

Figure 3.18 - Stabilization mechanism after cutting

By analyzing the information on unplanned stoppages due to the lower cutter and cross-referencing it with the order description, it was concluded that this type of jam mainly affects the production of cardboard orders with a length of less than 700 millimeters. The possible reasons are that the accessory used to help the cardboard remain stable after cutting is too small or does not offer the grip that the cardboard requires.

**Channels**

A more in-depth analysis of stoppages due to channels showed me that channel C is undoubtedly the channel with the highest frequency of unplanned stoppages. This behavior was associated with several different problems in the operation of the BHS machine.

The main reasons for these stoppages were discovered during in-depth interviews with the corrugator manager, the operators, the production and maintenance departments and by analyzing data from the company's software.

A significant cause of downtime is related to the machine's parallels. The parallels are bars that work automatically to adjust and limit the amount of glue applied to the paper. They recognize the width of the paper and feed glue along that width. The problem stems from the parallel sensor that measures the width of the paper. If the sensor applies more glue than necessary due to an erroneous assumption that the paper is wider than it actually is, this results in excessive accumulation and will consequently lead to a jam.

Figure 3.19 - Machine´s parallels

The motor roller belts are another reason for stoppages. These belts are located in an area where debris is likely to accumulate. The accumulation of debris can cause the belt to malfunction, which can lead to direct engine failure.

Figure 3.20 - Motor roller belts

The last and most common cause is stuck rollers The rollers make the corrugation in the cardboard and therefore have glue along them. These are replaced depending on the type of curl required. After several conversations with the operators and the machine manager regarding this problem, I have come to the conclusion that the only reason for this problem is poor washing performance on the part of the operators. This conclusion is essentially due to two reasons. The first is because this problem always happens when production starts on channel C and the second is because recent maintenance plans had been carried out on the rollers and the problem always remained. Therefore, it was concluded that there was a flaw in the subsequent production process since the glue remained on the rollers after they were replaced because of inadequate cleaning.

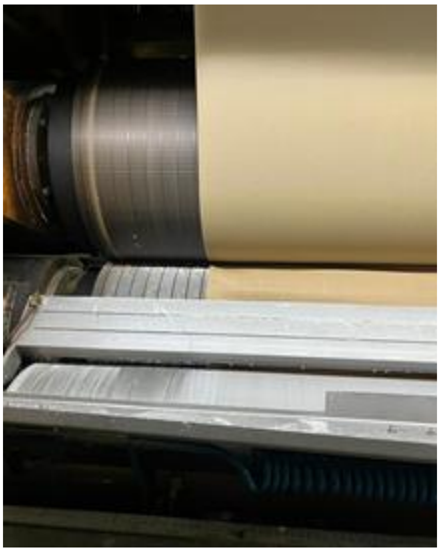


Figure 3.21 - BHS rollers

This individual analysis of the causes of unplanned downtime allows for a deeper understanding of the critical areas for improvement in the corrugating machine, providing valuable information for future interventions aimed at improving operational efficiency and minimizing interruptions in production. Once these reasons for unplanned downtime have been identified, the next stage involves designing improvement strategies.

## 3.4 Quality Department

The quality department is essential to any business because it ensures that the goods and services provided are of the highest caliber. This department, which is in charge of monitoring and managing all areas of quality, is essential to preserving customer happiness, adhering to legal requirements, and continuously streamlining corporate operations.

This company's quality department carries out several crucial tasks to guarantee the standard of the goods and services provided. Among the principal duties are:

- **Cardboard Quality Tests**: Quality tests are frequently carried out to evaluate the conformity of the cards manufactured with the prescribed quality standards. These tests include the Mullen and Edge Crush Test (ECT), as well as grammage measurement;
- **Handling Customer Complaints**: Customer complaints about cardboard quality are received, looked into, and resolved by the Quality Department, which makes sure that a prompt and efficient response is provided to keep customers happy;
- **Supplier Evaluation**: In order to make sure that suppliers fulfill the company's quality criteria, a comprehensive examination of them is conducted. This involves adhering to particular quality standards and requirements that the business has established;
- **Document Control**: Before being implemented, new papers must be validated by the Quality Department to make sure they adhere to the rules and guidelines;

- **Frequent Quality Meetings**: To address quality-related concerns and carry out ongoing process improvements, the Quality Department meets on a regular basis with all departments within the organization;
- **Internal Audits**: Every year, at least one internal audit is conducted to evaluate adherence to quality standards and pinpoint opportunities for enhancement;
- **Management of Applicable Legislation**: The Quality Department makes sure that the business complies with rules by keeping an eye on and guaranteeing adherence to pertinent laws in a variety of sectors, including water, safety, fire, environmental, and chemicals;
- **Supply of Material for Operators**: The Quality Department offers assistance and resources for process measurement and monitoring, guaranteeing adherence to set quality standards.

### 3.4.1 Quality tests

The company's Quality Department regularly conducts a number of demanding tests as part of its continual commitment to excellence and raising the standard of the boards it produces. These tests, which evaluate whether a product complies with the necessary norms and specifications, are carried out daily with an emphasis on quality control and assurance.

The Department of Quality conducts three main types of tests on produced cardboard in response to the growing demand for high-quality products and the need to meet customer expectations. To evaluate the various properties of the cardboard, ranging from its resistance to its density, each test is meticulously planned.

To ensure accurate and trustworthy results, each test is conducted in accordance with stringent protocols and makes use of specialized equipment. Only high-quality items are provided to consumers because the Quality Department strictly controls the quality of the cardboard manufactured, establishing acceptance limits and guidelines for each test.

The samples are first moved from production to the laboratory of the quality department, where they can rest for a full day in order to allow the cardboard's temperature and humidity to settle. The ideal temperature is 23±1 ºC and the ideal humidity is 50±2 %. The testing are then initiated based on the first-in, first-out (FIFO) concept.


Figure 3.22 - Sample stabilization zone

**Weight test**

Weight is important because it influences other properties of cardboard, including physical resistance, directly. The weight of a sample is calculated as the ratio of its surface area to its weight. g/m2.

First, we cut off 10x10 cm samples and place them on the scales to begin the test. For every sample that is gathered, a test is conducted.

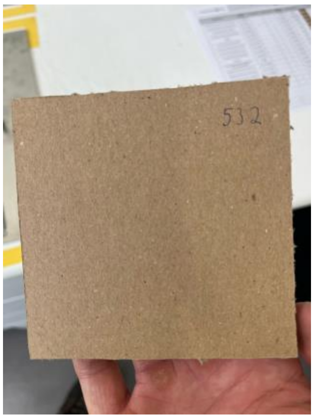


Figure 3.23 - 10x10cm sample

Figure 3.24 - Scale used for the tests

**Edge Crush Test (ECT)**

ECT represents the corrugated board's edgewise compressive strength.

This test aims to evaluate the cardboard's vertical compressive strength. A rectangular piece of corrugated cardboard with its corrugations positioned perpendicular to the plates is placed between the plates of the compression equipment. After this, the sample is further compressed until its maximum strength, measured in kN/m, is achieved.

Figure 3.25 - ECT machine

A cardboard sample that is 10 by 30 centimeters in size is first cut in order to perform the test. After that, a 2 x 10 cm specimen that will be used only for the ECT test is cut with a guillotine. Next, the specimen is placed vertically in the proper location. Five tests are carried out on each cardboard sample.

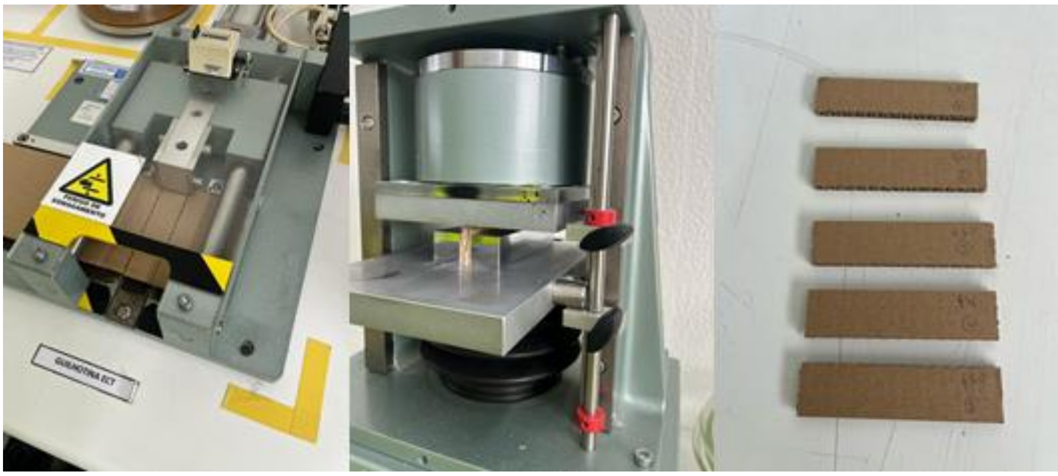


Figure 3.26 - ECT sample process

**Mullen Test**

The Mullen Burst Box Strength Test calculates how strong your cardboard boxes will burst when pressure is applied. The Mullen Test basically establishes the maximum pressure a box can bear before it ruptures or develops a hole. This makes it easier to determine how much weight and pressure your box can withstand from outside sources before breaking.

In this test, a piece of the cardboard sample is placed directly into the equipment. Three tests are carried out on each side of the card (inside and outside).

Figure 3.27 – Mullen test process

### 3.4.2 Tests Analysis

In this section, a detailed analysis of the quality tests was carried out in the company's quality department referred to in the previous section. Through this analysis, it was identified the lack of a well-defined rule regarding the number of tests carried out, both for the most produced cards and for those that require more rigor in certain tests.

| DATA | MFO/CO | CARTÃO | REFERENCIA | DESIGNAÇÃO PRODUTO | TIPO CARTÃO | GRAM MÉD | GRAM D.PAD. | Lim Inf | Valid | ECT MÉD | ECT D.PAD | Lim Inf | Valid | MULLEN MÉD | MULLEN D.PAD | Lim Inf | Valid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/8/2024 | 181836 | C0597AA1 | 10200 | Saida Superior | C (LARGO) | 485 | 1.5 | 477 | BOM | 6.19 | 0.2 | 5.2 | BOM | 1060 | 78.1 | 842 | BOM |
| 1/8/2024 | 181837 | C0597AA1 | 10200 | Saida Inferior | C (LARGO) | 489 | 2.5 | 477 | BOM | 5.62 | 0.1 | 5.2 | BOM | 1029 | 76.6 | 842 | BOM |
| 1/8/2024 | 182157 | C0356BA1 | 10200 | Saida Superior Lado Centro | C (LARGO) | 365 | 3.6 | 351 | BOM | 3.68 | 0.0 | 3.33 | BOM | 462 | 50.9 | 384 | BOM |
| 1/8/2024 | 182157 | C0356BA1 | 10200 | Saida Superior Lado Transmissao | C (LARGO) | 367 | 1.2 | 351 | BOM | 3.59 | 0.2 | 3.33 | BOM | 493 | 41.4 | 384 | BOM |
| 1/8/2024 | 182401 | C0539AA2 | 10200 | Saida Inferior LO + Centro | C (LARGO) | 447 | 1.5 | 426 | BOM | 5.05 | 0.1 | 4.57 | BOM | 644 | 30.8 | 554 | BOM |
| 1/9/2024 | 182372 | E0380BA1 | 10200 | Saida Superior Centro | E (MICRO) | 319 | 1.5 | 306 | BOM | 2.34 | 0.1 | 2.7 | MAU | 374 | 28.5 | 369 | BOM |
| 1/9/2024 | 182372 | E0380BA1 | 10200 | Saida Superior Lado Transmissao | E (MICRO) | 319 | 2.0 | 306 | BOM | 2.13 | 0.0 | 2.7 | MAU | 375 | 38.3 | 369 | BOM |
| 1/9/2024 | 182375 | EB0639AA1 | 10200 | Saida Inferior LO + Centro | DUPLO EB | 478 | 2.1 | 460 | BOM | 4.86 | 0.2 | 4.6 | BOM | 558 | 15.0 | 554 | BOM |
| 1/9/2024 | 182388 | EB0652BA1 | 10200 | Centro | DUPLO EB | 521 | 3.1 | 495 | BOM | 4.68 | 0.1 | 4.7 | MAU | 545 | 72.3 | 505 | BOM |
| 1/9/2024 | 182388 | EB0652BA1 | 10200 | Saida Inferior LO | DUPLO EB | 524 | 1.5 | 495 | BOM | 4.60 | 0.1 | 4.7 | MAU | 530 | 36.3 | 505 | BOM |
| 1/9/2024 | 182491 | B0355BA1 | 10200 | Saida Inferior LO | B (FINO) | 353 | 2.6 | 349 | BOM | 3.25 | 0.1 | 3.13 | BOM | 399 | 19.2 | 382 | BOM |

Figure 3.28 - Excel for test results

The quantity of tests that the quality department administered in January and February were noted, together with the corresponding success rate, in Figure 3.29. Whether the values obtained are above or below the specified lower limit determines whether the test findings are categorized as "GOOD" or "BAD". The ISO9001 quality standards and the business's quality goals are used to compute this lower limit. Test results that are below this threshold point to problems that should be addressed and improved in order to ensure the product's consistency and quality.

| TEST | No. Of Tests | "GOOD" (%) |
|---|---|---|
| Weight Test | 236 | 100 |
| Edge Crush Test | 236 | 37 |
| Mullen Test | 236 | 82 |

Figure 3.29 - Total number of tests carried out in January and February

An analysis of these tests reveal an obvious problem with the ECT (Edge Crush Test). Due to the critical importance of the ECT, it was decided to investigate this test further. The ECT is a crucial test that measures the edge strength of a cardboard sample, determining its ability to withstand vertical compression forces. This test is essential to ensure cardboard boxes are sturdy and of high quality, especially those made to support large loads. To guarantee that packaged goods are safeguarded during storage and transit, ECT is an essential measure of the structural integrity of cardboard.

The cardboard produced at the factory has two main purposes, the self-supporting boxes, which are boxes in which it is the product itself that supports the vertical loads; and support boxes, which are boxes that have the purpose of supporting other boxes on top. Strength and durability are crucial, as these boxes need to withstand the weight of other boxes stacked on top of them. In this way, ECT is especially important for support boxes, as it defines whether a carton is strong enough to withstand heavy loads, making the whole subsequent production process more efficient. Therefore, the aim was to focus on analyzing the tests carried out on the cardboard most produced in the company, and essentially, the cardboard that is produced for the purpose of support boxes.

Given the problem identified with the ECT tests, the focus was directed towards the cards most produced in the company, and above all those produced for support boxes. Therefore the focus of this analysis was on the two most produced cards in the factory, which although they are not for support boxes, represent around 30% of production, and on the most produced card in the factory that is intended for support boxes, the C0539. Since there is a great lack of tests, which makes a more in-depth analysis difficult, it is clear that increasing the number of tests carried out would be essential.

In conclusion, the initial analysis of the quality tests highlighted the need for a more structured and consistent test plan, especially for critical cards such as C0539. Implementing a standardized process for carrying out quality tests, with a special focus on ECT, is essential for improving the consistency and quality of the company's products.

### 3.4.3 Complaints

Customer concerns are handled in large part by the Quality Department. In addition to posing a challenge to the caliber of goods and services provided, the high amount of complaints has a big effect on the company's reputation and operational expenses.

The large number of complaints directly affects several facets of the business's operations. First of all, complaints point out areas that need quick attention and improvement in production and quality processes. Furthermore, the requirement to handle complaints uses up valuable resources, such as time and labor, adding to the company's expenses.

Once all the reasons for the complaints received have been analyzed, these are the three most relevant reasons:

- **Quantity less than ordered**: When customers receive fewer products than they ordered, this results in dissatisfaction and can negatively affect delivery times and customer relations;
- **Non-Conforming Product (NC)**: Complaints related to product quality, such as manufacturing defects or non-compliance with specified quality standards, represent a critical concern for the company. These complaints undermine customer confidence in the brand and can lead to returns and financial losses;
- **Product Damaged During Transportation**: Another frequent reason for complaints is damage to products sustained during transit. This impacts not just the company's reputation and customer satisfaction but also adds to the expenses of replacing or repairing the damaged goods.

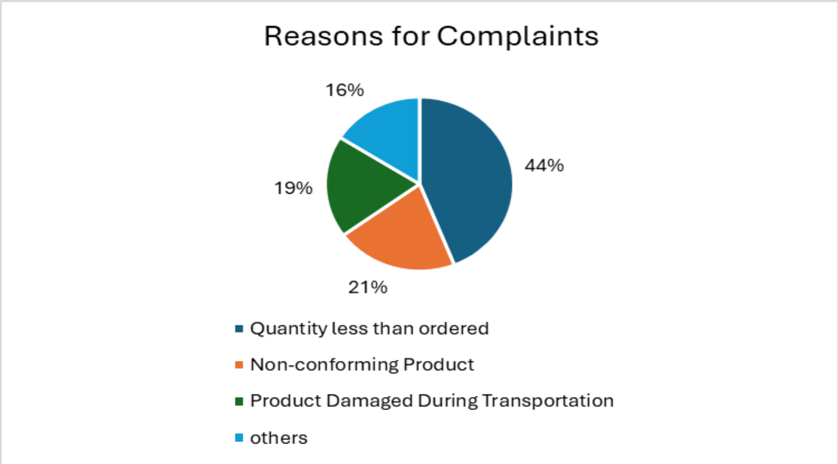



Figure 3.30 - Graph of complaint reasons

Given the high percentage of complaints about under-quantification, the focus was to investigate this reason more deeply. In order to accomplish this, it was conducted a few meetings with the production and quality departments in an effort to better grasp this issue. It was made a deeper analysis in order to arrange all the data.

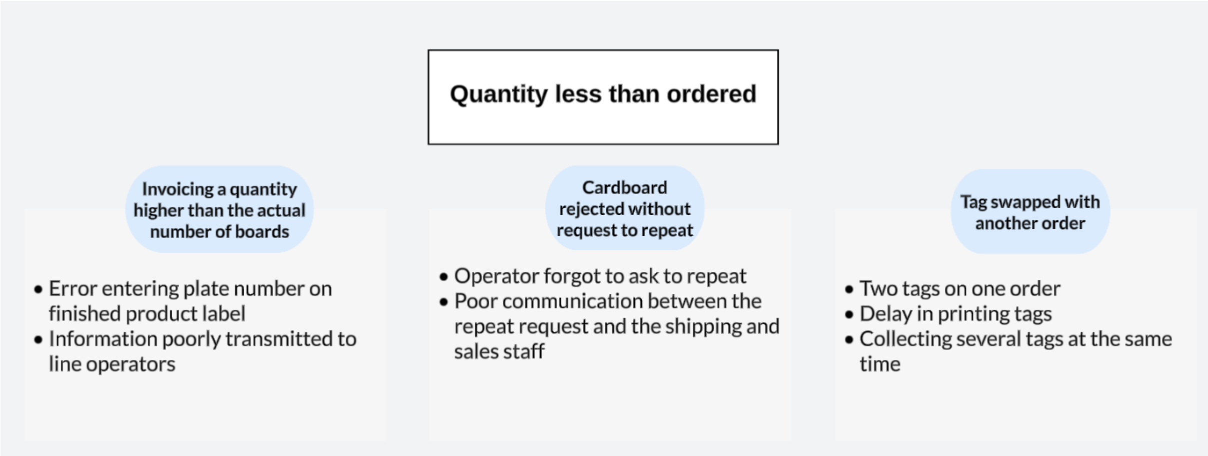



Figure 3.31 - "quantity less than ordered" complaints analysis

In order to prevent future recurrences, the Quality Department is responsible for taking proactive measures to respond to customer concerns, conducting thorough investigations into each case and implementing corrective and preventive measures. It is also responsible for ensuring efficient communication with customers, responding quickly and offering satisfactory solutions to effectively resolve complaints. The next chapter shows the work carried out and the actions implemented to help reduce complaints.

# 4 Project Development and Analysis

This chapter addresses the fixes and adjustments applied to the previously mentioned issues, outlining the different tactics used to cope them.

Not only the solutions´ implementation methods are explained, but also the difficulties encountered throughout the process, the outcomes obtained, the associated performance metrics, a comparative analysis and also it´s feedback.

## 4.1 Unplanned Downtime

In this section, it will detail the actions developed and implemented with the aim of reducing unplanned downtime at the Corrugator machine. Following the thorough examination described in Chapter 3, it was created an action plan with an emphasis on the "Do" phase by using the PDCA (Plan-Do-Check-Act) tool. It was implemented the RACI (Responsible, Accountable, Consulted, Informed) matrix to guarantee effective management and well-defined roles. It was made possible for better task monitoring and execution.

**Development of the Action Plan**

To combat the main causes of unplanned downtime, it was developed an action plan, you can see in Figure 4.1. This plan was drawn up in collaboration with the maintenance, production and quality departments, as well as with the head of the Corrugator. From the start of the project to the end, it was held weekly productivity meetings with these entities to discuss the problems encountered and the suggestions for improvement with the objective to arrive at consolidated and effective actions. At the same meetings, additional problems were presented and discussed, contributing to a even more insight into the factory's activity. It was thanks to these meetings that I was able to create this plan and achieve such good results.

| Problem | Action | Responsible | Accountable | Consulted | Informed | Data | Frequency | Status |
|---|---|---|---|---|---|---|---|---|
| Splicing failure | Tune the cutting blade | MD | MM | HC | | 04/08/2024 | weekly | DONE |
| | Changing the reel holder brakes | MD | MM | HC | | 19/4/2024 | | DONE |
| | Cleaning the base where the blade enters | MD | MM | HC | | 24/4/2024 | weekly | DONE |
| | Training the splicing process | HC | PM | HS | | 22/5/2024 | | DONE |
| | Maintaining the spool holder cylinders | MD | MM | | HC | 14/3/2024 | weekly | DONE |
| Lower cutter jam | Replacing the tubes with metal sheets | MD | MM | HS, HC | | 13/4/2024 | | DONE |
| | Replacing the sheets with new, more bendable tubes - develop project | MD | MM | HC | | 15/5/2024 | | DONE |
| BHS channel change | Cleaning the BHS rollers | MD | MM | | | 17/4/2024 | daily | DONE |
| | Training in the correct roller cleaning process | HC | PM | HS | | 05/08/2024 | | DONE |
| | Cleaning barriers | MD | MM | HC | | 17/4/2024 | weekly | DONE |
| | parallel sensor maintenance | MD | MM | HC | | 04/03/2024 | monthly | DONE |
| | Cleaning the belts | MD | MM | HC | | 04/10/2024 | weekly | DONE |
| | Develop belt protection | MD | MM | HC | PM | 22/5/2024 | | ON GOING |
| Others | Make it mandatory to justify unplanned stops | HC | PM | | | 17/4/2024 | daily | DONE |
| | Warehouse cleaning | MD | MM | | | 05/08/2024 | weekly | DONE |
| MD - Maintenance Department ; MM - Maintenance Manager ; HC - Head of Corrugator ; PM - Production Manager ; HS - Head of Security | | | | | | | | |

Figure 4.1 - Action plan for unplanned downtime

The steps were carried out in a structured way and were continuously monitored. Each step of the action plan was monitored through weekly meetings with the teams involved, i.e. there was always a follow-up after the actions had been implemented. In addition, the operators took part in specialized training sessions, with an emphasis on improving specific work processes, such as the splicing procedure, which is one of the main sources of downtime and is illustrated in the next section.

### Follow up

I conducted multiple follow-up activities and an effect confirmation in order to gauge the efficacy of the actions that were put into place. Through the collection and analysis of post-implementation data, it was possible to measure the decrease in unscheduled downtime and make the necessary adjustments to the activities. The outcomes and enhancements noted following the action plan's implementation are shown in Figure 4.2.

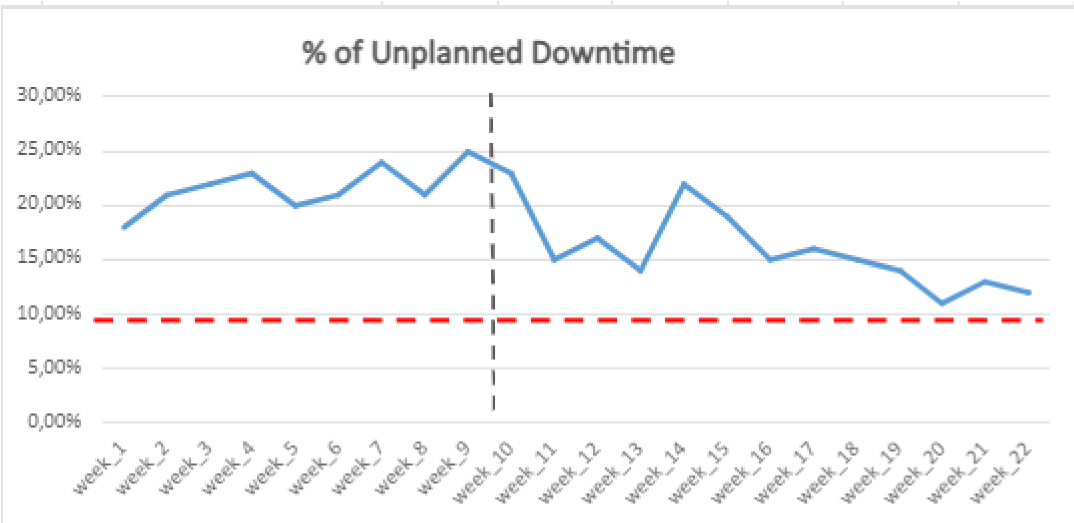



Figure 4.2 - Follow up of % of unplanned downtime graph

It can be analyzed that from the moment the actions were implemented, there was a decrease in the percentage of unplanned downtime. It can clearly be seen that up until week 10, the canneler had an average of 22% unplanned downtime and between week 17 and 22 she had an average of 13% downtime, which means a decrease of approximately 41%.

Through an individual analysis of the percentage of downtime for each unplanned stoppage that was worked on this project, as you can see in Figure 4.3, it is possible to see a significant improvement in all the causes analyzed, especially with regard to jams in the lower cutter, which fell by around 70%.

| Cause of Downtime | Jan | Feb | Mar | Apr | May | Impact |
|---|---|---|---|---|---|---|
| Splicing failure | 3,0% | 5,0% | 3,2% | 2,4% | 2,5% | 37.50% |
| Lower cutter jam | 1,0% | 1,2% | 1,5% | 0,9% | 0,3% | 72.70% |
| BHS change channel | 2,5% | 2,1% | 2,2% | 0,7% | 1,1% | 52.20% |

Figure 4.3 - Analysis of the percentage of major unplanned stops

| Month | Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|
| No. Of Unpanned Downtime | 394 | 365 | 359 | 288 | 237 | 244 |

Figure 4.4 - Unplanned downtime frequency

Another way of proving the effectiveness of the actions taken is the reduction in the frequency of unplanned stoppages. In the first quarter there was an average of 373 stops, while in the second quarter there was an average of only 256. This decrease means a reduction of approximately 31% in the frequency of unplanned stops.

**Conclusion**

The implementation of the actions described in this chapter proved to be significantly effective in reducing unplanned stoppages at the fluting machine. By utilizing management methods like PDCA and RACI, together with a cooperative and methodical approach, the primary reasons of inefficiency were found and addressed. The outcomes show how crucial it is to have thorough planning and ongoing oversight in order to ensure long-term increases in the output and standard of industrial operations.

## 4.2 Quality

This section focuses on the steps taken in response to the issues that were discovered and examined in the preceding chapter. These issues pertain to both product quality and issues that fall under the responsibility of the quality department's control.

To address these issues, it was developed an action plan, which you can view in Figure 4.5, to clarify the steps that were planned and implemented throughout the project to address the difficulties that arose.

The action plan consists of a number of strategic interventions intended to tackle the most pressing issues related to quality, employing a methodical approach to guarantee notable and long-lasting gains. This section provides a more detailed presentation of the most influential activities.

| # | Action | frequency | Data | Status |
|---|---|---|---|---|
| | **Low number of quality tests carried out** | | | |
| 1 | planning for production of the number of samples to be taken per carton type | monthly | 28/02/2024 | done |
| 2 | regular auditing of the samples taken by production | weekly | 30/04/2024 | done |
| 3 | monitoring the tests carried out by the quality department | weekly | 15/04/2024 | done |
| | **High percentage of negative ECT tests** | | | |
| 1 | Analysis of the production parameters used in cardboards produced with a "GOOD" test | - | 17/04/2024 | done |
| 2 | Creation of new recipes to increase the number of positive tests | - | 24/04/2024 | on going |
| 3 | Immediate alert when test is negative by quality department | daily | 01/05/2024 | done |
| | **High volume of complaints - Quantity lower than billed** | | | |
| 1 | Routine for checking and comparing quantities produced and labeled | weekly | 15/04/2024 | done |
| 2 | sensitizing operators to mark rejected quantities on labels as they leave the corrugator | monthly | 08/05/2024 | done |
| 3 | random/regular audits to check for counting errors at the corrugator machine | weekly | 08/05/2024 | done |
| 4 | Implementation of a computer vision system | - | 22/04/2024 | done |

Figure 4.5 – Quality problems action plan

The first action taken was to raise the quantity of samples collected on the production line and, as a result, the number of tests conducted in the laboratory, keeping in mind that the inadequate number of quality tests conducted led to a deficiency of specific information regarding the quality of the finished product. By implementing a methodical schedule of regular sample collection, the major goal was to get a larger amount of data for analysis.

In order to accomplish this, a detailed production line plan was created outlining how frequently samples of each kind of card were manufactured. Based on each board's production volume, this frequency was computed. Following a thorough examination and plan presentation at a production department meeting, the following was ascertained:

- For the three most produced cards, daily samples would be taken;
- For the fourth and fifth most produced cards, three weekly samples would be taken;
- For the sixth and seventh most produced cards, two weekly samples would be taken;
- For the remaining cards, a weekly sample would be taken.

Therefore, the goal was to complete 260 tests in a month, meaning that 260 samples were to be collected at the end of the production line.

| | | seg | ter | quar | quin | sex | | | seg | ter | quar | quin | sex | | | seg | ter | quar | quin | sex | | | seg | ter | quar | quin | sex | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 29 Abril | 30 Abril | 1 Maio | 2 Maio | 3 Maio | 4 M | 5 M | 6 Maio | 7 Maio | 8 Maio | 9 Maio | 10 Maio | 11 M | 12 M | 13 Maio | 14 Maio | 15 Maio | 16 Maio | 17 Maio | 18 M | 19 M | 20 Maio | 21 Maio | 22 Maio | 23 Maio | 24 Maio | 25 M | 26 M |
| 5x/SEM | B0264AA1 | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | |
| 5x/SEM | BC0423AA1 | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | |
| 5x/SEM | BC0548AA1 | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | |
| 3x/SEM | C0539AA2 | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | |
| 3x/SEM | C0597AA1 | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | | ☐ | ☐ | ☐ | ☐ | ☐ | | |
| 2x/SEM | C0368AA1 | ☐ | | | ☐ | | | | ☐ | | | ☐ | | | | ☐ | | | ☐ | | | | ☐ | | | ☐ | | | |
| 2x/SEM | C0396AA0 | ☐ | | | ☐ | | | | ☐ | | | ☐ | | | | ☐ | | | ☐ | | | | ☐ | | | ☐ | | | |
| 1X/SEM | B0283BA1 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | B0295AA1 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | B0325AA1 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | B0346AA0 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | B0355BA1 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | B0367AA1 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | B0372BA0 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | B0374BB0 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | B0386BA0 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | B0406BB0 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | B0409BA0 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | B0418BA0 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | B0432AA0 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | B0537AA2 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | BC0538BA2 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | BC0574AA1 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | BC0661BA1 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | BC0672AA1 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | BC0730AA0 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | BC0744BA1 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | BC0789AA1 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | BC0865AA2 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | BC0934AA1 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | BC0976BA2 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |
| 1X/SEM | BC1071AA1 | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | | | | ☐ | | | | |

Figure 4.6 - Planning for sample collection

Since this measure was put into place at the beginning of March, the following outcomes have been observed:

- The number of samples and tests performed increased significantly in March, presumably as a result of the planning's clarity, which effectively made the operators follow the directions;
- A significant decrease in the quantity of samples and tests conducted in April was ascribed to various factors, including operator carelessness and a lack of oversight;
- Thus far in May, the outcomes are encouraging. A weekly inspection that comprises of asking operators why samples aren't being taken has led to a closer adherence to the approach. In the first week of June, 58 samples were taken, which could indicate a monthly figure of around 232 samples, which is very close to the initial target set.

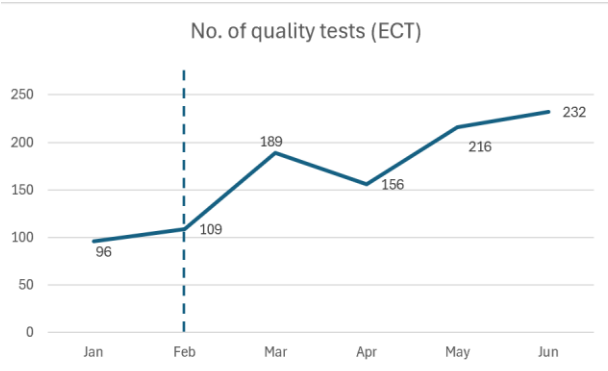



Figure 4.7 - Analysis of the number of tests carried out

Through the implementation of this action, there was an increase of approximately 113% in the number of samples collected and consequently in the number of quality tests conducted. With the implementation of these procedures, the company aims to significantly enhance its quality control and ensure that its production processes meet the high standards it has set for itself.

The impact of this increase in the number of tests was significant. The rate of early detection of negative tests increased dramatically, allowing faster intervention before problems affected a large amount of production. The reduction in response time to negative results, as evidenced by the decrease in the average time between the detection of a problem and corrective action, was one of the greatest benefits observed.

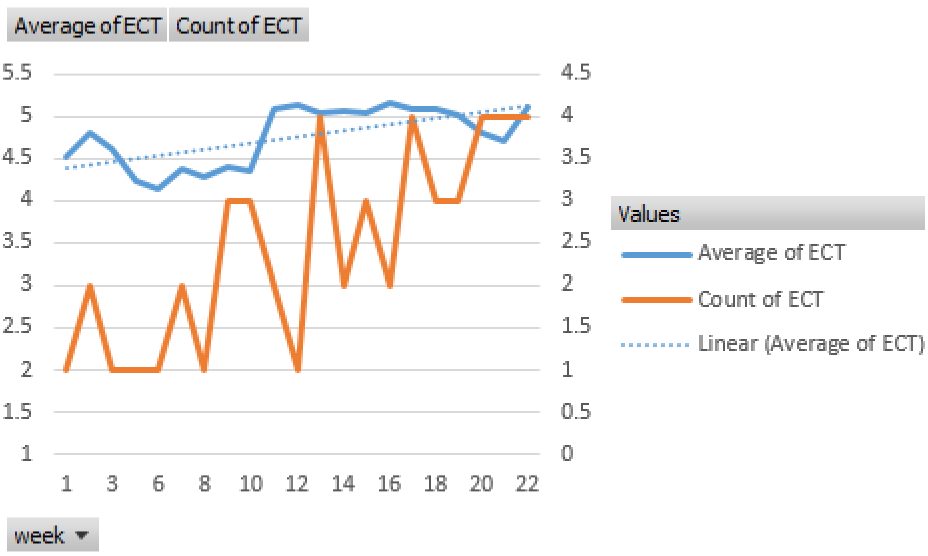



Figure 4.8 - ECT on cardboard C0539

Analysis of the data collected showed that the increase in the number of tests had a direct effect on stabilizing the production process. With the ability to identify and correct problems more quickly, variability in the process decreased, resulting in more consistent, high-quality production. Figure 4.8 shows the trend towards stabilization of the process, evidenced by the reduction in the variability of quality results.

### Computer Vision

Faced with customer complaints about the insufficient quantity of products delivered, a thorough analysis was conducted, followed by internal discussions with the quality and maintenance departments. The first action taken was to sensitize the operators in the palletizing area to confirm the quantity of product. To this end, it was asked the operators to always count the quantity of product in each order and compare it with the actual quantity ordered by the customer. As a result of in-depth brainstorming on this topic, an innovative system was also designed and implemented to deal with this recurring problem.

A solution has been developed to accurately estimate the amount of cardboard on a pallet before it is shipped. To do this, a camera has been strategically installed on the production line after palletizing and before strapping orders. This camera captures an image of the pallet, and specially designed software performs an approximate calculation of the amount of cardboard contained in the order. This estimated value is then compared with the actual quantity of the order.

Figure 4.9 - Palletizing zone

The system implemented is designed to act as a preventative measure, avoiding the delivery of orders with lower than expected quantities. If the difference between the actual quantity and the quantity calculated by the software exceeds 25%, the system automatically stops the progress of the order. This functionality ensures that only orders that meet the required quantity standards are sent to customers, thus minimizing complaints related to insufficient products being delivered.

This initiative demonstrates the company's commitment to ensuring customer satisfaction and constantly seeking innovative solutions to improve the quality of the services provided. Implementing this system not only addresses a recurring problem, but also strengthens the company's reputation as a reliable supplier committed to excellence.

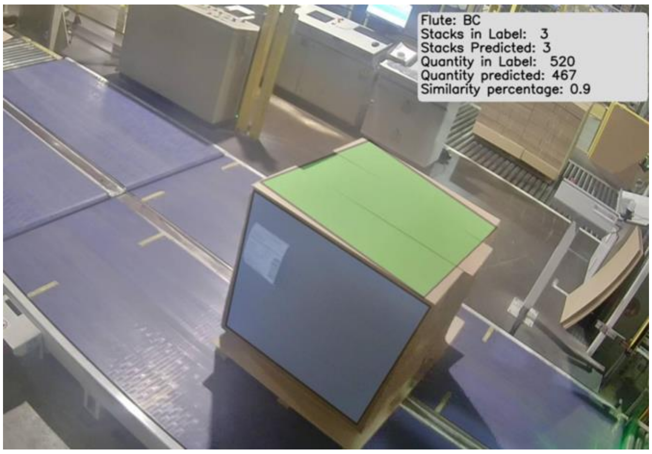



Figure 4.10 - Computer vision system software

After installing the equipment, programming it properly and carrying out the necessary tests, the company saw a significant improvement in order accuracy. In just two weeks, complaints about insufficient quantities of products being dispatched fell by approximately 25%. This positive result highlights the effectiveness of the system implemented, demonstrating that the use of advanced technology can solve critical problems and improve customer satisfaction. The substantial reduction in complaints strengthens customer confidence in the company, underlining the ongoing commitment to quality and precision in meeting their needs.


Figure 4.11 - Analysis of complaints about less quantity

Figure 4.10 shows the effectiveness of the action taken with regard to the large number of complaints about quantities below the order placed. It is clear that from the moment I met with the palletizing operators and asked them to start carrying out better checks, the number of complaints for this reason began to fall (red line 1). You can also see that after the implementation of the computer vision system (red line 2) this type of complaint dropped dramatically. In this way, it was concluded that from the beginning of the actions taken to address this problem to the present day, there has been a decrease of around 85% in the number of complaints for quantities shipped less than ordered.

## 4.3 Process and Work Standardization

This chapter aims to standardize a corrugator's internal industrial process, namely the splicing process, which is one of the main sources of unscheduled downtime and has a direct impact on the corrugator's productivity, as this thesis has previously analyzed. The goal is to establish a standardized procedure so that, with the help of efficient operator training methods, it will no longer be a challenge but rather an easy task to complete.

Initially, it was examined the current splicing procedure very carefully. Several on-site observations of the process being carried out by various operators served as the basis for this research. Simultaneously, it was held conversations with the operators to comprehend the primary challenges they faced throughout the procedure. These discussions yielded insightful commentary that improved understanding of the operators' viewpoints.

Afterwards, the splicing procedure was recorded. As you can see in Figure 4.11, it was monitored the procedures carried out by ten distinct operators and documented them. Time was not a critical component for the original goal, but it was a helpful secondary analysis.

| Operator | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time (s) | 249 | 262 | 241 | 309 | 252 | 255 | 271 | 264 | 332 | 276 |

Figure 4.12 - Operator´s splicing time

By analyzing these videos, it was divided the process into elementary tasks and created a table to better visualize the process, Figure 4.12. The tasks were created by viewing the recorded videos and using the operators' average times for each elementary task. Later, in a meeting with the head of the corrugator, it was analyzed all the videos to identify the best and worst practices for each elementary task. It was also concluded that there were significantly different approaches between the operators performing tasks 7 and 10, and that a general problem was observed in task 11. Looking deeper, these three tasks are related to measurements. In task 7, the operators fold a random number of sides to make it easier for the paper to pass through the barrier; in task 10, some operators place the double-sided tape higher up and others lower down on the barrier; in task 11, the operators cut off the amount they think is best and will make it easier to splicing.

| # | Task | Time(s) |
|---|---|---|
| 1 | open and lift the reel door (on the controller) | 19 |
| 2 | pull out the worn reel | 18 |
| 3 | send the new reel forward (on the controller) | 20 |
| 4 | close the reel holder and position it (on the controller) | 25 |
| 5 | turn the barrier over, remove the label from the reel and put it away | 17 |
| 6 | cut the reel to open it | 6 |
| 7 | fold two large triangles from the side to the center and pass the excess through the barrier | 28 |
| 8 | align the paper with the barrier and cut the paper close to the barrier | 21 |
| 9 | remove the excess | 6 |
| 10 | apply double-sided glue | 14 |
| 11 | cut a short piece diagonally from the sides and remove excess | 17 |
| 12 | remove the tape from the double-sided glue and send the barrier backwards (splicing position) | 20 |
| 13 | indicate the use of the reel in the system | 9 |

Figure 4.13 - Table of elementary tasks in the splicing process

To solve the most notable problems, tasks 7, 10 and 11, it was discussed a number of possible actions with the Head of Corrugator, one of which was approved. I created a measurement grid to apply to the barrier of each reel door. This idea was previously analyzed and tested on the shop floor and, after receiving positive feedback from the manager, the action was implemented.

The next phase consisted of, as shown in Figure 4.13, drawing a flowchart using best practices for all the elementary jobs and highlighting the correct execution of some in detail, as was the case with tasks 7, 10 and 11, which were flagged as the most critical. A meeting with the safety officer was held to finalize the validation and ensure that all the tasks assigned complied with company standards and were safe.

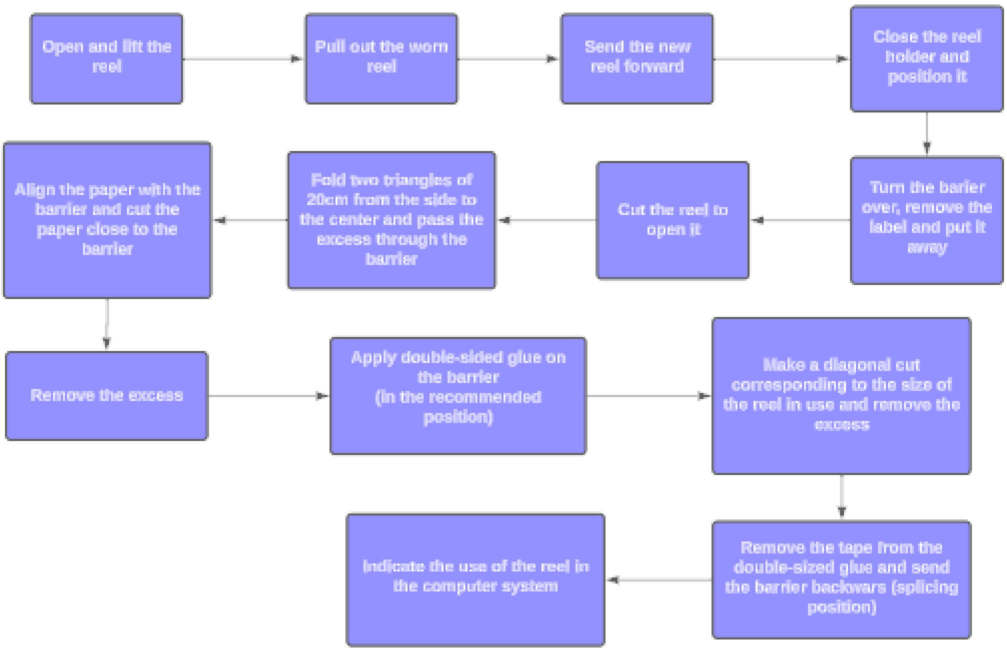



Figure 4.14 - Splicing process flowchart

The next job focused on developing effective training strategies for the operators. Initially, I met with several operators and explained the new splicing process in a simple way, using the flowchart. Afterwards, it was observed the newly implemented splices. Whenever a deviation was detected, it was addressed it with the operator and pointed out the errors. Another action taken was to create an A3 with the flowchart made earlier, but in Portuguese, and to post several printed A3s at all the splicing stations. This way, the operator can consult the correct method quickly and efficiently.

This comprehensive approach aims to ensure that the splicing process and the correct way to carry it out is standardized and optimized, decreasing the likelihood of failures in this process and reducing unplanned downtime and increasing the corrugator's overall productivity.

# 5 Conclusion and Future Works

This chapter presents conclusions from the work performed on the project, providing an overview of the outcomes and an approach for future study.

## 5.1 Conclusions

This dissertation presented an optimization project at International Paper's paper-to-cardboard mill, with the main objective of increasing the production of the fluting machine to 16,000 $m^2$/h. The primary goal of the optimization project was to raise the fluting machine's output to 16,000 $m^3$/h. This goal was broken down into four distinct targets: lowering unplanned stoppages to 10%, raising average speed to 135 m/min, cutting complaints by 20%, and standardizing work procedures. The comprehensive examination and subsequent measures yielded notable enhancements for the organization. One of the biggest obstacles overcome was the interaction with the workers. Initial resistance was overcome through constant communication and encouragement to adopt the new practices.

The work began with an in-depth understanding of the production process, interaction with the workers and integration into the teams. It was analyzed and organized crucial information, focusing on solving the most impactful problems. The actions developed included:

- Unplanned downtime: After analyzing the main causes, it was implemented specific actions to combat the most frequent causes;
- Complaints: It was drastically increased the number of samples taken and analyzed, and implemented a computer vision system to improve the accuracy of the final order count. To reduce negative tests related to ETC it was studied new cardboards production recipes;
- Standardized process and work: It was developed a standardized process and work for an industrial process that was causing a lot of entropy.

The main results achieved were:

- Increased Production: There was an increase in the production of the fluting machine to 15,547.8 $m^2$/h, an improvement of 12% since the project began;
- Average Speed: The average speed achieved was 129 m/min. Although this figure is higher than the average speed in January, 127 m/min, it did not reach the target set due to external factors such as the failure of circuit breakers;
- Reduction in unplanned stops: The unplanned stops reached 13% which despite not being the initial target represents a decrease of approximately 41%;

- Reduction in complaints: The implementation of the new actions resulted in a 51% reduction in the number of complaints, exceeding the target set of 20%;
- Standardized Processes: A standardized process was created and implemented for the splicing operation, which is one of the main causes of unplanned downtime.

The work contributed significantly to increasing the company's productivity, implementing new work and maintenance routines, and improving data collection and analysis. Before this project, there was no in-depth analysis of the causes of unplanned downtime, nor a detailed study of card recipes or a computer vision system for quality control.

The knowledge acquired throughout the course, especially during the master's degree, was fundamental to the success of this project. Concepts and tools from quality management, production management and smart factories, such as lean tools, process variability, operation sequencing, TPS (Toyota Production System) and industrial process analysis, were widely applied.

To conclude, despite not having achieved all the objectives initially set for this project, it was possible to make significant improvements in all the areas of intervention. The adversities inherent in the industrial environment, as well as the complexity of knowing and controlling all the variables, represented substantial challenges. However, each obstacle overcome contributed to deep and valuable learning. The experience gained and the wisdom gleaned from this process are invaluable and will serve as a solid foundation for future projects and professional challenges.

## 5.2 Future Works

There is a number of intriguing avenues for further research that might carry on optimizing and innovating the factory's processes, given the outcomes attained and the areas for improvement found throughout this project. Some suggestions and goals that may be further investigated are listed bellow:

- Increasing the Sensitivity of Computer Vision in Palletizing, with the aim of improving the efficiency of the palletizing process, i.e. improving the accuracy and effectiveness of the system. This could involve implementing more advanced algorithms or using more sophisticated hardware to detect and correct errors more efficiently;
- Lowering the number of fluting machine operators will necessitate a pilot study based on process standardization efforts, particularly in the splicing process. The objective is to determine whether it is feasible to decrease the number of operators required in the splicer while preserving or raising existing standards of effectiveness and caliber. A thorough examination of the tasks, execution times, and potential automation enhancements will all be included in this study;
- Progression of the Card Recipe: Research by examining card recipes further and trying to find formulations that can raise the caliber of the card generated, the goal is to enhance the final product's quality. To improve results in quality parameters, like the Edge Crush Test (ECT), this entails conducting extra tests and modifying the compositions;
- Integrating Artificial Intelligence into Factory Processes with the aim of advancing automation and operational efficiency. In order to prevent failure and perform predictive maintenance, as well as to maximize operational functions, it would be

necessary to investigate the potential of incorporating artificial intelligence into different production processes. This could involve streamlining production procedures, enhancing resource management, and analyzing data in real time using AI.

These upcoming paths offer tremendous chances to carry on the plant's development, enhancing productivity, caliber, and process innovation. The investigations are well-founded in the work completed thus far, and the company's productivity and competitiveness may increase even more if these measures are put into action.

## Bibliography


Bowles, J. B., & Gardiner, L. R. (2018). Process mapping: A guide to improving business processes. American Society for Quality.

Cabral, J. (2006). Organização e Gestão da Manutenção. Lidel.

Cabral, J. (2009). Gestão de Manutenção de Equipamentos, Instalações e Edifícios. Lidel.

Carpenter, S. Donna, W. P. J. J. D. T. R. D. (2007). The machine that changed the world. page 1997.

Cerón, A. M., Gracia, T. J. H., and Avila, D. D. (2022). Application of value stream mapping (vsm) as a lean manufacturing management tool. Journal of Administrative Science, 4:2–4.

Chiarini, A., B. C. M. V. (2018). Lean production, toyota production system and kaizen philosophy: A conceptual analysis from the perspective of zen buddhism. TQM Journal, 30:425–438.

Dennis, Pascal. 2015. Lean Production Simplified: A Plain-Language Guide to the World's Most Powerful Production System. Taylor & Francis Group.

Deshmukh M., Gangele A., G. D. K. D. S. (2022). Study and implementation of lean manufacturing strategies: A literature review. Materials Today: Proceedings.

Dhillon, B. (2006). Maintainability, maintenance, and reliability for engineers.

Fritze, C. (2021). The toyota production system. Operational Auditing, pages 333–337.

Gupta, M., & Campbell, V. S. (1995). "The Cost of Quality." Production and Inventory Management Journal, 36, 43-43

Hoover, R. R. K. & Hoover, M. (2012). "The History of Quality in Industry." Sandia Natl. Lab, 1-17.

Imai, M. (1986). Kaizen: The Key to Japan’s Competitive Success. Becoming lean Inside stories of US manufacturers.

Jasiulewicz-Kaczmarek, M., & Antosz, K. (2023). Industry 4.0 Technologies for Maintenance Management – An Overview. Lecture Notes in Mechanical Engineering, 68–79. https://doi.org/10.1007/978-3-031-09382-1_7

Juran, J. M. and Godfrey, A. B. (1999). Juran’s Quality Handbook. McGraw-Hill Professional Publishing.

Kinz A., Bernerstaetter R., & Biedermann H. (2016), “Lean Smart Maintenance –Efficient and Effective Asset Management for Smart Factories”, MOTSP 2016 – 8th International Scientific Conference.

Kumar U., & Galar D. (2018), “Maintenance in the Era of Industry 4.0: Issues and Challenges”, [in:] Quality, and Business Operations: Modeling and Optimization, 231–250.

Lander, E. and Liker, J. K. (2007). The toyota production system and art: Making highly customized and creative products the toyota way. International Journal of Production Research, 45:3681–3698.

Liker, J. K. (2004). The Toyota Way 14 Management Principles from the World´s Greatest Manufacturer, volume 2004.

Liker, J. K. and Hoseus, M. (2008). Toyota Culture. McGraw-Hill

Macpherson, W. G., Lockhart, J. C., Kavan, H., and Iaquinto, A. L. (2015). Kaizen: a japanese philosophy and system for business excellence. Journal of Business Strategy, 36:3-9.

Martin, M. J., & Osterling, M. (2014). Process mapping: A tool for enhancing communication. Journal of Business and Management.

Medić, S., Karlović, B., & Cindrić, Z. (2016). "NEW STANDARD ISO 9001:2015 AND ITS EFFECT ON ORGANISATIONS." Interdisciplinary Description of Complex Systems: INDECS, 14(2), 188-193.

Melton, T. (2005). The benefits of lean manufacturing: What lean thinking has to offer the process industries. Chemical Engineering Research and Design, 83:662–673.

Mohan, R. T., Preetha Roselyn, J., & Annie Uthra, R. (2021). Autonomous Maintenance in Industrial Revolution 4.0 During Covid-19 - A Real Time Approach. Proceedings of the 8th International Conference on Signal Processing and Integrated Networks, SPIN 2021, 53–58. https://doi.org/10.1109/SPIN52536.2021.9566019

Monden, Y. (2011). TOYOTA Production System: An Integrated Approach to Just-In-Time, volume 59.

Muller, Max. 2003. Essentials of Inventory Management. American Management Association.

Ohno, T. (1988). Toyota production system-beyond large-scale production.

Ovar, E. C. 2018. Sistema de Gestão CdR - EUROPA&C OVAR.

Pinciroli, L., Baraldi, P., & Zio, E. (2023). Maintenance optimization in industry 4.0. Reliability Engineering and System Safety, 234. https://doi.org/10.1016/j.ress.2023.109204

Pinto, J. L. Q., Matias, J. C. O., Pimentel, C., Azevedo, S. G., and Govindan, K. (2018). Lean Manufacturing and Kaizen.

Powell, Taman, and Tanya Sammut-Bonnici. 2015. “Pareto Analysis.” January. doi:10.1002/9781118785317.weom120202.

Priede, J. (2012). "Implementation of Quality Management System ISO 9001 in the World and its Strategic Necessity ". Procedia-Social and Behavioral Sciences, 58, 1466-1475.

Scorecard, B. (1996). Handbook for basic process improvement.

Slack, Nigel, Stuart Chambers, and Robert Johnston. 2010. Operations Management. Pearson Education Limited

Sriputtha, N. and Satuprapakarn, V. (2021). Implementing value stream mapping as a lean manufacturing tool in the water pipe production. Academic Journal of Manufacturing Engineering, 19:36–37.

Trout, J. (2020). Fishbone Diagram Explained | Reliable Plant. Reliable Plant.

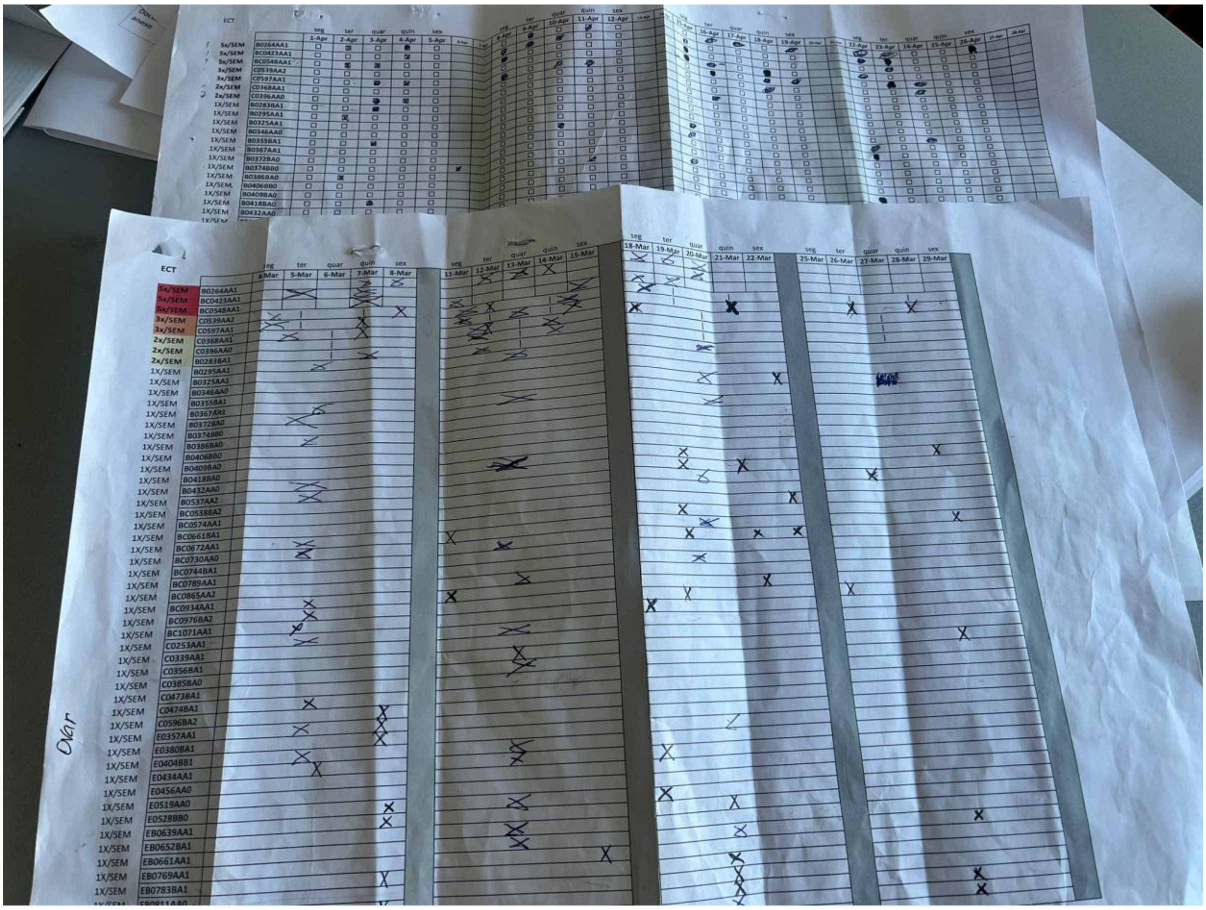
Watson, G. (2004). The legacy of ishikawa. Quality progress, 37(4):54.

Womack, James P., J. D. T. (2003). Lean Thinking: Banish waste and create wealth in your corporation, volume 18.

Zonta T., Costa C. A. D., Righi R. D. R., Lima M. J. D., Trindade E. S. D, & Li G. P. (2020), “Predictive maintenance in the Industry 4.0: A systematic literature review”, Vol 150, 106889. https://doi.org/10.1016/j.cie.2020.106889

## Appendix A: White Belt Certification

## Appendix B: Sample Collection



## Appendix C: Flowchart For Production Line