TPM methodologies application on a HDPE Bottle-Blowing production line

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Abstract

This master's engineering thesis, integral to the culmination of the academic journey, explores a comprehensive project aimed at optimizing manufacturing processes within the In House Bottle Blowing (IHBB) department of a prominent industrial facility. The primary objective is to address critical operational challenges and enhance overall efficiency in response to increasing production demands.

The initial chapters provide a contextual background, introducing the manufacturing environment, production teams, and operational shifts within the IHBB department. Chapter 1 establishes the organizational structure, highlighting the distribution of team members, operational shifts, and the crucial role of an administrative department overseeing various support functions. The central focus is on the IHBB department, which houses nine blow molding machines vital for bottle production.

Chapter 3 delves into the existing maintenance strategy, shedding light on the roles of unit leaders, technical coordinators, and maintenance coordinators. The current approach involves daily and weekly cleaning and inspection tasks, quality controls, and breakdown registrations. Alarming Rate Loss (RL) values prompt this project, necessitating an in-depth investigation into the causes behind the RL deviation from the company's defined target. The absence of standardized procedures for various tasks, suboptimal task sequencing, and tool organization inefficiencies contribute to subpar operational performance. By implementing standard work procedures for machine operation and maintenance tasks, substantial time reductions are achieved.

Chapter 4 outlines the meticulous methodology adopted for the project. Notably, the transformation of tool cart organization and the implementation of standard work procedures for machine operation and Cleaning, Inspection, and Lubrication (CIL) tasks demonstrate significant time savings and efficiency improvements.

The thesis strategically addresses the identified challenges by integrating lean management principles. A Value Stream Mapping (VSM) analysis uncovers inefficiencies, leading to the development of standardized procedures for machine operation and CIL tasks. Planned downtime strategies are introduced, offering a systematic approach for comprehensive maintenance interventions.

This research contributes to the field of engineering by showcasing a holistic strategy that combines process optimization, standardized procedures, and planned downtime interventions to enhance operational efficiency in response to dynamic manufacturing demands. The thesis establishes a foundation for sustainable production practices, aligning the IHBB department with evolving market requirements and ensuring long-term viability.

Resumo

Aplicação de metodologias de TPM numa linha de produção de insuflagem de polietileno de alta densidade

Esta tese de mestrado em engenharia, parte integrante do culminar do percurso académico, explora um projeto abrangente destinado a otimizar os processos de fabrico no departamento de In House Bottle Blowing (IHBB) de uma instalação industrial proeminente. O objetivo principal é abordar desafios operacionais críticos e melhorar a eficiência global em resposta às crescentes exigências de produção.

Os capítulos iniciais fornecem um contexto, apresentando o ambiente de produção, as equipas de produção e as mudanças operacionais no departamento de IHBB. O Capítulo 1 estabelece a estrutura organizacional, destacando a distribuição dos membros da equipa, os turnos operacionais e o papel crucial de um departamento administrativo que supervisiona várias funções de apoio. O foco central é o departamento IHBB, que abriga nove máquinas de moldagem por sopro vitais para a produção de garrafas.

O capítulo 3 aprofunda a estratégia de manutenção existente, esclarecendo os papéis dos chefes de unidade, dos coordenadores técnicos e dos coordenadores de manutenção. A abordagem atual envolve tarefas diárias e semanais de limpeza e inspeção, controlos de qualidade e registos de avarias. Os valores alarmantes da Taxa de Perda (RL) motivaram este projeto, obrigando a uma investigação aprofundada das causas do desvio da RL em relação ao objetivo definido pela empresa. A ausência de procedimentos padronizados para várias tarefas, a sequência de tarefas não otimizada e as ineficiências na organização das ferramentas contribuem para um desempenho operacional inferior. A implementação de procedimentos de trabalho normalizados para as tarefas de operação e manutenção das máquinas permite obter reduções de tempo substanciais.

O capítulo 4 descreve a metodologia meticulosa adoptada para o projeto. Em particular, a transformação da organização do carro de ferramentas e a implementação de procedimentos de trabalho normalizados para a operação da máquina e para as tarefas de Limpeza, Inspeção e Lubrificação (CIL) demonstram poupanças de tempo significativas e melhorias de eficiência.

A tese aborda estrategicamente os desafios identificados através da integração de princípios de gestão optimizada. Uma análise de Mapeamento do Fluxo de Valor (VSM) revela ineficiências, levando ao desenvolvimento de procedimentos padronizados para a operação de máquinas e tarefas CIL. São introduzidas estratégias de tempo de inatividade planeado, oferecendo uma abordagem sistemática para intervenções de manutenção abrangentes.

Esta investigação contribui para o campo da engenharia ao apresentar uma estratégia holística que combina a otimização de processos, procedimentos padronizados e intervenções planeadas de tempo de inatividade para melhorar a eficiência operacional em resposta a exigências dinâmicas de fabrico. A tese estabelece uma base para práticas de produção sustentáveis, alinhando o departamento de IHBB com as exigências do mercado em evolução e garantindo a viabilidade a longo prazo.

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"Problems cannot be solved with the level of thinking existing when they were created"

Albert Einstein

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Acronyms and Symbols

AM	Autonomous Maintenance
CIL	Cleaning Inspection and Lubrication
HDPE	High Density Polyethylene
IHBB	In House Bottle-Blowing
IWS	Integrated Working System
KPI	Key Performance Indicator
OEE	Overall Equipment Efficiency
PDCA	Plan Do Check Act
PM	Preventative Maintenance
PLC	Programmable Logic Controller
RL	Rate Loss
SU	Market Standard Unit
SW	Standard Work
TPM	Total Productive Maintenance
TPS	Toyota Productive System

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Chapter 1

Introduction

This thesis was conducted as part of the industrial dissertation associated with the Integrated Master's program in Mechanical Engineering, specifically within the Production Management specialization. In this section, an exposition is provided on the company where the project unfolded, elucidating its principal goals, delineating the applied methodology, and presenting the structural framework of the dissertation.

1.1 Fater Group

Fater is an Italian company founded in 1958 by Francesco Angelini. In 1992 it became an equal joint venture between Procter & Gamble and Angelini Industries. The Fater Group's motto is "People First" and focuses on five areas: Listen; Growth & Impact; Enjoy; Inspire and Include. Fater is a dynamic company that invests around 4% of its annual turnover in innovation and employs 1,500 people worldwide.

Fater manufactures and distributes the branded products ACE Neoblanc and Comet in 38 countries worldwide. In Italy, the company has been developing the personal care market since the late 1960s and today produces and distributes branded products such as Pampers, LINES, LINES Specialist and Tampax. Fater has four production sites in three different countries: In Italy in Pescara, the headquarters, and in Campochiaro, in Turkey in the city of Gebze and in Portugal in Porto, where the plant is located. Fater also has several affiliates in Bucharest and Istanbul.

Fater Portugal is one of Fater's production sites, which is responsible for the production of two brands of bleach: Ace and Neoblanc. Each brand has several types of bleach adding to 12 different formulas.

1.2 Project Framework and Motivation

The project was executed at Fater's Portugal factory, specifically at the In House Bottle-Blowing department (IHBB). Industries must gradually invest in maintenance in order to reduce plant downtime and machine wear, extend production times and increase the life expectancy of equipment.

Hence, maintenance has become a paramount area due to the increasing costs and activities required to keep operations running. The increasing demand and consequent necessity to keep the production lines running, leaves little room for unplanned breakdowns. However, the rate loss observed at the department on previous months is on average 20%, which is far from the scorecard which targets this Key Performance Indicator (KPI) at 3%. in order to accomplish the demand objectives a suitable maintenance strategy shall be applied to the machinery Therefore, a necessity to analyse and explore the Preventative Maintenance (PM) and Autonomous Maintenance (AM) emerged to better understand and control the factors that influence the functioning of production lines and their efficiency.

1.3 Project Goals

The main objective of this project is to enhance the operational efficiency of a bottle-blowing production line through the implementation of TPM methodologies. To accomplish this, it is necessary to institute a standardized work process, thereby mitigating waste and eliminating non-value-added activities. This strategic approach aims to increase the availability of machinery, leading to a consequential escalation in overall productivity.

At the beginning of the project, the company lacked comprehensive and up-to-date documentation of processes, which led to a lack of regulation. This was mainly due to the lack of precisely defined procedures and process times at the workplaces. The introduction of standards not only reduces variability and improves process predictability, but also streamlines daily process control, which has a direct impact on the performance of the production area. Accordingly, new operator procedures have been developed through training and the refinement of methods inspired by *lean* methodologies.

1.4 Method followed in the project

In order to achieve the objectives of this project a deep analysis of the productive process was made. This included a complete understanding of the whole productive process, followed by a meticulous study of the functioning of the machinery at IHBB, as well as, the work tasks of its operators.

Consequently, the following process inefficiencies were identified and listed: high variability on starting the machines; lack of standardized work and work floor organization; lack of unplanned downtime data; ineffective maintenance strategy. To mitigate them a planned and organized strategy was defined targeting standard work, data gathering, work floor organization and maintenance strategy.

Afterwards, the strategy was implemented step by step, aiming one inefficiency at the time, in order to make sure it was solidified among everyone involved.

1.5 Project Structure

In this report, the subject of the dissertation: "TPM methodologies application on a HDPE Bottle-Blowing production line" is addressed. The report is structured into five chapters.

The present chapter introduced the hosting company of the project and elucidated the project's objectives and the methodology employed in its execution.

The second chapter comprises a literature review on the relevant topics to the project, providing a theoretical foundation for its realization, namely on *Lean* Manufacturing and TPM.

Moving to the third chapter, it is given a characterization of the initial situation, where the productive process is explained and the primary challenges existing are identified and analyzed.

The fourth chapter presents the proposed solutions to the identified problems, offering a detailed description of their implementation and an analysis of the results obtained.

To conclude the report in the fifth chapter, conclusions are drawn, emphasizing the objectives achieved, and outline proposals for future developments.

Chapter 2

Literature Review

In this present chapter, the philosophy of lean thinking management is addressed, encompassing an exploration of the concept and principles of *lean*. The eight key types of waste in a production system are elucidated, accompanied by a description of various techniques and tools supporting this model. Additionally, this chapter focuses on Total Productive Maintenance methodology, explaining its pillars and useful metrics. The development of this chapter aligns with techniques and thought processes applied in the project.

2.1 Historical Background of *Lean* Manufacturing

Lean manufacturing, a management philosophy and production practice, traces its roots to the Toyota Production System (TPS), developed by Toyota Motor Corporation in Japan during the mid-20th century. After World War II, Japan faced severe economic challenges and resource scarcity that had direct consequences on Toyota, leading to the emergence of innovative manufacturing techniques. Therefore, TPS was defined having as key contributors to its development Taiichi Ohno, Shigeo Shingo, and Eiji Toyoda. This new approach differed from the traditional mass production model. TPS was characterized by its emphasis on waste reduction, continuous improvement, and the creation of value for the customer. By the 1980s, as competition intensified, the principles of TPS gained international recognition, influencing industries beyond automotive manufacturing, and started to be recognized as *Lean* principles [7].

2.2 Fundamentals and Principles of *Lean* Manufacturing

As stated, *Lean* manufacturing is a strategic management philosophy and production methodology that originated from the Toyota Production System (TPS). Its core objective is the efficient use of resources, elimination of waste, and continuous improvement to deliver maximum value to the customer. In order to understand how can these objectives be achieved, it is necessary to fully acknowledge the fundamental principles that constitute the foundation of *lean* manufacturing.

2.2.1 *Lean* Fundamentals - Pursuit of Value

At the center of *lean* manufacturing is the unwavering commitment to deliver value to the customer. In the *lean* context, value is defined as any activity or process that directly contributes to meeting customer needs. All other activities are considered non-value-adding and are targeted for elimination or minimization. The emphasis on customer-centric value is a paradigm shift that distinguishes *lean* thinking from traditional production approaches [8].

2.2.2 *Lean* Principles

This section delves into the core principles that represent the essence of *lean* manufacturing. Building upon the overarching pursuit of value discussed in the preceding section, the focus shifts to the five fundamental principles that guide organizations towards operational excellence. Rooted in the Toyota Production System (TPS), these principles serve as a blueprint for streamlining processes, eliminating waste, and delivering maximum value to the customer. From identifying value and mapping the value stream to creating flow, establishing pull, and the continuous pursuit of perfection, they form the essence of *lean* manufacturing philosophy [9]. Through a detailed examination of each principle, this section aims to provide a nuanced understanding of how these concepts collectively contribute to the transformative power of *lean* manufacturing.

The aforementioned principles are:

- **Identify Value -** The first principle involves a meticulous understanding and identification of what constitutes value from the customer's perspective. This requires organizations to engage in a comprehensive analysis of customer needs and expectations, allowing for the identification of features and attributes that genuinely contribute to value.

- **Map the Value Stream -** Once value is identified, the next step is to map the value stream, which represents the entire set of activities required to deliver a product or service. Value stream mapping is a visual tool that enables organizations to understand the flow of materials and information, facilitating the identification of inefficiencies and areas for improvement.

- **Create Flow -** Creating a polished and continuous flow of work is crucial in *lean* manufacturing. This principle entails eliminating interruptions, delays, and batch processing. By optimizing the flow of materials and information, organizations reduce lead times, enhance flexibility, and respond more effectively to changes in demand.

- **Establish Pull -** The concept of pull production is a key tenet of *lean* manufacturing. Instead of pushing products through the production process based on forecasts, organizations operate on a pull system where items are produced in response to actual customer demand. This minimizes overproduction, reduces excess inventory, and improves responsiveness to market fluctuations.

- **Seek Perfection -** *Lean* manufacturing is a journey towards continuous improvement and perfection. This principle emphasizes an ongoing commitment to identifying and eliminating waste, improving processes, and adapting to changing circumstances. Perfection is considered an ideal state that may never be fully reached but serves as a guiding principle for relentless improvement [8].

By adopting the five principles of *lean* manufacturing, organizations can create value, streamline their operations, and respond more effectively to customer demands. The emphasis on a culture of continuous improvement, as advocated by *Kaizen*, reinforces the commitment to perfection and adaptability.

The objectives of *lean* manufacturing are the quality and flexibility of the process, reinforcing its ability to compete in an increasingly demanding and globalized scenario. Due to the relatively recent nature of *lean* thinking as a philosophy, some companies may still find it challenging to believe in the possibility of producing at low cost while maintaining quality and service. Additionally, it is worth noting that besides acknowledging the techniques and tools mentioned in this chapter, it is crucial to understand how to apply them and to keep in mind that people are the most critical part in all processes and changes.

Moving forward, this chapter will explore additional aspects of *lean* manufacturing, including specific tools and techniques.

2.2.3 The Eight Wastes in *Lean* Manufacturing

When aiming to optimize a certain productive process by the concept of *lean* manufacturing, the identification and elimination of wastes, or "*Muda*", play a pivotal role in achieving operational excellence. Therefore, following is an in-depth exploration of each of the eight recognized wastes, emphasizing their impact on efficiency and the overall value stream:

- **Overproduction-** Overproduction occurs when a company manufactures more goods than demanded by the customer. This not only leads to excess inventory but also amplifies the risk of producing defective items. The surplus inventory ties up capital and storage space, increasing holding costs and hindering the adaptability of the production system to changes in demand.

- **Waiting-** The waste of waiting encompasses any idle time between production stages or delays in the workflow. This can result from inefficient processes, equipment breakdowns, or inadequate planning. Waiting not only elongates lead times but also diminishes the overall efficiency of the production process, hindering the smooth flow of value through the system.

- **Transportation-** Transportation waste involves any unnecessary movement of materials or products. Excessive handling and transportation not only add logistical costs but also pose the risk of damage or defects during transit. Lean manufacturing aims to minimize transportation waste by optimizing the layout and flow of materials within the production environment.

- **Motion-** Motion waste pertains to any unnecessary movement of people or equipment that does not contribute value to the product or service. Minimizing unnecessary motion enhances operational efficiency, reduces the risk of injuries, and contributes to a safer and more streamlined workplace.

- **Overprocessing-** Overprocessing waste occurs when activities are performed that do not contribute to the customer's perceived value. This may involve redundant steps or unnecessary precision in the production process. Identifying and eliminating these steps is crucial for reducing production time and costs without compromising quality.

- **Inventory-** Excess inventory, whether it is raw materials, work-in-progress, or finished goods, represents a significant form of waste. Maintaining large inventories ties up capital and increases the risk of obsolescence. *Lean* manufacturing seeks to establish just-in-time production systems, minimizing inventory levels and enhancing responsiveness to changes in customer demand.

- **Defects-** Defects constitute a waste in terms of both resources and time spent on rework. The production of defective items can lead to customer dissatisfaction and increased costs for corrections. *Lean* manufacturing places a strong emphasis on error prevention and detection mechanisms to ensure high-quality standards and minimize defects.

- **Underutilized Talent-** Underutilized talent represents a form of waste where the skills and capabilities of employees are not fully leveraged. *Lean* manufacturing emphasizes the importance of engaging and empowering employees in the continuous improvement process. Recognizing and utilizing the talents of the workforce contributes to a more efficient and innovative production environment [8], [10].

Understanding and addressing these eight wastes is not merely a checklist but a continuous and dynamic process within *lean* manufacturing. By delving into the concepts of each waste, organizations can systematically identify areas for improvement, foster a culture of waste elimination, and move closer to achieving the ideals of perfection and continuous improvement inherent in *lean* thinking.

2.3 *Lean* Tools and Techniques

This section elaborates a comprehensive investigation into the array of methodologies essential for the integration of *lean* thinking within a manufacturing facility. In the pursuit of operational excellence and sustained production, a meticulous examination of specific tools that express the principles of *lean* manufacturing is imperative. This chapter unfolds a nuanced analysis of pivotal *lean* tools, encompassing standard work, *kaizen*, *gemba*, *jidoka*, PDCA (Plan-Do-Check-Act), and 5S. Each of these tools represents a strategic way to minimizing waste, optimizing efficiency, and fostering a culture of continuous improvement.

2.3.1 Standard Work

Standard Work, a fundamental component within the *Lean* manufacturing framework, stands as a process where it is described the best current way of performing a given operation. Developed by Taiichi Ohno in the 1950s, Standard Work serves as a structured approach to formalize and execute operational rules and procedures, playing a crucial role in minimizing process waste and ensuring stability [11].

At its core, Standard Work seeks to eliminate variation and inconsistency in outcomes by instructing workers to adhere to well-defined procedures. This meticulous approach establishes a foundation for stability and measurability, contributing to a culture of continuous improvement. The three key components to achieve this are process documentation, process improvement and operator trainings.

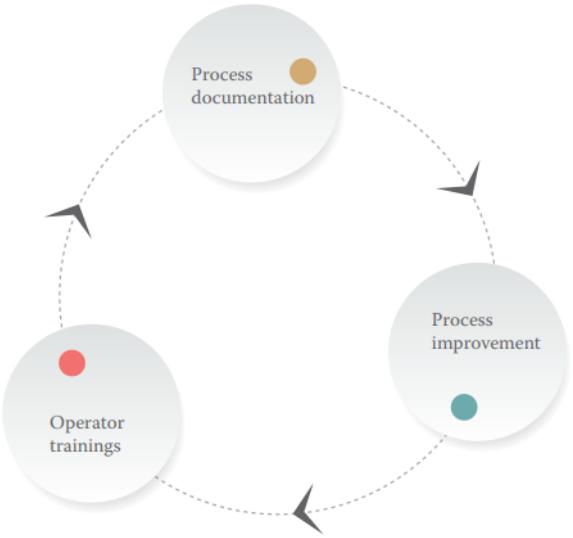


Figure 2.1: Three Key elements of Standard Work [1]

The correct utilization of Standard Work makes work efforts stable and measurable, effectively reducing process variability and minimizing waste derived from inefficient procedures, while reducing the number of defective parts. By documenting all necessary steps for a specific task, Standard Work not only eliminates non-value-added steps but also serves as a baseline for ongoing improvements. As the standard is enhanced, it becomes the new baseline for further refinements, perpetuating a cycle of continuous improvement [12]. Nonetheless, standardizing work also adds discipline—an often underestimated but essential element for successful Lean implementation. The adherence to standardized procedures ensures that unnecessary movements and steps become evident, paving the way for increased efficiency. Finally, Standard Work serves as a learning tool, supporting audits, promoting problem-solving, and engaging teams in the development of mechanisms like *Poka Yoke*, which aim to minimize the probability of errors [1].

2.3.2 *Kaizen*

The Kaizen philosophy, which is deeply rooted in Japanese culture, represents a central principle of lean production and embodies the essence of continuous improvement. Derived from "kai", meaning change, and "zen", meaning good, Kaizen advocates gradual, ongoing positive change to achieve significant improvements over time [13].

At the heart of *Kaizen* is the realization that small, consistent improvements can lead to transformative progress. This philosophy challenges the conventional wisdom of sporadic, radical change and emphasizes a steady, evolutionary approach. *Kaizen* encourages participation at all organizational levels and empowers employees to take an active role in identifying inefficiencies, suggesting improvements and implementing change.

The principles of *Kaizen* include a deep respect for people and recognizing employees as the most important source of knowledge about their work processes. The concept of "*gemba*", or where the work gets done, emphasizes the importance of observing, understanding and improving processes at the grassroots level. Continuous improvement is not seen as a one-off initiative, but as an integral part of daily work, rejecting the notion of settling for "good enough" [14]. In *lean* manufacturing, *Kaizen* fits seamlessly into the principles of waste reduction. Through its continuous improvement cycles, *Kaizen* aims to identify and eliminate the eight types of waste — overproduction, waiting, transportation, motion, over-processing, inventory, defects and underutilized talent. By involving employees in the improvement process, *Kaizen* not only boosts morale, but also improves problem-solving skills and strengthens commitment to the company's goals.

The *Kaizen* philosophy blends harmoniously with just-in-time production and facilitates the smooth flow of materials and information. It works in conjunction with *lean* tools such as the Plan-Do-Check-Act cycle (PDCA), the 5-Whys technique for root cause analysis and value stream mapping. These tools provide structured methods for problem solving and improvement initiatives and reinforce the practical application of *Kaizen* [14].

Once acknowledging the problem a typical *Kaizen* process follows the following six steps illustrated on the Figure 2.2:



Figure 2.2: Kaizen Process Steps [2]

Kaizen events, organized workshops that focus on specific improvement goals, are an example of the practical application of the *Kaizen* philosophy. These time-limited and cross-functional events accelerate improvement efforts and illustrate the dynamic application of *Kaizen* principles [14].

2.3.3 *Gemba*

The concept of "*gemba*" stands as a cornerstone principle that embodies a philosophy that goes beyond traditional production methods. *Gemba* is a Japanese term that means "the real place" or "the actual place" and refers to the physical place where value is created — the factory floor, the office or any other place where work takes place. Understanding *gemba* and recognizing its importance is fundamental to achieving optimal process optimization and improvement [13].

Gemba revolves around three interconnected pillars: Observation, Interaction and Problem Solving. The concept involves managers and improvement teams going to the place where the work takes place, observing processes first-hand, collaborating with front-line employees and actively engaging in problem solving. This approach fosters a culture of continuous improvement and ensures that insights gained at the source guide decision-making and lead to immediate action.

Being physically present at the *gemba* provides executives with real-time insights into operational processes, which surpasses the benefits of reports and facilitating prompt, accurate decision making. *Gemba* becomes a fertile ground for identifying and eliminating various types of waste, from overproduction to waiting times, contributing significantly to overall operational efficiency.

Gemba is inextricably linked to the philosophy of continuous improvement known as Kaizen. It provides a dynamic platform for continuous, incremental improvement and encourages and empowers every employee to actively contribute to the continuous improvement of processes [14].

Engaging with employees on the *gemba* fosters a deep sense of involvement and empowerment. This practice signals to the workforce that leadership truly values their insights and experiences, resulting in higher morale and a stronger commitment to organizational goals.

Gemba's emphasis on addressing problems at their source ensures efficient problem resolution. Immediate action is taken to address problems directly, prevent them from escalating and ensure the efficiency of the overall process.

The consistent application of the *gemba* principles becomes a catalyst for cultural change in an organization. It leads to a pervasive mindset of continuous improvement, where every team member is committed to optimizing processes and creating lasting value from the ground up.

In essence, *gemba* is not confined to a physical location, but embodies a mindset and commitment to excellence. By adopting *gemba* in *lean* manufacturing, organizations unlock the full potential of their processes, engage employees at all levels and embark on a transformative journey of continuous improvement that lays the foundation for sustainable success.

2.3.4 *Jidoka*

Jidoka, a term rooted in the philosophy of *lean* manufacturing, embodies the fusion of automation and human influence for proactive error prevention. The concept, coined by Taiichi Ohno, emphasises the fundamental role of *Jidoka* in introducing quality into processes.

A notable observation from a study conducted by Harvard University and MIT sheds light on the automotive sector — there is a minimal correlation between improved quality and the level of automation [15]. While a higher degree of automation increases efficiency, it also leads to greater complexity, making it more difficult to detect and avoid potential deviations.

Jidoka grants autonomy to both operators and machines, empowering them to stop a process if they detect anomalies. This proactive approach makes problems visible and enables operators to quickly identify and eliminate the causes [16].

Shingo's perspective, which he sets out in his 1989 work, sees *jidoka* as a precursor to full automation. Here, the machine takes on the role of problem detection, while the operator is responsible for immediate correction. Shingo introduced the poka-yoke system, which is an integral part of *jidoka* — a mechanism that prevents mistakes and facilitates their rapid detection [7].

Poka-yoke is useful for both human-performed tasks and machine processes. It enables employees to recognize deviations from standards and correct them quickly. This is in line with the general lean philosophy, which focuses on continuous improvement and the reduction of waste [7].

The implementation of *jidoka* involves setting standards and using visual elements to highlight potential quality issues in specific tasks and workstations. An *andon* system, a concrete example of a poka-yoke system, uses visual or audible alerts to signal the presence of a quality issue on the production line to encourage immediate attention and action.

To summarize, *jidoka* as a *lean* technique is a beacon for quality improvement through autonomy. By seamlessly integrating human intelligence into automated processes, *jidoka* not only

prevents errors but also promotes a proactive culture of problem solving and continuous improvement. For companies grappling with the intricacies of modern manufacturing, *jidoka* is an invaluable tool in their quest for efficiency, quality and *lean* excellence.

2.3.5 PDCA

Continuous improvement, or *Kaizen*, stands as a fundamental philosophy within Lean production. Initially focused on enhancing quality in the production domain, continuous improvement has evolved into a holistic management principle that demands engagement throughout the entire organization.

A prominent method for implementing continuous improvement is the PDCA (Plan-Do-Check-Act) cycle, a concept rooted in Western quality management theory, introduced by W.Demming after transforming the cycle elaborated by Walter Shewhart in the 1930s [17]. Integrated into the TPS, the PDCA cycle illustrated in Figure 2.3, serves as a pivotal approach to actualize the *lean* principle of continuous improvement, commonly known as *Kaizen*.

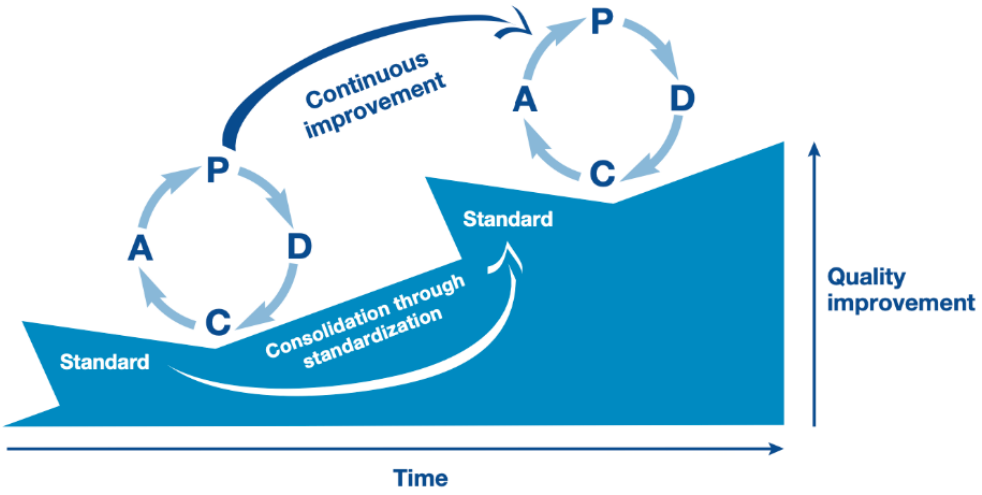


Figure 2.3: PDCA cycle [3]

Presently, the PDCA cycle serves as a tool for controlling and standardizing diverse processes to ensure customer satisfaction. The cycle comprises four stages:

- **Plan** Establish processes, set objectives, and identify potential error causes to formulate a comprehensive plan for achieving the desired improvement.
- **Do** Execute the plan and collect relevant data.
- **Check** Identify any issues within the process and meticulously analyze the gathered data.
- **Act** Following a comparison of achieved results with expectations, take necessary actions on the plan, modifying it if required to foster continuous improvement.

During the planning phase, a thorough analysis of problems occurs, and one or more solutions are developed, including a detailed execution plan. Implementation involves executing what appears to be the most viable solution. Verification requires a careful observation of the results obtained through the implemented solution in comparison to the desired outcomes. Finally, the action phase entails analyzing and interpreting the variances between achieved and anticipated results, seeking innovative solutions and plans to address these disparities. Notably, this phase incorporates customer complaints and dissatisfaction into the planning process for subsequent cycles [16].

The inherent versatility of the PDCA cycle makes it applicable across all organizational levels, involving individuals or entire groups, spanning from design and production to upper management levels.

By consistently scrutinizing and controlling the repercussions of planning decisions and implementation outcomes, and subsequently taking corrective measures when necessary, the entire organization undergoes a gradual learning process. This ongoing learning dynamic positions the organization to continually enhance and refine its objectives.

2.3.6 5S

The 5S methodology, deeply ingrained in the principles of *Lean* manufacturing, is a systematic approach designed to optimize workplace organization, efficiency, and employee satisfaction. Originating from Japanese terms—Seiri (Sort), Seiton (Set in Order), Seiso (Shine), Seiketsu (Standardize), and Shitsuke (Sustain)—5S provides a structured framework for creating and maintaining an organized, efficient, and safe workplace.

- **Sort (Seiri) -** The first step involves sorting and eliminating unnecessary items from the workplace. It is a process of decluttering and ensuring that only essential tools and materials are readily available, thereby reducing the risk of errors and enhancing workflow efficiency.

- **Set in Order (Seiton) -** Following the sorting phase, this step focuses on arranging the remaining items in a logical and ergonomic manner. Everything has its designated place, contributing to a visually organized and efficient workspace. This not only reduces search and retrieval times but also facilitates a smooth and standardized workflow.

- **Shine (Seiso) -** The third S emphasizes cleanliness and regular maintenance. Workspaces and equipment are cleaned thoroughly to eliminate dirt, dust, and potential sources of contamination. Regular cleaning not only ensures a safe and healthy work environment but also contributes to equipment longevity.

- **Standardize (Seiketsu) -** Standardization is about establishing and maintaining uniform procedures and practices across the organization. This involves documenting the processes developed during the Sort, Set in Order, and Shine phases. Standardized practices ensure consistency, facilitate training, and provide a baseline for continuous improvement.

- **Sustain (Shitsuke) -** The final S, Sustain, focuses on ingraining the 5S principles into the organizational culture. This requires ongoing training, regular audits, and continuous improvement initiatives to ensure that the benefits of 5S are sustained over the long term [18].

This methodology offers numerous benefits that contribute to organizational excellence. Firstly, it enhances workplace safety by eliminating hazards and promoting a clean and organized environment. Secondly, it improves operational efficiency by reducing waste, minimizing search times, and optimizing workflow. Thirdly, 5S fosters a sense of pride and ownership among employees, contributing to higher morale and increased job satisfaction. Moreover, the standardized processes established through 5S lay the foundation for continuous improvement efforts, aligning seamlessly with the overarching goals of *Lean* manufacturing [1]. Implementing 5S requires a systematic approach. Beginning with comprehensive training to ensure that all employees understand the principles and objectives of 5S. Engaging employees in the sorting and organizing process to foster a sense of ownership and empowerment. Regularly conduct audits to assess the adherence to 5S principles and identify areas for improvement. Additionally, it is crucial to sustain the momentum by incorporating 5S principles into everyday practices and ensuring that the organizational culture promotes cleanliness, order, and continuous improvement [8].

2.4 Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is a management philosophy that aims to maximize equipment effectiveness throughout the lifetime of the equipment by maintaining it in optimum condition to contribute to the success of the factory and the organization's objectives. It was created to address the need for improved maintenance management in manufacturing organizations, focusing on the integration of maintenance practices with quality improvement strategies and overall equipment effectiveness (OEE) [19], [4].

2.4.1 TPM Pillars

TPM is a comprehensive approach to maintenance management that encompasses various aspects of maintenance, including preventive maintenance, autonomous maintenance, and corrective maintenance. It aims to create a seamless integration between maintenance activities and the organization's overall manufacturing strategy, ensuring that maintenance efforts contribute to the achievement of the organization's goals and objectives [20]. TPM is based on eight key principles, also known as the 8 pillars, which serve as the foundation for its implementation and success. These pillars are:

- **Continuous Improvement:** Continuous Improvement is a fundamental pillar of Total Productive Maintenance (TPM), emphasizing the ongoing pursuit of better processes and outcomes. It involves fostering a culture of innovation, encouraging employees at all levels to identify and implement improvements in their work areas. Continuous Improvement is

driven by the principle that small, incremental changes lead to significant advancements over time.

- **Autonomous Maintenance:** Autonomous Maintenance empowers frontline operators to take responsibility for the upkeep and basic maintenance of their equipment. It involves training operators to perform routine maintenance tasks, conduct inspections, and detect abnormalities early on. By decentralizing maintenance responsibilities, organizations enhance equipment reliability, reduce downtime, and engage operators in the care of the machinery they operate.

- **Planned Maintenance:** Planned Maintenance focuses on scheduled, systematic maintenance activities to prevent breakdowns and prolong equipment life. It involves creating detailed maintenance plans, scheduling regular inspections, and conducting overhauls as needed. Planned Maintenance helps to optimize the use of resources, reduce unplanned downtime, and ensures that equipment operates at peak efficiency.

- **Training and Education:** Training and Education are essential for building the skills and knowledge necessary for effective TPM implementation. This pillar emphasizes continuous learning, skill development, and knowledge sharing among employees. Well-trained personnel contribute to better equipment operation, efficient maintenance practices, and a workforce that is adaptive to changes and challenges.

- **Early Management:** Early Management, also known as Early Equipment Management (EEM), focuses on minimizing losses and improving efficiency during the introduction of new equipment or processes. It involves cross-functional collaboration in the early stages of project development to identify potential issues, optimize designs, and ensure a smooth transition from project initiation to full-scale production.

- **Quality Maintenance:** Quality Maintenance in TPM aims to ensure that equipment and processes consistently produce high-quality outputs. It involves integrating quality management practices into maintenance activities, monitoring and controlling variations, and preventing defects in the production process. Quality Maintenance supports overall product quality and customer satisfaction.

- **TPM in Administration and Offices:** Extending TPM principles to administrative and office functions ensures that the benefits of TPM are not limited to the shop floor. This pillar involves applying TPM concepts such as standardized work, continuous improvement, and autonomous maintenance to administrative processes. It promotes efficiency, faster problem resolution, reduces errors, and enhances the overall effectiveness of office operations.

- **SHE (Safety, Health, and Environment):** Safety, Health, and Environment is a critical pillar that underscores the importance of creating and maintaining a safe and healthy workplace while minimizing the environmental impact of operations. It involves implementing

safety protocols, promoting health and wellness initiatives, and adhering to environmental regulations. A strong SHE focus contributes to a secure work environment, employee well-being, and environmental sustainability [21], [22].

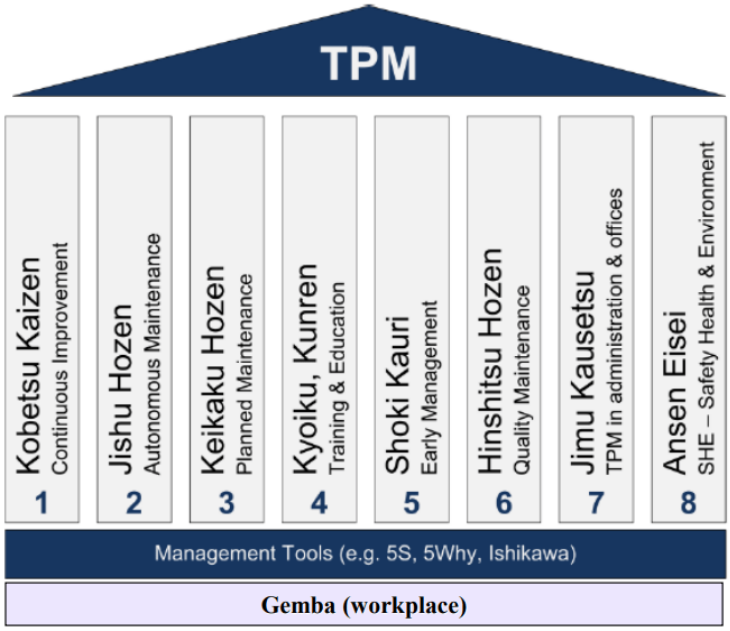


Figure 2.4: TPM Building [4]

It is important to be familiar with the *gemba* where TPM is going to be implemented, as well as useful management tools such as 5S and 5Whys, in order to be assertive when going through everything that is necessary in each case. Figure 2.4 shows the fundamental pieces of TPM.

2.4.2 OEE

Within Total Productive Maintenance (TPM), Overall Equipment Efficiency (OEE) is an essential metric. It offers a comprehensive view of equipment effectiveness, aiding organizations in assessing the success of their TPM initiatives. OEE, closely tied to TPM and *Lean* Manufacturing, supports a holistic approach to achieving manufacturing excellence. Its data-driven insights enable organizations to comprehend their current status and make informed decisions for enhancing overall efficiency [23]. Key Characteristics of OEE further underscore its significance:

- **Simplicity and Practicality:** OEE's robustness lies in its simplicity and practicality, addressing common and critical sources of productivity loss. It offers a clear and actionable evaluation of manufacturing efficiency.

- **Categories of Loss:** OEE methodically breaks down efficiency into three primary categories—Availability, Performance, and Quality—providing a targeted understanding of areas for improvement and streamlining the path to enhanced overall efficiency.

- **Data-Driven Approach:** Being inherently data-driven, successful OEE implementation relies on robust data collection and analysis. The acquisition of accurate and comprehensive data forms the foundation for insightful performance evaluations and guides strategic decision-making.
- **Continuous Improvement:** OEE serves as a catalyst for continuous improvement, systematically identifying areas of inefficiency and quantifying them through metrics. This approach fosters a culture of ongoing enhancement within organizations, promoting sustained improvements in manufacturing processes.

Overall Equipment Efficiency (OEE) serves as a best-practice methodology for monitoring and improving manufacturing efficiency. Covering machines, manufacturing cells, and assembly lines, OEE simplifies the complex landscape of productivity loss. It categorizes sources into three primary areas, distilling them into metrics that provide an excellent gauge for current performance and avenues for improvement:

- **Downtime -** Time when the machine should be running but it is stopped affecting its availability. It happens due to equipment failures or setups and adjustments.
- **Speed Losses -** Equipment is running, however, it is not running at its maximum target speed, impacting on its performance. The main causes for this are: idling and minor stoppages, and reduced speed operation.
- **Defect Losses -** Equipment is producing products that do not fully meet the specified quality standards, negatively affecting the quality. These losses are originated from scrap and rework of the defective products and startup losses [4], [24].

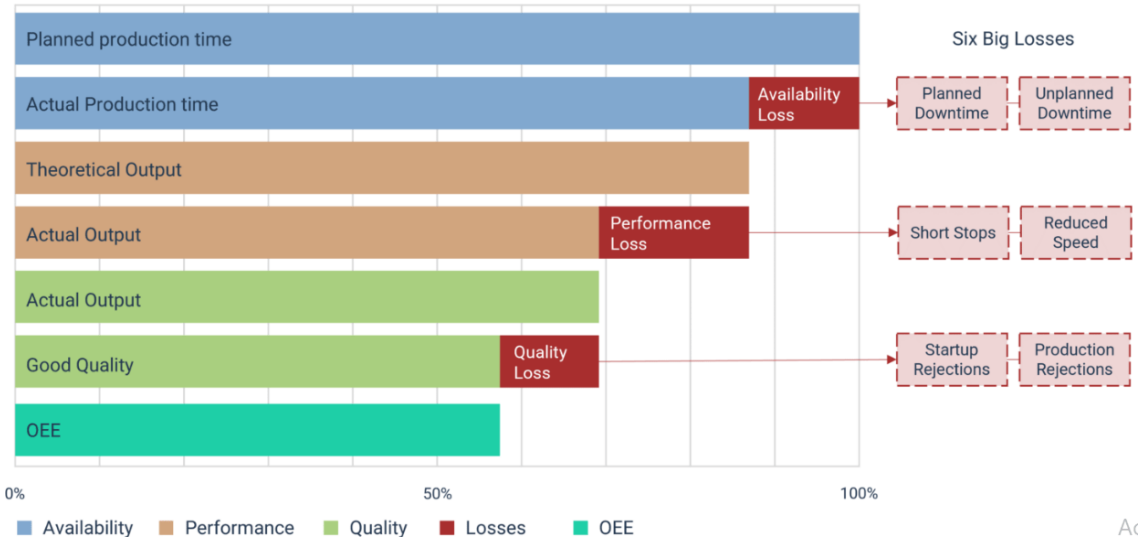


Figure 2.5: OEE Calculation [5]

Figure 2.5 illustrates how the losses described above have undesired consequences to the process efficiency making it clear where shall efforts be applied and what needs to be optimize in

order to achieve a better OEE. These losses can be represented through a mathematical calculation of the OEE illustrated on Equation 2.1.

$$OEE = Availability * Performance * Quality \tag{2.1}$$

Chapter 3

Analysis of the current situation

The first step to solve a problem is to identify the main ingredients of it, as *Kidlin*'s law states, "If you write the problem down clearly, the matter is already half solved". Therefore, it is crucial to understand the whole process, and the best way to do this is to be where the problems actually occur, *gemba*, and interview the employees who deal with these problems on a daily basis. Thus, Chapter 3 presents the current situation giving a factory overview, explaining the production process and providing a detailed analysis on the department focused on this project, concluding with the problems identified.

3.1 Factory Description

The factory focuses on producing bleach, an important cleaning supply, for Portugal and Spain. In order to achieve the required high quality standards on a sustainable basis, the organization is managed by an Integrated Work System (IWS) strategy which comprises a set of systems and tools that enable organizations to achieve planned business outcomes. This approach is based on ten pillars that are shown on Figure 3.1.

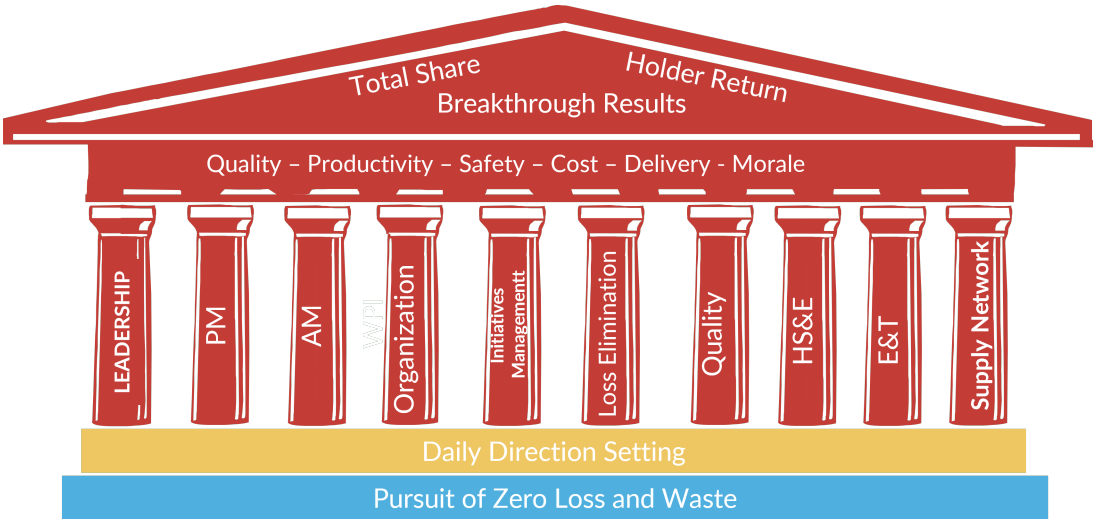


Figure 3.1: IWS pillars [6]

The desired outcomes are achieved through the sequential and methodical implementation of a series of clearly defined steps with calculated objectives. This systematic process is executed by dedicated teams assigned to each pillar and drawn from different areas within the organization. This strategy ensures that all operational requirements are taken into account when implementing tools. The IWS strategy serves as an overarching framework that encourages 100% employee engagement and the cultivation of a zero-loss, and defect mindset. It ensures that every member of the organization is aligned, engaged and actively participating through continuous learning and the application of acquired skills towards the company's goals, referred to as Compelling Business Needs (CBN). The zero-loss mentality inherent in IWS promotes the identification and prioritization of losses within the system, ultimately leading to their elimination and the creation of a continuous flow of value creation without waste. This comprehensive strategy integrates pillars, systems and tools, ensuring that the organization achieves higher quality, efficiency and flexibility, while reducing the costs, through a carefully defined and targeted implementation process carried out by dedicated teams across multiple departments.

Inherent to the IWS program, the company implements a range of tools and methodologies across its branches. Within this framework, alongside the defined priorities being the Security and Quality, four key concepts adopted by Fater Portugal are delineated, serving as a compass for team performance and guiding the pursuit of organizational objectives.

- **Compelling Business Needs (CBN)-** The CBN methodology at Fater Portugal aligns the company's vision and cultural principles with quantifiable business objectives, set as medium-term goals. The overarching objective is for the combined efforts of IWS pillars to yield the desired results.

- **Daily Directing Setting (DDS)-** Fostering employee involvement in problem-solving, the DDS has the purpose of aligning the performance results of each IWS pillar to the ones that were benchmarked. Therefore, it conducts daily meetings with the supervisors from the

different areas of the manufacturing unit, so teams can identify issues, conduct resolution methodologies, and establish improvement objectives on a daily basis, ensuring the goals are being achieved on a sustainable way.

- **Cleaning, Inspection, Lubrication (CIL)-** Integral to AM, the CIL concept defines tasks for Cleaning, Inspection, and Lubrication in each factory area or equipment. These tasks are essential for smooth process operation, enabling the operations team to comprehend equipment functioning, detect and prevent anomalies, ensuring production with zero defects, and reducing breakdowns, waste, rework, and safety incidents.

- **Centerline (CL)-** Linked to AM as well, CL hedges in parameters whose variability impacts equipment operation. CL routes involve daily inspections to maintain these parameters within pre-established values range. At the start of each shift, operators shall perform CL routes for various equipment in their work area.

In terms of the factory layout, Figure 3.2 illustrates all the manufacturing areas: IHBB, Packing and Making.

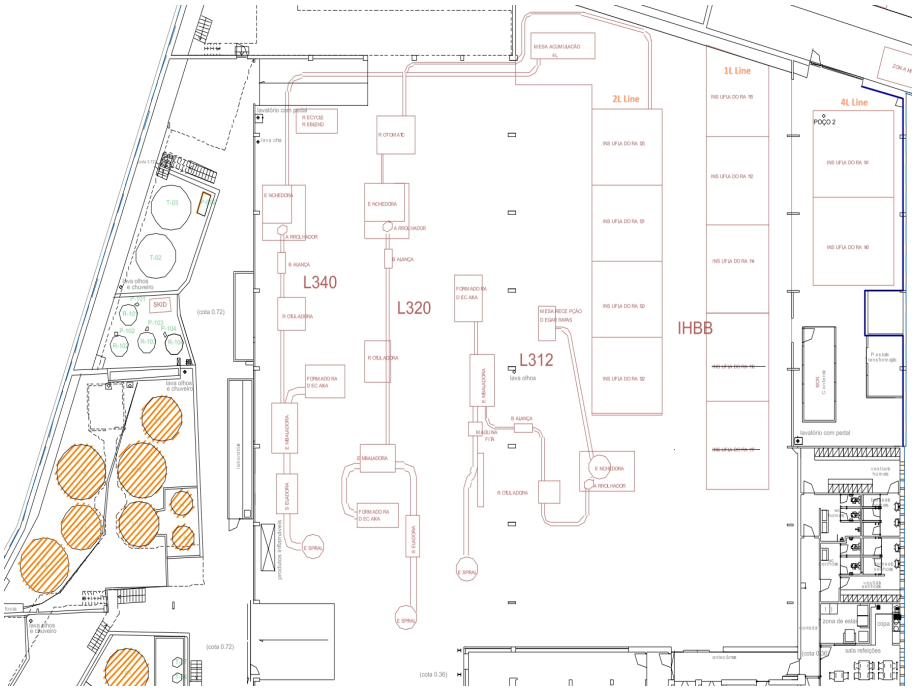


Figure 3.2: Plant layout

As it can be seen, the factory lays out three different production lines on IHBB and several tanks on the Making area that culminates on lines 312, 320 and 340 of the Packing sector.

3.2 Productive Process

Since Covid-19 emerged, the demand for cleaning supplies has risen. Consequently, the factory that was producing 500.000 standard units (SU) annually, bumped its production to 800.000 SU's in order to meet the clients' demand. Therefore, the requirements on the excellence of the productive process are even more important since the factory capacity doesn't leave much room for errors. To illustrate a complete overview of the productive process flow, a chain diagram was drawn and is represented on Figure 3.3.

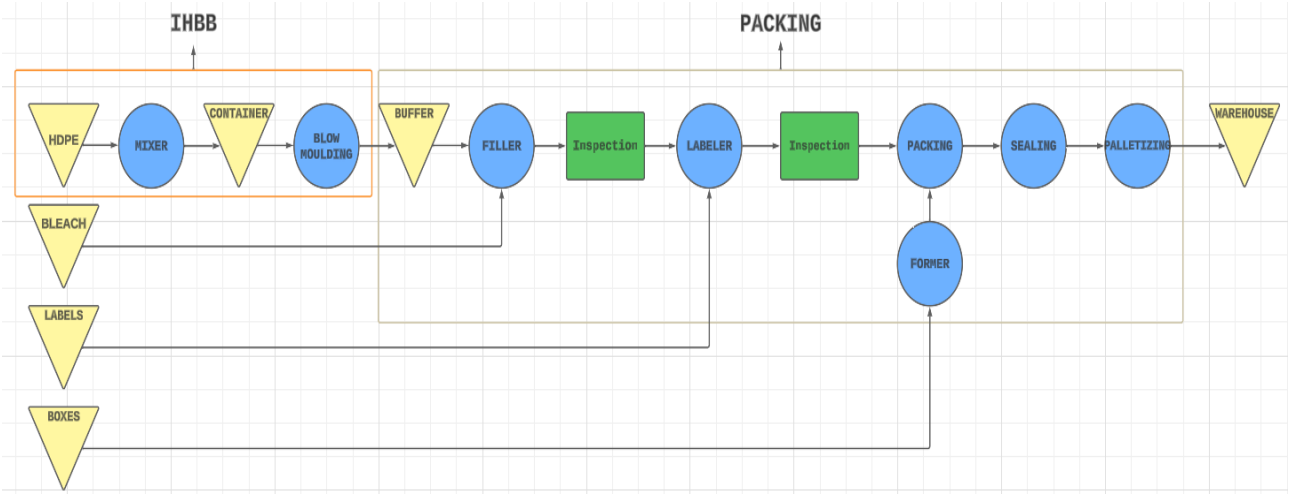


Figure 3.3: Chain Diagram of the Productive Process

For a more efficient comprehension, the process can be divided into four different sections:

- **In House Bottle Blowing (IHBB)-** This section is responsible for the bottle production. It incorporates nine machines producing three different bottle sizes: four dedicated to produce 2 Liter bottles; three are assigned to produce 1 Liter bottles; and the remaining two are responsible for the 4 Liter bottles. These machines all have hydraulic, pneumatic and electric circuits which make them very complex to understand and study.

- **Making -** This section is mainly controlled automatically and has the responsibility of producing the bleach. For that, it mixes the necessary bleach components, filters, and leads the product to three containers for different types of bleach.

- **Packing -** At this section the products resulting from the two previous sections are combined: the bottles from IHBB are filled with the bleach from Making. Besides filling the bottles, this area is also responsible to seal and label the bottles and group them into boxes creating the end product.

- **Warehouse -** This area is responsible to receive the boxes of the end product already on pallets and place them on the racks accordingly. Additionally, it is where the end product is set into the shipping trucks.

Presently, the production process engages 21 team members distributed across diverse sectors, operating within three shifts: the morning shift from 7:00 AM to 3:00 PM, the afternoon shift from 3:00 PM to 11:00 PM and the night shift from 11:00 PM to 7:00 AM. Depending on the demand the night shift operates with only one or two production lines. Additionally, a department dedicated to administrative services comprises 14 employees overseeing various production support functions such as production planning, sales, quality and cost management.

3.3 IHBB Department

After giving an understanding of the whole process flow, it is important to focus on detailing the department in which this project was conducted: the In House Bottle Blowing. This department has a total of 9 assigned workers following the organization presented on Figure 3.4.

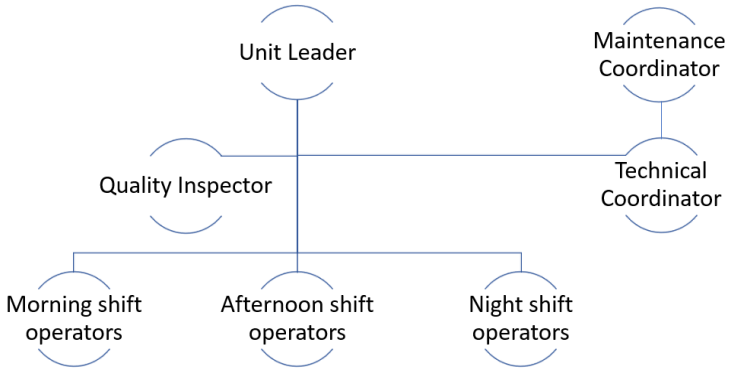


Figure 3.4: IHBB organizational chart

As previously mentioned, this department ensures the plant has bottles that are going to be filled. Therefore, the department possesses nine blow molding machines from *Magic*. To produce 2 Liter bottles which supplies the line 320 with a rate up to 80 bottles/min there are four machines labeled: 120, 121, 122 and 125. The machines 112, 114 and 115 supply line 312 correspondent to 1 Liter bottles, at a maximum rate of 84 bottles/min. Finally, machines 140 and 141 manufacture 4 Liter bottles to line 340 with a maximum rate of 30 bottles/min. The machine output rates are represented on Table 3.1.

Table 3.1: Machine ouput rates

Machine	112	114	115	120	121	122	125	140	141
Rate (bottles/min)	24	24	36	20	20	20	20	15	15

In order to satisfy the current factory demand, these machines are required to have an OEE of 75%. Additionally, the factory demands that the Rate Loss (RL) shall not be higher than 3% for each line. This KPI is paramount, since the process flow is continuous and the machines at IHBB represent the bottleneck of the whole process, any variation on the bottle production rate

affects the rate of the whole process. Consequently, the RL represents the percentage of time lost to produce the target number of bottles, which can be calculated following the Equations 3.1 and 3.2. For instance, if a machine stops 1 hour during an 8 hour shift, then the RL would be 12.5%.

$$t_{RL} = \sum_{i=1}^{N} \left(\frac{C_{\text{real},i} * t_{\text{production},i}}{C_{\text{target},i}} \right), \quad \forall i \in \{1,\text{N}\} \tag{3.1}$$

$$RL = \frac{t_{RL}}{t_{\text{scheduled}}} * 100 \tag{3.2}$$

Where:

$$N = \text{Total number of machines of the production line}$$
$$C = \text{Machine speed rate}$$
$$t_{production} = \text{Machine uptime}$$
$$t_{schedule} = \text{Line schedule time}$$

Although the plant has a scorecard defined at 3% for the RL, the latest months indicate RL values rounding the 30% as it can be examined on Figure 3.5. These alarming results are the reason of this project and the causes are to be investigated on the following sections.

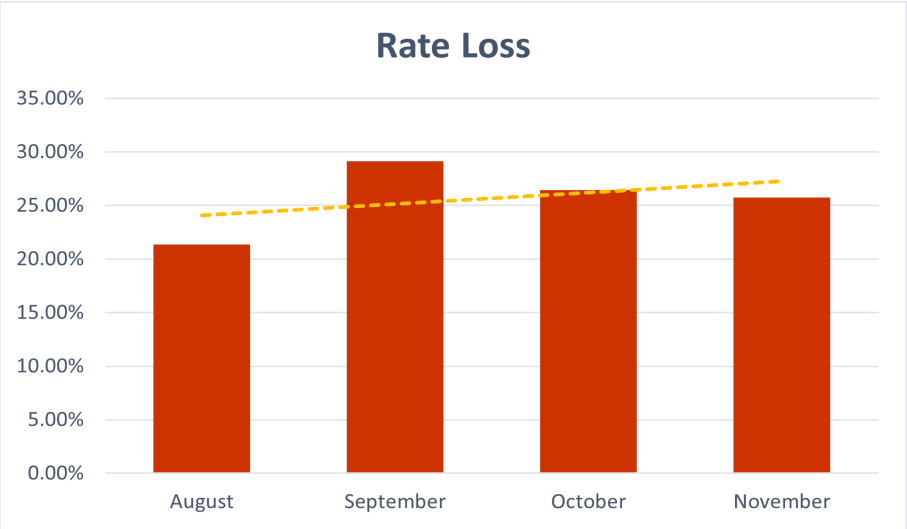


Figure 3.5: RL values on previous months

These manufacturing area counts with 2 line operators per shift, excluding the night shift where it only has one. Each operator is assigned with the following tasks:

- **Daily CIL** of the machines, which includes cleaning the spinnerets, filters and the conveyor belts. Figure 3.6 shows the standard tasks for the daily CIL of a machine from the 2 Liter line.

	TAREFAS	Frequência	Estado	Tempo
CIL - 1	Limpar filtro superior da tremonha asp mistura de PE e Filtro da tampa	Diário	T	3
CIL - 2	Limpar filtro em rede da bomba de vácuo do sist PE	Diário	T	3
CIL - 3	Limpar filtro de saída de ar da bomba	Diário	T	1
CIL - 4	Limpar por cima das fieiras, cabeça e zona extrusora (plástico queimado)	Diário	P	5
CIL - 4	Limpar tapete de gitos horizontal e vertical de contaminações de óleo e plastico queimado	Diário	P	3
CIL - 5	Limpar todas as fotocélulas (tapete de saída, contagem de garrafas, rejeição de garrafas, etc.)	Diário	P	1
	Fatores Q - Qualidade	RESULTADO CIL TURNO		

Figure 3.6: Daily CIL for 2 Liter machines

- **Weekly CIL** of the machines, which includes a scrupulous cleaning of several parts of the machine, alongside of an inspection on those parts and lubricating the components exposed to the most wear. Figure 3.7 indicates the tasks required to perform a complete weekly CIL for each machine of the 2 Liter line.

TAREFAS		Frequência	Estado	Tempo
CIL - 1	Limpar por cima das fieiras, cabeça e zona extrussora (plástico queimado)	Semanal	P	10
CIL - 2	Limpar tanque/valvulas	Semanal	P	10
CIL - 3	Limpar óleo e gitos do chão debaixo do tapete de gitos horizontal	Semanal	P	20
CIL - 4	Limpar poço das Insufladoras	Semanal	P	30
CIL - 5	Limpar moldes incluindo faces do encosto	Semanal	P	5
CIL - 6	Limpar filtro de ar condicionado (quadro elétrico) (120,121,125)	Semanal	P	10
CIL - 7	Limpar interior maquina e protecções do poço da 120, 121 e 125	Semanal	P	15
CIL - 8	Limpar estrutura da máquina - exterior, motores e por cima do quadro elétrico	Semanal	P	20
CIL - 9	Limpar estrutura do Ventilador - exterior e interior	Quinzenal	P	20

Figure 3.7: Weekly CIL for 2 Liter machines

- **Controlling the operative machine parameters** while they are running. This includes knowing the standard operative parameters and continuously checking them while the machines are operating, as they are shown on the machine's Programmable Logic Controller (PLC) that is represented on the Attachment A .

- **Controlling the amount of HDPE and dye** on the containers checking the display of the monitor from the control room that is represented on Figure 3.8.

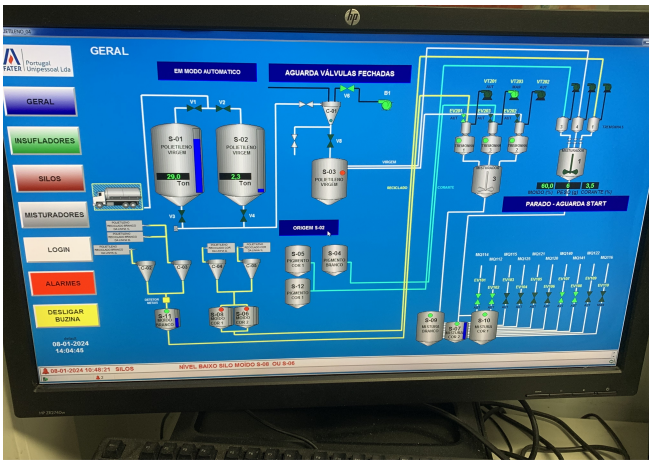


Figure 3.8: Monitor display on the IHBB control room

- **Starting up** and **shutting down** the machines every time it is planned or required. Additionally, it is necessary to know the starting or shutting of a machine procedure depends on the time it has been running or stopped;
- **Registering the breakdowns** detailing the downtime, the cause and immediate action taken. This information is written manually on the Shift Handover template;
- **Performing quality controls** of the bottles from each machine. There are four quality tests to guarantee the bottles are within the quality standards: weight, compression, watertightness and the fall test. These tests are explained on Attachment B.

In order to be able to perform the aforementioned work tasks, a complete training on operation and quality is set to be given to every worker. This job is assured by the Unit Leader who is also responsible for all the operation activities, including managing the operators tasks and AM tasks, and to realize a weekly inventory of the HDPE and dye quantities. Finally, the technical coordinator, who is linked to both operational and maintenance activities, is assigned with the responsibility of performing PM tasks outlined by the maintenance coordinator and give training to the operators in order to share his knowledge. The technical coordinator also has a key role on providing a link between the line operators and the administrative management. Besides outlining the PM strategy for IHBB the maintenance coordinator also has to manage the spare parts and tools that are required for the maintenance. The number of PM tasks realized versus the planned and the costs of these tasks are two of the KPIs the maintenance coordinator has to keep track.

3.3.1 Current Maintenance Strategy

Presently, the factory has a defined strategy for both AM and PM. Regarding AM, the approach defines a 15 minute stoppage for the daily CIL in order to keep the machinery lubricated and cleaned. Additionally, the plant also has defined a weekly planned downtime of four hours on Mondays to perform the weekly CIL alongside with PM work orders. On this day of the week, from 7:00

AM until 11:00 AM all the machinery is stopped, therefore none of the lines are producing. As detailed on Figure 3.7, the weekly CIL tasks are focused on a deeper cleaning, a well rounded inspection and the necessary lubrication. The operators on this shift are expected to execute them on all nine machines. Alongside with the weekly CIL, the technical coordinator executes the PM tasks established with the maintenance coordinator. These tasks are a result of the maintenance strategy implemented on SAP software. On the Attachment C an example of a work order on SAP that is delivered to the technical coordinator is presented. Half an hour before 11:00 AM, the technical coordinator helps the operators preparing and starting up all the necessary machines for the operation that day.

3.3.2 Work floor organization

Currently, IHBB possesses two tool carts to aid the operators providing them with the necessary tools to execute their tasks and keep the machines running. Each car tool shall have:

- **Ratchets**
- **Wrenches**
- **Allen wrenches**
- **Universal pliers**
- **Cutting pliers**
- **Pruners**
- **Files**
- **Tape measure**
- **Copper wrenches**
- **Wire Brushes**
- **Screwdrivers**
- **Nut drivers**
- **Torque wrench**
- **Sandpaper**
- **Hammer**
- **Lubricating oils**

These tools are essential for the operation since they are required for CIL tasks, to prepare the start of the machines, to regulate the párison when necessary, which corresponds to the extruded polyethylene before it is molded, and to perform maintenance tasks. Currently, they are divided into the six different shelves the carts possess as it is demonstrated on Figure 3.9.



Figure 3.9: Current tool cart organization

3.4 Problems Identified

After spending significant time observing the *gemba*, analysing the current process, questioning the line operators and applying the shadowing technique with them, several aspects of the operational process with great room for improvement were identified. Therefore, an *Ishikawa* diagram was drawn and is represented on Figure 3.10.

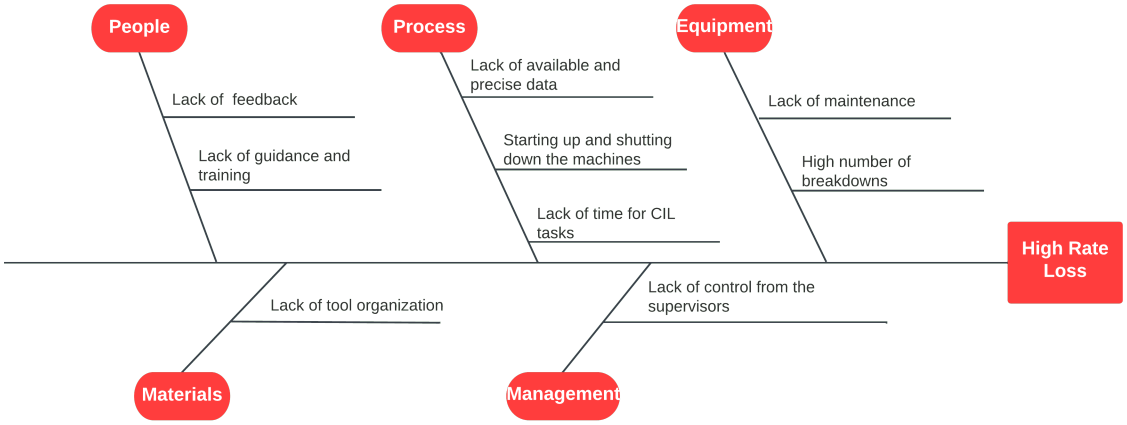


Figure 3.10: *Ishikawa* diagram referring to the high RL

Firstly, the register of the breakdowns that is supposed to be filled on a paper, lacks a lot of information due to being unpractical for the operators to fill it when it is located on the monitoring room, leading them to move away from the machines. Therefore, the operators write the data only when they have time and the operation is running well. This creates an important loss of data lot data, which prevents the Unit Leader and the Maintenance Coordinator from having accurate data to perform precise analysis and elaborate improvement measures to prevent the breakdowns.

Figure 3.11 represents one Shift Handover filled which demonstrates the lack of precise information while only containing a small number of the breakdowns of that day. Besides this, since it is written on paper the Unit Leader has to copy every piece of information to the computer which is extremely time-consuming.

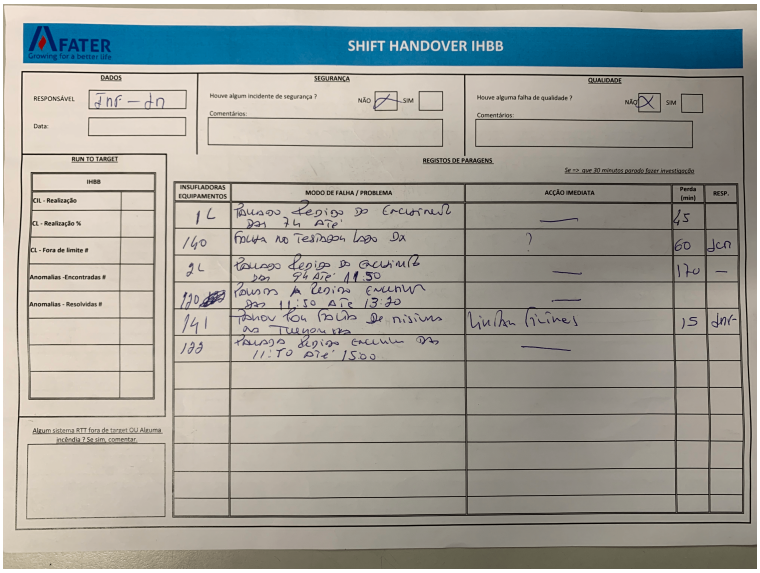


Figure 3.11: Shift Handover filled by the operators

Secondly, most of the operator tasks enumerated lack a standard procedure which highly increases the variability when performing them. Particularly, the starting up and shutting down of the machines is an assignment that if it is not performed with a certain method it can take significantly more time to actually execute, while causing unnecessary damage on the machine components. Upon being present on the *gemba*, several stops were observed causied by an incorrect starting of the machine. Furthermore, the daily and weekly CILs lack in task sequence optimization which causes significant unnecessary movement and poor cleaning, since there are parts of the machine that shall be cleaned first to not influence other parts cleaning. Nonetheless, the coordination and task sequencing of the operators does not exist, which results in time wastage and increase probability of an operator repeat a task already performed. Thirdly, the tool carts, which are supposed to be easily accessed and well organized so the operator does not lose much time looking for a specific tool, are used without any organized method. The tools the carts carry are all spread across the cart shelves where some of the same family are put into more than one shelf, making it really hard for the operators to find the right tools within minimal time. Figure 3.12 demonstrates some of the cart shelves.



Figure 3.12: Tool cart shelves

Finally, the current AM and PM strategy is not aligned with the actual necessities of the machinery. The AM strategy establishes 15 planned minutes for the daily CIL, however, to perform the correspondent tasks it is expected to take 15 minutes per machine. Consequently, with two operators available, the daily CIL totals a downtime of 65 minutes due to one of them needing to execute it on five machines. Moreover, the weekly CIL defines an expected downtime of 120 minutes per machine, therefore it corresponds to a 600 minute downtime, which is significantly higher than the planned 240 minutes. These facts cause the operators to never do a complete job on cleaning, inspecting and lubricating the machines. Consequently, only basic cleaning is actually performed which is a major cause for the poor availability of the machines currently. Regarding the PM strategy, due to constant unexpected anomalies happening, the planned maintenance work orders change day to day, which results on a corrective maintenance approach instead of a planned one.

The list of challenges outlined earlier intricately sheds light on the existing inefficiencies in the factory's operations that hinder the achievement of sustainable production levels and consequently affect the plant's ability to meet increasing demand. These challenges form a complex web of issues, each of which contributes significantly to the overarching hurdles faced by the production facility.

At the forefront, the problems identified act as catalysts for process inefficiencies and disrupt the seamless flow of production activities. Factors such as sub-optimal machine performance, misalignment of the supply chain and operational bottlenecks combine to hinder the production flow. This not only impacts overall output, but also creates a domino effect that undermines consistent adherence to production quotas. Another layer of complexity is how these challenges affect the motivation and effectiveness of the available workforce. The persistently difficult working conditions, coupled with the frustration that results from inconsistent production levels, casts a shadow over employee motivation. This not only affects individual productivity, but also permeates the corporate culture and is a significant barrier to optimal employee motivation and effectiveness.

In essence, the challenges outlined together form an important obstacle that requires a refined and comprehensive approach to solving. Addressing these challenges requires a holistic strategy involving process optimization, ergonomic improvements, and targeted interventions to bolster workforce motivation. The interconnected nature of these facets underscores the need for a synchronized and strategic initiative to instigate transformative change within the factory's operational landscape. By meticulously addressing each facet of the identified challenges, the factory can pave the way for sustainable production practices, aligning itself with market demands and ensuring long-term viability.

Chapter 4

Proposed Improvements

Building on the opportunities identified in Chapter 3, efforts were initiated to plan and implement solutions. Collaborating with the company's leadership, a realistic approach was taken to establish an effective project timeline, considering resource availability. The present chapter details the definition of solutions for ongoing monitoring, and the subsequent execution phase. The solution identification process involved a comprehensive analysis, addressing root causes to ensure long-term effectiveness. This approach aims not only to resolve immediate issues but also to lay the groundwork for sustained improvement. The subsequent section outlines the implementation process, highlighting key milestones, resource allocation, and dependencies. By offering a transparent roadmap, top management can track progress and anticipate potential challenges. This chapter concludes with the implementation strategy, discussing coordination efforts and adjustments made during the execution, and overall impact. This holistic view emphasizes the evolutionary process, showcasing tangible outcomes.

After breaking down the crucial problems on the department, solutions for each issue were studied and are listed on Table 4.1:

Table 4.1: Proposed solutions

Problem Identified	Consequent Loss	Proposed Solution
Lack of data	Poor data analysis	User-friendly template to record machine breakdowns
Lack of tool organization	Time waste	Organized tool cart
Lack of Standard Procedures	High process variability Time waste Unnecessary damage	Elaborate Standard Procedures for machine operation and CIL tasks
Poor Maintenance strategy	Insufficient time for AM and PM tasks	New planned downtime strategy based on stopping one line at the time

4.1 Unplanned Downtime data collection

Efficient data collection plays a pivotal role in understanding and mitigating unplanned machinery stoppages, making it a crucial aspect of effective industrial management. Accurate and high-quality data regarding these stoppages not only serves as a diagnostic tool but also forms the basis for informed decision-making and strategic planning.

Collecting quality data on unplanned machinery stoppages provides valuable insights into the root causes and patterns, enabling businesses to identify recurring issues and implement targeted solutions. This information is instrumental in optimizing maintenance schedules, improving overall equipment effectiveness, and minimizing downtime, thereby enhancing productivity and operational efficiency.

In this context, transitioning from traditional paper-based templates to a user-friendly Excel template represents a strategic leap forward in data collection methodology. The digital format not only streamlines the data entry process but also facilitates real-time analysis and reporting. A user-friendly Excel template ensures that data is consistently recorded in a standardized manner, reducing the risk of errors and enhancing data integrity.

Moreover, the digital template allows for easy integration with other data analysis tools, enabling the Unit Leader and Maintenance Coordinator to harness the power of advanced analytics for optimizing operational tasks and for predictive maintenance, respectively. This forward-looking approach helps in identifying potential machinery issues before they escalate into major stoppages, leading to a proactive and cost-effective maintenance strategy. The simplicity and accessibility of an Excel-based solution make it user-friendly for operators and maintenance personnel, fostering greater participation in data collection. This, in turn, contributes to a more comprehensive and accurate data-set, which is indispensable for making informed decisions regarding equipment reliability, maintenance planning, and overall operational optimization.

Consequently, after consulting with the operators and the Unit Leader to ensure its viability, a template using Microsoft Excel VBA was built providing a digital and easy platform to collect the data. The VBA code can be consulted on the Attachment D, while Figure 4.1 illustrates how the template looks for the operator.

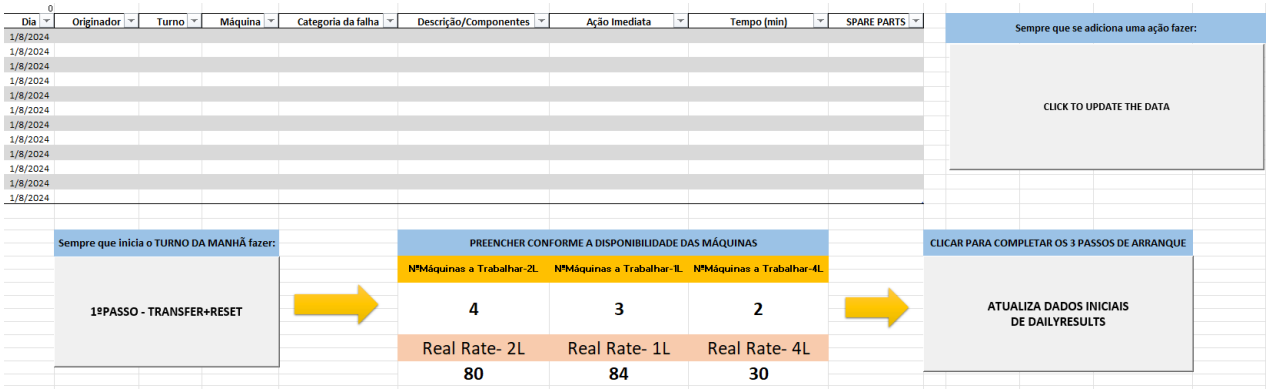


Figure 4.1: Template view for the operator

As it can be seen, the template contains three buttons each of them with a brief description of what they do and when they shall be clicked. In order to fill it correctly, the instructions, that can be consulted on the Attachment E, shall be read. However, Figure 4.1 also shows how intuitive the template is, since every part is properly described. The correct sequence of use starts with clicking on the bottom on the left, which enables the whole information from the previous day to be transferred to another sheet and resettled for the current day. Following, as the arrow indicates, the number of machines working per line and the respective line rate shall be input. For instance, if on that they only three machines of the 2 Liters line are available, the operator must insert the number 3 and the rate of 60. Succeeding this step, the operator shall click on the bottom with the description "Atualiza dados iniciais de dailyresults", which updates the values for the daily RL calculation on a different sheet. After these three steps, the table shown is set to record every unplanned stoppage. For that, the operator that dealt with the stoppage shall fill all the columns. In order to minimize the time needed and to reduce human errors on the writing, each table cell has a drop-down list as represented on Figure 4.2 with every possible information for that cell.

Dia	Originador	Turno	Máquina	Categoria da falha	Descrição/Componentes	Ação Imediata
1/8/2024	Pedro	Manhã	125	Anomalia	Faca de corte	
1/8/2024						
1/8/2024						
1/8/2024						
1/8/2024						
1/8/2024						

Substituir
Parar
Reparar
Limpar
Lubrificar
Repor
Ajustar

Figure 4.2: Drop-down list example

The only column that is an exception is the one labeled "Descrição/Componentes" since it requires either the component that caused the stop or if it was not identified a brief description of what happened. After filling every column, the operator shall click the bottom right next to the table which enables the information to update the daily results instantly. Upon having the information typed, the Unit Leader can access this shared document and monitor how the operation is performing by checking the number of stops and checking the sheet named "DAILYRESULTS" which provides the daily RL for each line as it is demonstrated on Figure 4.3.

	2L	1L	4L
Target Rate (bottles/min)	60	72	30
Schedule Time (min)	5040	2520	1680
Uptime (min)	4800	2220	1500
Production (bottles)	96000	53280	22500
Rate Loss (%)	29%	24%	11%

Figure 4.3: Daily Rate Loss table filled

Additionally, in order to aid the Maintenance Coordinator elaborating and constantly updating the PM strategy, the daily data input by the operators regarding the stoppages is transferred to a sheet named "ALLFAILURES" which provides a full list of all the stops recorded by the operators and it is illustrated on Figure 4.4.

Dia	Originador	Turno	Máquina	Categoria da falha	Componentes	Ação imediata	Tempo (min	Repetitividade (#)	Total time	Spare Parts
10/17/2023	Ricardo	Manhã	141	Falha de processo	Tanque de óleo	Repor	20	1	20	
10/17/2023	Ricardo	Manhã	125	Falha de processo	Tanque de óleo	Repor	20	1	20	
10/17/2023	Ricardo	Manhã	140	Enchimento	Setup de Produto	Parar	40	2	80	
10/17/2023	Ricardo	Manhã	112	Falha de processo	Ventilador de Transf.	Parar	80	1	80	
10/17/2023	Ricardo	Manhã	141	Enchimento	Paletizadora	Parar	15	1	15	
10/17/2023	Margarida	Tarde	121	Anomalia	Alimentador da barra estática	Substituir	120	1	120	Ionizador
10/17/2023	Margarida	Tarde	122	Anomalia	Sensor carro DX	Reparar	20	1	20	
10/17/2023	Margarida	Tarde	114	Falha de processo	Filtros da tremonha	Limpar	20	1	20	
10/25/2023	Ricardo	Manhã	120	Enchimento		Parar	20	4	80	
10/25/2023	José Freitas	Manhã	121	Avaria	Contra molde SX	Reparar	200	1	200	
10/25/2023	José Freitas	Tarde	121	Avaria	Cilindro de fecho SX	Substituir	90	1	90	Cilindro hidráulico
10/25/2023	Ricardo	Manhã	140	Falha de processo	Zona de Trabalho	Limpar	40	1	40	
10/25/2023	Ricardo	Manhã	115	Falha de processo	Pinol SX desapertado	Ajustar	15	1	15	

Figure 4.4: Record of the input breakdowns

4.2 Work floor organization

Work floor organization, particularly when meticulously applied to a tool cart, serves as a pillar for operational success and employee well-being. The 5S methodology, encompassing Sort, Set in Order, Shine, Standardize, and Sustain, offers a comprehensive approach to achieving and maintaining this organization. By systematically tiding up and retaining only necessary tools (Sort), arranging them in a logical and easily accessible manner (Set in Order), maintaining cleanliness and regular inspection (Shine), implementing standardized procedures (Standardize), and consistently reinforcing these practices (Sustain), the tool cart becomes more than a storage solution; it transforms into an embodiment of operational efficiency and workplace order.

The benefits of a well-organized tool cart are manifold, particularly concerning time management. With essential tools readily available in a structured layout, operators can seamlessly locate and retrieve what they need, minimizing downtime and increasing overall productivity. The streamlined organization not only saves time but also contributes to a safer and more ergonomic work environment. By reducing the physical strain associated with searching for tools or dealing with clutter, the organized tool cart enhances work ergonomics, promoting employee well-being and minimizing the risk of workplace injuries. In essence, the investment in work floor organization, particularly through a systematically arranged tool cart, yields tangible benefits in terms of efficiency, safety, and overall workplace satisfaction, with minimal to no costs. Thus, all the operators involved on IHBB were surveyed in order to reach a solution for an optimal cart organization that facilitates the tool access for them. Firstly, it was agreed that it was important to have a shelf containing specifically the tools for CIL tasks, namely the copper wrenches, sandpaper and the individual protection equipment such as protection gloves and visor. Secondly, the remaining shelves were organized from top to bottom grouping the tools with the most use on the higher shelves. Consequently, a list of the tools sorted by their use was built and the grouping was done considering the amount of space needed for each tool family. This step allowed the tool access to be completely enhanced and the cart to go from a chaotic cart to a well organized and cleaned car which can be pictured on Figure 4.5.

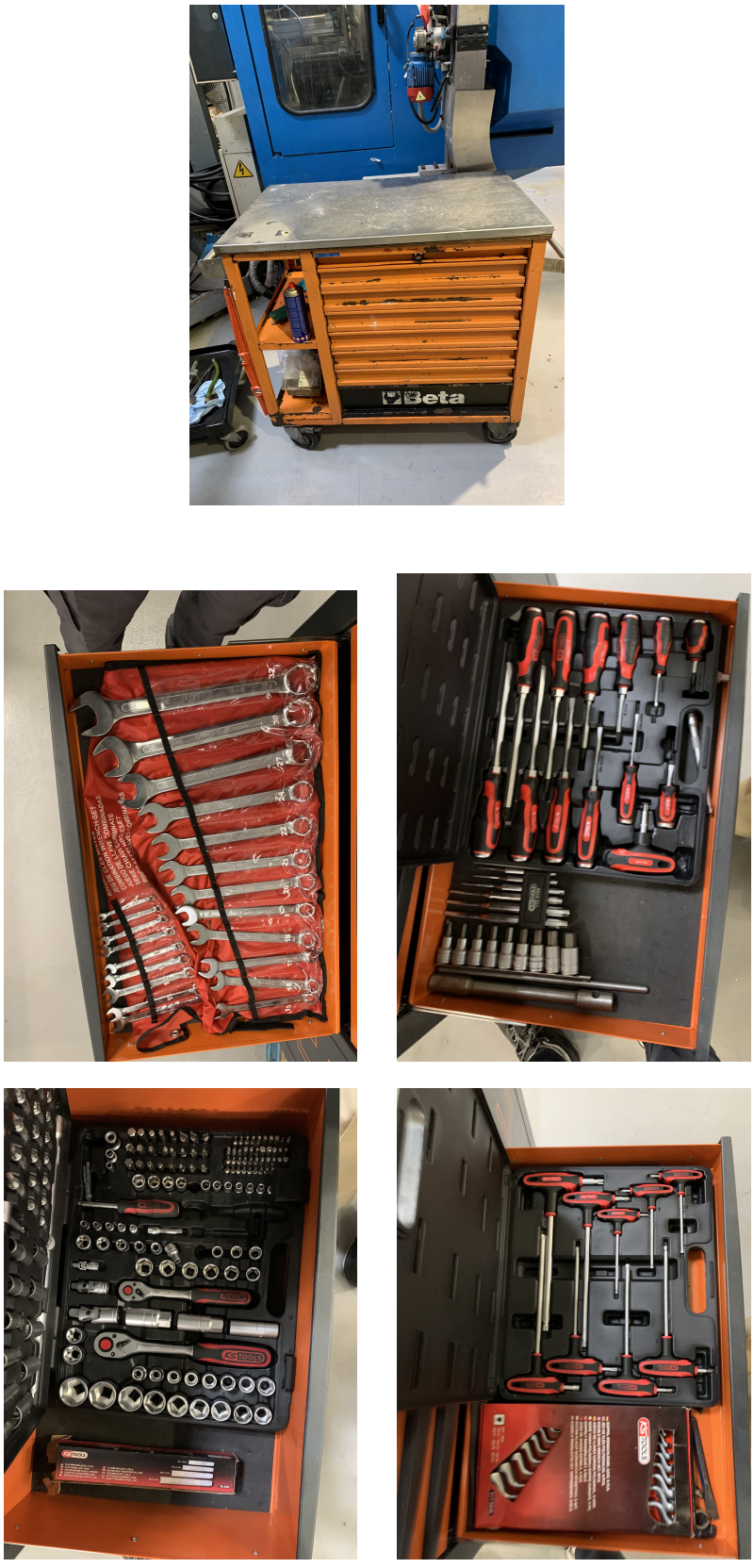


Figure 4.5: Tool cart shelf transformation

While executing the shadowing technique, several times were registered before and after this transformation, which resulted on a slight improvement on the operation as it can be analysed on Figure 4.6 which shows the average time for an operator to access the desired tool went from 111 seconds to only 20 seconds, representing a 82% less time.

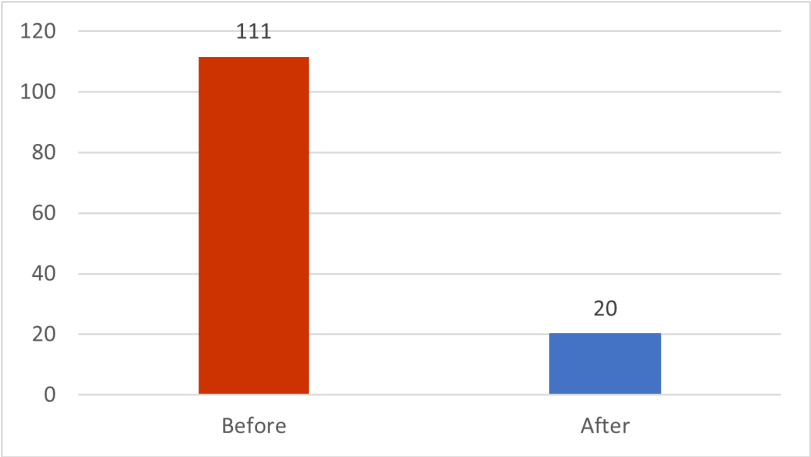


Figure 4.6: Times registered for acquiring a tool from the cart

In order to keep the cart constantly organized, when there is a shift changeover, one operator from the new shift shall check every shelf of the cart to see if all the necessary tools are correctly organized,

4.3 Standard Work for the operation

Implementing standard work procedures is paramount in optimizing operational efficiency and mitigating common challenges faced in various industries. A standardized approach to tasks serves as a cornerstone for achieving consistency, reducing human errors, minimizing variability, and eliminating unnecessary downtime.

One of the primary benefits of standardized work is its ability to significantly decrease human errors. By clearly defining and documenting the prescribed steps for each task, employees have a reliable reference point to follow. This helps in ensuring that processes are executed consistently and in accordance with best practices, thereby reducing the likelihood of errors that can lead to quality issues, safety concerns, or operational disruptions such as unnecessary equipment damage.

Moreover, standard work procedures are instrumental in curbing variability across operations. Consistency in how tasks are performed streamlines workflows, reduces the chance of deviations, and ensures that the output meets predefined quality standards.

The implementation of standard work also contributes to a notable reduction in unnecessary time wastage. When tasks are standardized, employees can work more efficiently as they become familiar with the most effective and streamlined processes. This not only enhances productivity but also allows for better resource allocation, as time is optimized for maximum output.

Additionally, unnecessary stops in operations can be significantly minimized through the adoption of standard work procedures. By having clear guidelines and a standardized approach to problem-solving, employees can quickly address issues without resorting to prolonged breaks. This proactive approach contributes to improved overall equipment effectiveness and helps in maintaining a steady and continuous workflow.

4.3.1 SW for machine operation

Consequently, a standard work was elaborated regarding starting up the machines with *Automa*'s PLC, which is the most recent among the IHBB machines, and it is the one installed on the machines from the 2 Liter line which is the line with priority number one. Two SW for the two different types of starting up were created with the aid of the technical coordinator, so the tasks were sequenced with a correct order and considering minimizing unnecessary movements to optimize the time required.

Firstly, regarding the starting up a machine after a long period of stoppage, the operator must check the machine temperatures that are displayed on the monitor, to ensure the temperatures are within the allowed range for operation. Thereafter, the safety protocol of shutting down the hydraulic, pneumatic and electric systems is executed. This procedure is designated as "LOTO" and already has a standard procedure. Following that, the spinnerets are cleaned using a copper wrench and adequate protection of gloves and a visor. This cleaning task ensures there is no burnt plastic on the spinnerets which would cause quality issues on the bottles. Then the operator starts up the all the machine systems and moves to the back of the machine and open the valves on the water system enabling the mold refrigeration system. Afterwards, the worker returns to the PLC turning on the oil pump and the extruder, which enable all the mechanic movements and plastic flow, respectively. Consequently, while he closes the molds from both sides of the machine, the operator lets some plastic flow and then he starts the production cycle activating the automatic bottle rejection. To prevent unnecessary damage on the cutting components, the cutting system is deactivated in the first cycles. Once the initial cycles are produced, the operator retrieves two bottles to check the weight and the visual appearance and if they are up to standard the automatic rejection is turned off and the bottles are sent to the Packing area. Within the first production hour a quality control has to be executed.

Secondly, when starting up the machine after a brief stop, the procedure is not as long since the operator does not need to clean the spinnerets or letting any plastic flow before starts producing. Additionally, it also does not require opening the water refrigeration system since it was already opened. The final versions of the SW can be consulted on the Attachment F.

When instructing all the operators with these standard procedures it was observed a reduction of the total time required for this task as well as its variability, as it can be perceived from the chart on Figure 4.7. The average time to execute this task was reduced 46% dropping from 365 seconds to 197 seconds.

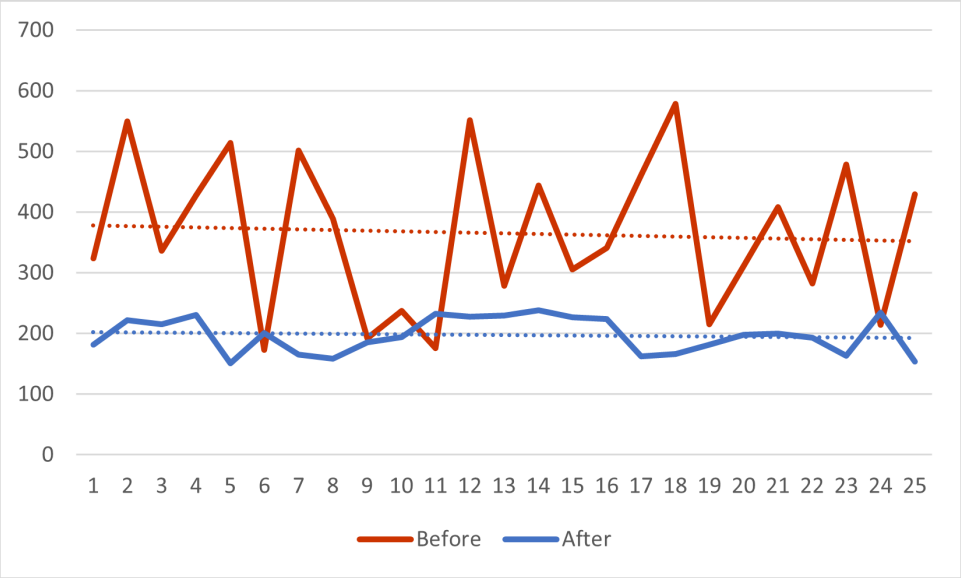


Figure 4.7: Time observation before and after following the SW

4.3.2 SW for CIL tasks

In addition, the standard work for the CIL tasks both daily and weekly were redefined and enhanced in order to encompass every key aspect while mitigating unnecessary actions. For the SW elaboration, both the technical coordinator and the Unit leader were involved to help reach the best possible solution. On top of that, the shadowing technique was applied allowing for a better comprehension of the procedure sequence. During the weekly CIL, the operators movements observed are represented on Figure 4.8 through a spaghetti diagram.

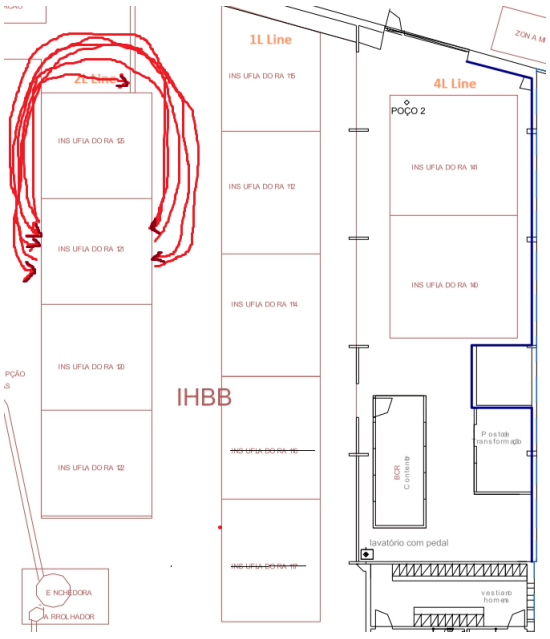


Figure 4.8: Spaghetti diagram for the old weekly CIL for machine 121

This diagram helped inferring there were some movements that were delaying the operator unnecessarily, specifically the five times the operator moves between the front and back of the machine. Additionally, an inadequate cleaning sequence was also spotted where the operator was using compressed air to clean one part of the machine resulting on spreading the dirt to areas previously cleaned. Therefore, an improved weekly CIL was elaborated as it can be seen on Figure 4.9.

Ordem	Tarefa	Frequência	Estado	Tempo (min)	Observações
1	Limpar exterior da máquina- válvulas, tanque, motores e por cima do quadro elétrico	Semanal	Parada	20	Tarefas a realizar com a máquina parada
2	Limpar estrutura do Ventilador - exterior e interior	Semanal	Parada	10	
3	Limpar filtro de ar condicionado	Semanal	Parada	3	
4	Limpar interior da máquina, poço e protecções do poço	Semanal	Parada	30	
5	Limpar moldes	Semanal	Parada	5	
6	Limpar todas as fotocélulas	Semanal	Parada	2	
7	Limpar por cima das fieiras, cabeça e zona extrusora (plástico queimado)	Semanal	Parada	7	
8	Limpar Fieiras	Semanal	Parada	5	
9	Limpar vidros da Insufladora	Semanal	Parada	3	
10	Limpar tapete de gitos horizontal e vertical	Semanal	Final de cada linha	10	Tarefa a realizar no final de realizar CIL em todas as máquinas da linha
11	Limpar filtro superior da tremonha e filtro da tampa	Semanal	Run	3	Tarefas a realizar após arranque das máquinas
12	Limpar filtro em rede da bomba de vácuo do sistema de PE	Semanal	Run	3	
13	Limpar filtro de saída de ar da bomba	Semanal	Run	1	
14	Limpar óleo e gitos do chão al	Semanal	Run	-	
Total				85	

Figure 4.9: New SW for the weekly CIL

On top of having an optimized cleaning sequence, this new CIL is also less time-consuming comparing to the previous one, mostly due to the transformation of internal activities, that are performed with the machine stopped, into external ones executed with the machine running, such as cleaning oil contamination on the floor. Figure 4.10 shows the spaghetti diagram for the new defined weekly CIL, where it can be seen a significant reduction on the operator movements eliminating several unnecessary motion.

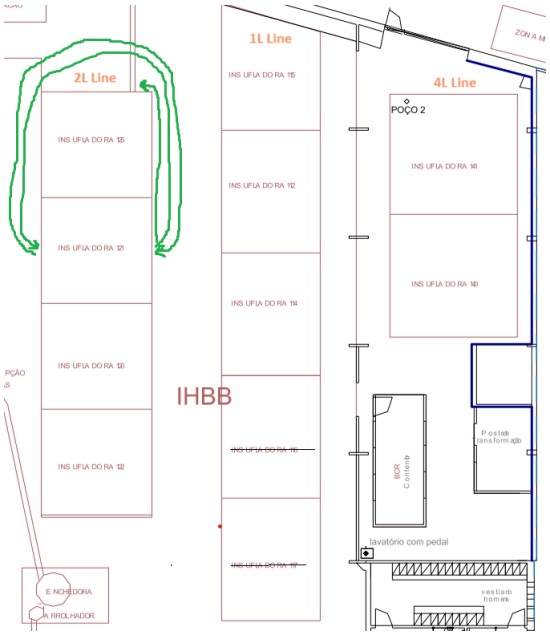


Figure 4.10: Spaghetti diagram for the new weekly CIL for machine 121

This resulted on a new standard expected time of 85 minutes, which represents a time reduction of 29%. This is extremely significant since one of the other problems identified consisted on insufficient planned time for CIL tasks.

4.4 Planned Downtime per line

Optimizing planned downtime in an industrial environment is an essential part of improving the overall efficiency and reliability of machinery. A careful approach to planned downtime not only enables strategic interventions, but also facilitates a targeted focus on preventive and autonomous maintenance tasks for each machine. The proposed strategy involves staggered shutdowns, focusing on one production line per day during the allocated 4-hour time frame. This deliberate sequence provides operators with a longer and more concentrated period of time to perform the necessary interventions on each machine. By strategically allocating time for preventative and autonomous maintenance tasks, workers can perform complicated inspections, address potential issues before they escalate and restore the basic conditions of each machine which has been lost over time. In addition, these maintenance tasks can be performed in full, allowing operators to fix minor issues immediately, minimizing the likelihood of unexpected breakdowns which is currently the major cause of production losses. Furthermore, the sequential approach of stopping one production line per day corresponds to a systematic and organized workflow. This ensures that operators can devote their attention and expertise to each individual machine without being overly pressurized by simultaneous interventions and limited time. Therefore, a specific action plan was created for three different scenarios: stopping the 2 Liter line, the 1 Liter line and the 4 Liter

line, since they all have different amount of machines and associated maintenance tasks. However, besides defining that each production line must stop once per week, the production process requires one week per month where all the lines have to be stopped in order to perform required maintenance tasks on the Making and the Warehouse.

Starting with the 2 Liter line, the first goal is to guarantee the other two lines are producing as planned. Therefore, the first step is to launch them as it would be on a normal day, following the standard procedures of starting up the machine and the daily CIL. Due to the fact these two lines account five different machines, the best strategy is assigning one operator to each line. Afterwards, with the 1 Liter and 4 Liter lines already in motion, since there are four 2 Liter machines for both operators, each of them performs the weekly CIL tasks on two of them. Alongside the two operators, the technical coordinator executes the planned work orders for the 2 Liter line machines. This task sequencing is presented on Figure 4.11.

OPERATOR 1	
ORDER	**TASK**
1	Preparar + arrancar 141
2	Preparar + arrancar 140
3	Fazer CIL máquina 125
4	Fazer CIL máquina 121
5	Arrancar máquina 125
6	Arrancar máquina 121
7	Operar

OPERATOR 2	
ORDER	**TASK**
1	Preparar + arrancar 115
2	Preparar + arrancar 114
3	Preparar + arrancar 112
4	Fazer CIL máquina 122
5	Fazer CIL máquina 120
6	Arrancar máquina 122
7	Arrancar máquina 120
8	Operar

Technical Coordinator	
ORDER	**TASK**
1	Tarefas de PM

Figure 4.11: Operators task sequencing during the planned downtime for the 2 Liter line

To give an overview about the times needed for this task sequence and its viability, using the standard times for each of the assigned tasks a table was generated and is shown on Table 4.2. It elucidates on the time needed for each task and the total time assigned to each operator which cannot surpass the 240 planned minutes, and, as it can be seen, for both operators the total time doesn't reach the 4 hour benchmark validating this strategy and also giving the operation an opportunity to boost production.

Table 4.2: Proposed task sequencing for the 2L scenario

TASK NAME	Operator 1	Operator 2	Technical Coordinator
Preparar + arrancar 141	0:10:00	0:00:00	0:00:00
Preparar + arrancar 140	0:10:00	0:00:00	0:00:00
Preparar + arrancar 115	0:00:00	0:10:00	0:00:00
Preparar + arrancar 114	0:00:00	0:10:00	0:00:00
Preparar + arrancar 112	0:00:00	0:10:00	0:00:00
Fazer CIL máquina 125	1:25:00	0:00:00	0:00:00
Fazer CIL máquina 122	0:00:00	1:25:00	0:00:00
Fazer CIL máquina 121	1:25:00	0:00:00	0:00:00
Fazer CIL máquina 120	0:00:00	1:25:00	0:00:00
Arrancar máquina 125	0:03:00	0:00:00	0:00:00
Arrancar máquina 122	0:00:00	0:03:00	0:00:00
Arrancar máquina 121	0:03:00	0:00:00	0:00:00
Arrancar máquina 120	0:00:00	0:03:00	0:00:00
Tarefas de PM	0:00:00	0:00:00	4:00:00
Total	3:16:00	3:26:00	4:00:00

Regarding the 1 Liter line, the first goal stays the same, which is to guarantee the other two lines are producing as planned. Therefore, the first step is to launch the 2 Liter and 4 Liter machines. Due to the fact these two lines account six different machines, the best strategy is assigning three machines for each operator, specifically the two 4 Liter machines and one 2 Liter machine for one operator and the remaining three 2 Liter machines for the second operator. Afterwards, with the 2 Liter and 4 Liter lines already producing, since there are three 1 Liter machines one operator must execute the weekly CIL on two machines and the other on the remaining one. The technical coordinator executes the planned work orders for the 1 Liter line machines, following the same strategy as the 2 Liter line scenario. The task sequencing for this situation is presented on Figure 4.12.

OPERATOR 1	
ORDER	**TASK**
1	Preparar + arrancar 141
2	Preparar + arrancar 140
3	Preparar + arrancar 125
4	Preparar + arrancar 121
5	Fazer CIL máquina 114
6	Arrancar máquina 114
7	Operar

OPERATOR 2	
ORDER	**TASK**
1	Preparar + arrancar 122
2	Preparar + arrancar 120
3	Fazer CIL máquina 115
4	Fazer CIL máquina 112
5	Arrancar máquina 115
6	Arrancar máquina 112
7	Operar

Technical Coordinator	
ORDER	**TASK**
1	Tarefas de PM

Figure 4.12: Operators task sequencing during the planned downtime for the 1 Liter line

Finishing with the 4 Liter line, the first step is to launch the 2 Liter and 1 Liter machines, where one operator starts the 1 Liter line while the other starts the 2 Liter line. Afterwards, with the seven machines producing, since there are two 4 Liter machines each operator must execute the weekly CIL on one machine, while the technical coordinator executes the planned work orders. The task sequencing for this situation is presented on Figure 4.13.

OPERATOR 1	
ORDER	**TASK**
1	Preparar + arrancar 125
2	Preparar + arrancar 121
3	Preparar + arrancar 120
4	Preparar + arrancar 114
5	Fazer CIL máquina 140
6	Arrancar máquina 140
7	Operar

OPERATOR 2	
ORDER	**TASK**
1	Preparar + arrancar 122
2	Preparar + arrancar 115
3	Preparar + arrancar 112
4	Fazer CIL máquina 141
5	Arrancar máquina 141
6	Operar

Technical Coordinator	
ORDER	**TASK**
1	Tarefas de PM

Figure 4.13: Operators task sequencing during the planned downtime for the 4 Liter line

By adopting this strategy, the intervention time per machine has an increase of 756%, providing the necessary time for AM and PM tasks. Figure 4.14 illustrates a chart representing the monthly increase of intervention time per machine.

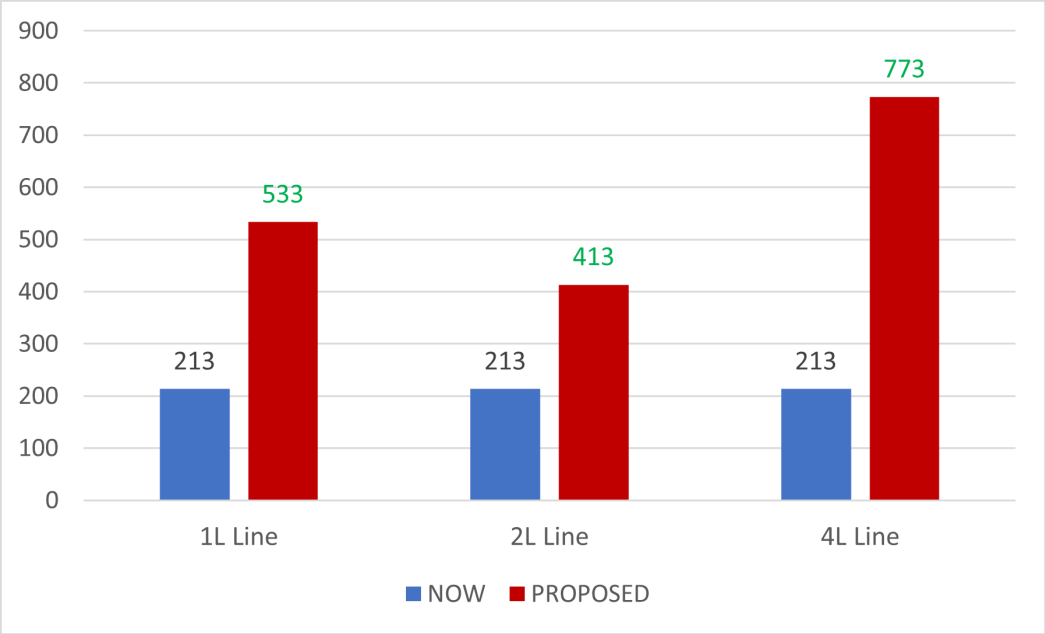


Figure 4.14: Monthly intervention time per production line

Additionally, this approach also reduces the staff stress, since every required task can be performed in time, which increases their motivation and performance. Nonetheless, it provides a flexibility on the production planning that until now was impossible, since the days each line stops can be modified according to production needs.

However, it was not possible to implement this strategy due to lack of available personnel during the internship, where on days AM tasks were to be performed the necessary two operators were not available, the company should try to implement this strategy as soon as possible.

Chapter 5

Conclusions and future work perspectives

The comprehensive analysis and interventions conducted in this study aimed at addressing critical challenges within the In House Bottle Blowing (IHBB) department have yielded significant insights and improvements. The investigation commenced with an overview of the production process, highlighting the operational structure, workforce distribution, and the pressing issue of Rate Loss (RL) exceeding acceptable limits. The identified RL values, reaching 30%, triggered a detailed examination of the IHBB department's practices and processes.

A thorough analysis of the current situation was conducted within the IHBB department. *Gemba* walk and Shadowing techniques were used to closely monitor the daily operation. The identified problems ranging from incomplete breakdown records to inefficient task sequencing and disorganized tool carts have been thoroughly reviewed. During this phase the observations and insights acquired formed the basis for the subsequent improvement strategies.

The transformation of tool carts led to an impressive 82% reduction in the time required to access tools for operators. Standardization of work procedures for machine operation resulted in a 46% reduction in the time taken for machine startup tasks. A revised standard work routine was introduced for CIL tasks reducing the time needed by 29%. The introduction of a new method for planned downtime provided a systematic approach to maintenance activities. The staggered shutdowns focused on a production line per day were strategically designed to give operators plenty of time for preventive and autonomous maintenance tasks. This approach addresses the challenges associated with unexpected breakdowns but also provides flexibility in production planning.

In conclusion, the interventions and strategies introduced in this study collectively contribute to a more efficient and streamlined production process within the IHBB department. The significant reductions in tool access time, machine startup time, and CIL task duration are indicative of improved operational efficiency. The planned downtime methodology ensures a proactive approach to maintenance, minimizing unexpected disruptions and contributing to sustained production levels.

These improvements not only enhance the technical aspects of operations but also positively

impact the workforce. The standardized work procedures provide a structured framework, reducing variability and human errors. The strategic approach to planned downtime alleviates stress on the staff and allows for more flexible production planning.

The success of these interventions underscores the importance of continuous improvement methodologies in manufacturing processes. The holistic nature of the strategies, addressing both technical and human factors, positions the IHBB department for sustained success in meeting production demands. As the implemented changes become ingrained in the department's practices, further monitoring and adjustments can be made to ensure ongoing optimization and adaptability to evolving challenges. Overall, this study serves as a testament to the transformative power of targeted interventions and systematic improvement methodologies in enhancing manufacturing operations.

Finally, as every process can always be improved no matter how good results can be, new improvements shall be made in order to keep pushing the company to a constant better position. Therefore, communication in between departments can be improved so all the respective parts of the process are actively aligned. Additionally, the planned maintenance tasks on SAP software can also be refined, so the work order contain every relevant information the person assigned to each maintenance task must have, such as tools and spare parts required. Nonetheless, a complete training schedule should be elaborated and a worker should be assigned to give that training for every new operator and also to the current ones, ensuring the required knowledge for operational activities.

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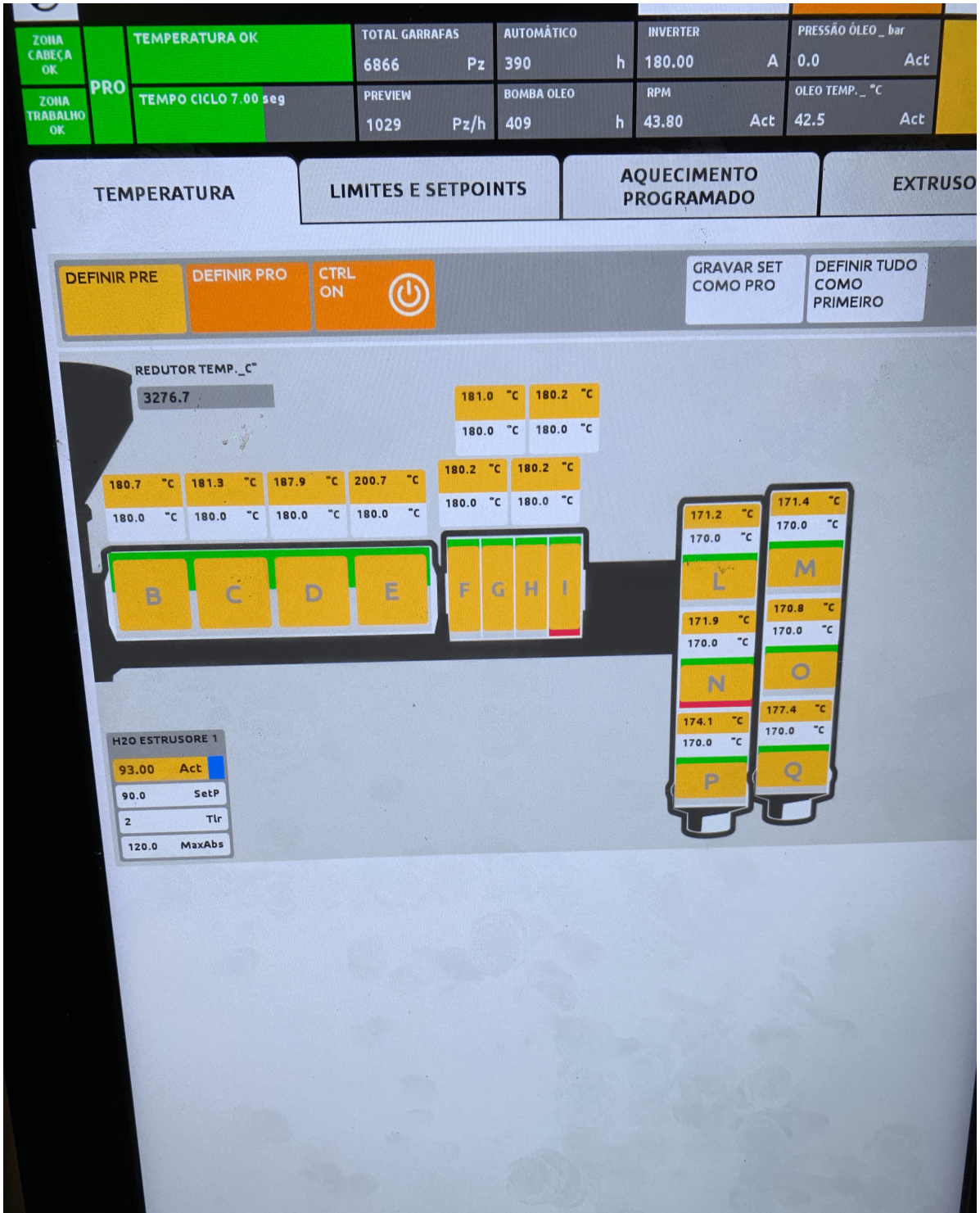
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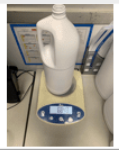
Appendix A

Automa's PLC display



Appendix B

Bottle Quality Tests

Test	Description	Illustration
Compression	Verify any possible damages on the bottle when pressed with a specific force, to ensure safe transportation.	
Fall	Verify any leakage on the bottle when dropped from a determined height	
Watertightness	Verify the bottleneck and the cap to prevent any leakage. If the bottle when submerged on water doesn't produce any bubbles, it is reliable.	
Weight	Weigh the bottle to check if is within the quality range	

Appendix C

Work Order on SAP

Manteinance Order 20376305
printed on 08.01.2024 at 14:68:44 - Pag.1 of 1

TL_Calibrar moog

Fater s.p.a.

JobTicket
SAP Plant Maintenance

Creation date: 26.06.2023	**Author:** IP1020230626	**Status:** RIL.
Type: FM02 Base Tempo o Base Ciclo	**Activity:** FM2 A Tempo	**Priority:** ()

Planning Group: PO2 GRP_PO-0710 / 1355

Notification:
Reservation: 0047916244

Bsc Start Date: 14.12.2023
Bsc Fin. Date : 14.12.2023

Func.Location: BLPO-001-020-004 cabeça e moog
Assembly:
Equipment:

Operation: 0010 TL_QA_Calibrar moog

S- LOTO, Luvas e viseira.

P- Limpar e calibrar o jogo do moog.
Inspeccionar o estado do aro de afinação
manga e lubrificar os parafusos.

T- Chave de umbraque, chaves de fendas,
chaves de bocas e escova

Duration: 400,0 MIN | **Num.Persons:** 1 | **Work:** 400,0 MIN

WC: PO_BLOW CdL_PO_Blowing

Start: 14.12.2023 - 08:00:00 | **End:** 14.12.2023 - 15:30:00

Material	Description	C.R.	Reqmt Qty.

** End Operation 0010 **

Appendix D

VBA Code

```
Sub UpdateResultsTable()
    Dim wsDailyFailures As Worksheet
    Dim wsResults As Worksheet
    Dim tempodisp1 As Double
    Dim tempodisp2 As Double
    Dim value1 As Double
    Dim value2 As Double
    Dim value3 As Double

    ' Set the worksheet containing DailyFailures
    Set wsDailyFailures = ThisWorkbook.Sheets("PREENCHER")  ' Update with yo

    ' Set the worksheet containing the Results table
    Set wsResults = ThisWorkbook.Sheets("DAILYRESULTS")  ' Update with your

    ' Define tempodisp value
    tempodisp1 = 1260
    tempodisp2 = 840

    ' Get the values from B23, C23, and D23 in DailyFailures
    value1 = wsDailyFailures.Range("F21").Value
    value2 = wsDailyFailures.Range("G21").Value
    value3 = wsDailyFailures.Range("H21").Value

    ' Update the third row in the Results table
    wsResults.Cells(3, 3).Value = value1 * tempodisp1
    wsResults.Cells(3, 4).Value = value2 * tempodisp2
    wsResults.Cells(3, 5).Value = value3 * tempodisp2

    For i = 3 To 5
        If wsResults.Cells(4, i).Value > wsResults.Cells(3, i).Value Then
        wsResults.Cells(4, i).Value = wsResults.Cells(3, i).Value
        End If
    Next
End Sub
```

```
Sub UpdateAndSubtract()
    Dim wsSource As Worksheet
    Dim wsTarget As Worksheet
    Dim tbl As ListObject
    Dim dataRange1 As Range
    Dim dataRange3 As Range
    Dim dataRange4 As Range
    Dim dataRange5 As Range
    Dim dataRAnge7 As Range
    Dim lastRow As Long
    Dim i As Long
    Dim valueToSubtract1 As Double
    Dim valueToSubtract2 As Double
    Dim valueToSubtract3 As Double
    Dim column2Value As Variant
    Dim column3Value As Variant
    Dim column4Value As Variant
    Dim column5Value As Variant
    Dim column7Value As Variant
    Dim lastProcessedRow As Long

    ' Define the source and target worksheets
    Set wsSource = ThisWorkbook.Sheets("PREENCHER")
    Set wsTarget = ThisWorkbook.Sheets("DAILYRESULTS")
    ' Define the source table
    Set tbl = wsSource.ListObjects("DailyFailures")
    ' Define the data range for the second and third columns
    Set dataRange1 = tbl.ListColumns(2).DataBodyRange
    Set dataRange3 = tbl.ListColumns(3).DataBodyRange
    Set dataRange4 = tbl.ListColumns(10).DataBodyRange
    Set dataRange5 = tbl.ListColumns(5).DataBodyRange
    Set dataRAnge7 = tbl.ListColumns(7).DataBodyRange

    ' Find the last row in the data range
    lastRow = dataRange4.Rows.Count

    ' Initialize the variable to store the total
    valueToSubtract1 = 0
    valueToSubtract2 = 0
    valueToSubtract3 = 0

    ' Read the last processed row from cell A1
    lastProcessedRow = wsSource.Range("A1").Value

    ' Loop through the data range starting from the last processed row
    For i = lastProcessedRow + 1 To lastRow
```

```
column5Value = dataRange5.Cells(i, 1).Value
column4Value = dataRange4.Cells(i, 1).Offset(0, -6).Value
column7Value = dataRAnge7.Cells(i, 1).Value

If column7Value = "Trabalhar com 1 molde" Then
    If column4Value = 120 Or column4Value = 121 Or column4Value = 12
        valueToSubtract1 = valueToSubtract1 + dataRange4.Cells(i, 1)
    ElseIf column4Value = 112 Or column4Value = 114 Or column4Value
        valueToSubtract2 = valueToSubtract2 + dataRange4.Cells(i, 1)
    ElseIf column4Value = 140 Or column4Value = 141 Then
        valueToSubtract3 = valueToSubtract3 + dataRange4.Cells(i, 1)
    ElseIf column4Value = "2L" Then
        valueToSubtract1 = valueToSubtract1 + (dataRange4.Cells(i, 1
    ElseIf column4Value = "1L" Then
        valueToSubtract2 = valueToSubtract2 + (dataRange4.Cells(i, 1
    ElseIf column4Value = "4L" Then
        valueToSubtract3 = valueToSubtract3 + (dataRange4.Cells(i, 1
    End If
End If

If column5Value = "Paragem planeada" Then
    If column4Value = "2L" Then
        wsTarget.Range("C3").Value = wsTarget.Range("C3").Value - da
    ElseIf column4Value = "1L" Then
        wsTarget.Range("D3").Value = wsTarget.Range("D3").Value - da
    ElseIf column4Value = "4L" Then
        wsTarget.Range("E3").Value = wsTarget.Range("E3").Value - da
    ElseIf column4Value = 120 Or column4Value = 121 Or column4Value
        wsTarget.Range("C3").Value = wsTarget.Range("C3").Value - da
    ElseIf column4Value = 112 Or column4Value = 114 Or column4Value
        wsTarget.Range("D3").Value = wsTarget.Range("D3").Value - da
    ElseIf column4Value = 140 Or column4Value = 141 Then
        wsTarget.Range("E3").Value = wsTarget.Range("E3").Value - da
    End If
End If

If column4Value = 120 Or column4Value = 121 Or column4Value = 122 Or
        valueToSubtract1 = valueToSubtract1 + dataRange4.Cells(i, 1)
    ElseIf column4Value = 112 Or column4Value = 114 Or column4Value
        valueToSubtract2 = valueToSubtract2 + dataRange4.Cells(i, 1)
    ElseIf column4Value = 140 Or column4Value = 141 Then
        valueToSubtract3 = valueToSubtract3 + dataRange4.Cells(i, 1)
      ElseIf column4Value = "2L" Then
        valueToSubtract1 = valueToSubtract1 + dataRange4.Cells(i, 1)
    ElseIf column4Value = "1L" Then
        valueToSubtract2 = valueToSubtract2 + dataRange4.Cells(i, 1)
    ElseIf column4Value = "4L" Then
        valueToSubtract3 = valueToSubtract3 + dataRange4.Cells(i, 1)
```

```
        End If


    Next i

    ' Update Results based on the calculations
    wsTarget.Range("C4").Value = wsTarget.Range("C4").Value - valueToSubtract1
    wsTarget.Range("D4").Value = wsTarget.Range("D4").Value - valueToSubtract2
    wsTarget.Range("E4").Value = wsTarget.Range("E4").Value - valueToSubtract3

    ' Store the last processed row in cell A1
    For i = lastProcessedRow + 1 To lastRow
        column2Value = dataRange1.Cells(i, 1).Value
        column3Value = dataRange3.Cells(i, 1).Value
        If Not IsEmpty(column2Value) And Not IsEmpty(column3Value) Then
            wsSource.Range("A1").Value = i
        End If
    Next i


End Sub


Sub TransferData()

    Dim wsSource As Worksheet
    Dim wsTarget As Worksheet
    Dim tblSource As ListObject
    Dim tblTarget As ListObject
    Dim lastRow As Long
    Dim sourceRow As ListRow
    Dim targetRow As ListRow
    Dim sourceCell As Range
    Dim targetCell As Range


    ' Define the source and target worksheets
    Set wsSource = ThisWorkbook.Sheets("PREENCHER")
    Set wsTarget = ThisWorkbook.Sheets("ALLFAILURES")

    ' Define the source and target tables
    Set tblSource = wsSource.ListObjects("DailyFailures")
    Set tblTarget = wsTarget.ListObjects("CollectedFailures1")
    ' Find the last row in the source table
    lastRow = tblSource.ListRows.Count

    ' Loop through the rows in the source table
    For Each sourceRow In tblSource.ListRows
```

```
        ' Check if columns 2 and 3 are filled
        Set sourceCell = sourceRow.Range.Cells(1, 2) ' Assuming column 2 is
        If Not IsEmpty(sourceCell) Then
            Set sourceCell = sourceRow.Range.Cells(1, 3) ' Assuming column 3
            If Not IsEmpty(sourceCell) Then
                ' Copy the data from the source row to the target table
                Set targetRow = tblTarget.ListRows.Add
                For Each sourceCell In sourceRow.Range
                    Set targetCell = targetRow.Range.Cells(sourceCell.Column
                    targetCell.Value = sourceCell.Value
                Next sourceCell
            End If
        End If
    Next sourceRow

End Sub

Sub UpdateALLRESULTS()
    Dim wsResults As Worksheet
    Dim wsAllResults As Worksheet
    Dim tblResults As ListObject
    Dim tblAllResults As ListObject
    Dim lastRow As ListRow
    Dim currentDate As Date
    Dim i As Integer

    ' Set the worksheet containing the "Results" and "AllResults" tables
    Set wsResults = ThisWorkbook.Sheets("DAILYRESULTS")
    Set wsAllResults = ThisWorkbook.Sheets("ALLRESULTS")

    ' Set the "Results" and "AllResults" tables
    Set tblResults = wsResults.ListObjects("Results")
    Set tblAllResults = wsAllResults.ListObjects("AllResults")

    ' Get the current date
    currentDate = Date

    ' Check if the AllResults table is empty
    If tblAllResults.ListRows.Count > 0 Then
        Set lastRow = tblAllResults.ListRows(tblAllResults.ListRows.Count)

        ' Check if the last date matches the current date
        If lastRow.Range.Cells(1, 1).Value = currentDate Then
            ' Update the values in the subsequent three columns
            For i = 1 To 3
                lastRow.Range.Cells(1, i + 1).Value = tblResults.ListColumns
            Next i
            Exit Sub ' Exit the subroutine if date matches
```

```
        End If
    End If

    ' Add a new row to AllResults if the dates don't match
    Dim newRow As ListRow
    Set newRow = tblAllResults.ListRows.Add
    newRow.Range.Cells(1, 1).Value = currentDate

    ' Copy values from row 4 of Results to AllResults for the last three columns
    For i = 1 To 3
        newRow.Range.Cells(1, i + 1).Value = tblResults.ListColumns(i + 1).DataB
    Next i
End Sub

Sub ResetResults()
    Dim ws As Worksheet
    Dim ws1 As Worksheet
    Dim tbl1 As ListObject
    Dim rng1 As Range
    Dim cell1 As Range
    Dim colToPreserve As Long
    Dim rowToPreserve As Long
    Dim tempodisp1 As Double
    Dim tempodisp2 As Double
    Dim targetCell As Range


' Define the column number to preserve
    colToPreserve = 2
    rowToPreserve = 3
    tempodisp1 = 1260
    tempodisp2 = 840


' Define the worksheet containing the table
    Set ws1 = ThisWorkbook.Worksheets("DAILYRESULTS")
    Set ws = ThisWorkbook.Worksheets("PREENCHER")
' Define the table
    Set tbl1 = ws1.ListObjects("Results")

' Define the data range of the table (excluding headers)
    Set rng1 = tbl1.DataBodyRange

' Loop through each cell in the data range and clear the values
    For Each cell1 In rng1
    ' Check if the cell is in the specified column to preserve
        If cell1.Column <> colToPreserve Then
            If cell1.Row = rowToPreserve Then
```

```
                If cell1.Column = 3 Then
                    cell1.Value = tempodisp1 * 4
                ElseIf cell1.Column = 4 Then
                    cell1.Value = tempodisp2 * 3
                ElseIf cell1.Column = 5 Then
                    cell1.Value = tempodisp2 * 2
                End If

            ElseIf cell1.Row <> rowToPreserve Then
                If cell1.HasFormula = False Then
                    cell1.ClearContents
                End If
            End If
        End If
    Next cell1
    Set targetCell = ws1.Range("C4")
        targetCell.Value = targetCell.Offset(-1, 0).Value
     Set targetCell = ws1.Range("D4")
        targetCell.Value = targetCell.Offset(-1, 0).Value
     Set targetCell = ws1.Range("E4")
        targetCell.Value = targetCell.Offset(-1, 0).Value
End Sub

Sub ResetPreencher()
    Dim ws As Worksheet
    Dim tbl As ListObject
    Dim rng As Range
    Dim cell As Range

    ' Define the worksheet containing the table
    Set ws = ThisWorkbook.Worksheets("PREENCHER") ' Replace "Sheet1" with yo

    ' Define the table
    Set tbl = ws.ListObjects("DailyFailures") ' Replace "TableName" with you

    ' Define the data range of the table (excluding headers)
    Set rng = tbl.DataBodyRange

    ' Loop through each cell in the data range and clear the values
    For Each cell In rng
        If cell.Column <> 1 And cell.Column <> 10 Then
            cell.ClearContents

        End If
    Next cell

    ' Reset values in specific cells
    ws.Range("F27").Value = 80
```

```
    ws.Range("G27").Value = 84
    ws.Range("H27").Value = 30
    ws.Range("A1").Value = 0
    ws.Range("F21").Value = 4
    ws.Range("G21").Value = 3
    ws.Range("H21").Value = 2

    ' Reset values in the ninth column of the table to 1
    tbl.ListColumns(9).DataBodyRange.Value = 1
End Sub



Sub MasterMacro1()
    Call UpdateResultsTable
    Call UpdateAndSubtract
End Sub
Sub MasterMacro2()
    'Join the macros here
    Call TransferData
    Call UpdateALLRESULTS
    Call ResetResults
    Call ResetPreencher
End Sub
```

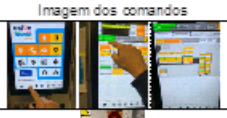
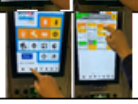
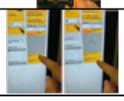
Appendix E

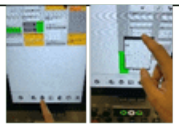
Guidelines for the Shift Handover Excel template

Guião	
Para o turno da MANHÃ	
1º PASSO	CLICAR BOTÃO TRANSFER + RESET
2º PASSO	PREENCHER DADOS DE Nº DE MÁQUINAS E RATE- APENAS ESCOHER DA LISTA
3º PASSO	CLICAR BOTÃO UPDATE ATUALIZA DAILYRESULTS
4º PASSO	SEMPRE QUE ADICIONAR UMA AÇÃO CLICAR NO BOTÃO UPDATE DATA
Para o turno da TARDE E NOITE	
ÚNICO PASSO	SEMPRE QUE ADICIONAR UMA AÇÃO CLICAR NO BOTÃO UPDATE DATA
SEMPRE QUE NECESSÁRIO, ACRESCENTAR LINHAS NA TABELA DE REGISTO DE PARAGENS- - (CLICK NO LADO DIREITO DO RATO, INSERIR, TABLE ROW)	

Appendix F

Standard Work to start up a 2L machine

Standard Work- Arranque de Insufladora com PLC AUTOMA			
Step	Descrição	Imagem dos comandos	Observações
1	Verifcar Temperaturas		
2	Fazer LOTO		Desligar sistemas da máquina e colocar aloquete
3	Limpar Fieiras		Utilizar luvas, viseira e chave de cobre
4	Clicar RESET + ALARME		
5	Abrir válvulas de água		
6	Ligar BOMBA DE ÓLEO + EXTRUSORA		
7	Clicar PURGA MANGA		O botão está ativado quando fica laranja
8	Deixar correr Polietileno durante aproximadamente 1 min		Retirar manga comprida do tapete
9	Clicar PURGA MANGA		
10	Clicar CORTAR MANGA		
11	Clicar em MANUAL		
12	Fechar MOLDES SX e DX		
13	Inserir velocidade da extrusora		Ajustar se necessário para que o tamanho do gito seja de 2 dedos
14	Clicar em AUTO		
15	Clicar em REPOR		
16	Clicar START CICLO		Clicar quando ouvir o sinal sonoro
17	Desativar corta-gitos		Evita o desgaste desnecessário do corta-gitos
18	Ativar Corta-Gitos		
19	Verificar Peso e Ajustar se necessário		Ter em atenção o peso de referência das normas de qualidade
20	Desativar Descarte		

Standard Work- Arranque de Insufladora com PLC AUTOMA após paragem curta			
Step	Descrição	Imagem dos comandos	Observações
1	**Verificar Temperaturas**		
2	**Clicar RESET + ALARME**		
3	**Clicar em MANUAL**		
4	**Fechar MOLDES SX e DX**		
5	**Inserir velocidade da extrusora**		Ajustar se necessário para que o tamanho do gito seja de 2 dedos
6	**Clicar em AUTO**		
7	**Clicar em REPOR**		
8	**Clicar START CICLO**		Clicar quando ouvir o sinal sonoro
9	**Desativar corta-gitos**		Evita o desgaste desnecessário do corta-gitos
10	**Ativar Corta-Gitos**		
11	**Verificar Peso e Ajustar se necessário**		Ter em atenção o peso de referência das normas de qualidade
12	**Desativar Descarte**		