Productivity improvement in a corrugated case conversion line through the application of Lean Manufacturing tools

Rodrigo Luís Monarca Pimenta

Master's Dissertation

Supervisor at FEUP: Jonas André Rodrigues Henriques de Lima

U.PORTO

FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

Master's in Mechanical Engineering

2026-06-28

Abstract

This dissertation was developed within the Master's Degree in Mechanical Engineering, with a specialisation in Production Management, at the Faculty of Engineering of the University of Porto (FEUP). This project was conducted at the DS Smith unit in Guilhabreu, a manufacturer of corrugated board sheets and packaging (CAE 17211).

The industrial environment of growing competition, in which the continuous improvement of productivity is decisive for sustaining operational efficiency and meeting market demands, motivated the selection of the UP02 line for this project. This line has an Emba Casemaker as its main machine, which converts corrugated board sheets into cases through printing, slotting, cutting, folding and gluing. Given its strategic importance within the unit and its persistent difficulty in reaching the productivity targets set by the company, this line became the focus of the project, and raising its productivity through the application of Lean Manufacturing tools became the main objective.

An initial diagnosis identified the main causes of productivity loss and defined four areas of intervention: workspace organisation, the reduction of unplanned downtime, the reduction of setup time and the study of the factors limiting the execution speed. These were addressed in sequence, starting with the organisation and standardisation of the workspace through the 5S methodology. Unplanned downtime was then tackled through interventions on the pre-feeder and the counter stacker, identified as the main sources of jams on the line, while setup time was reduced by applying SMED. Finally, the analysis of the execution speed revealed that the difficulty in maintaining print quality and ensuring a reliable visual inspection at high speeds was the main barrier to its increase.

These interventions produced the following results: the average proportion of time in unplanned downtime fell from 30% to 19%, a reduction of approximately 37%; the average setup time dropped from 19 to 17 minutes, a reduction of approximately 11%; the average execution speed rose from 4,637 to 5,386 sheets/h, an increase of approximately 16% driven both by the improvements in unplanned downtime and by the update of the speed targets for several products; and the average productivity rose accordingly from 1,522 to 2,024 m^2/h, an increase of approximately 33% that surpassed the project's 31% target and translates into an estimated gain of approximately 6,285 euros per month for the unit.

All the objectives set for the dissertation were met, confirming that the structured application of Lean Manufacturing tools can raise the performance of an industrial operation and deliver substantial productivity gains without the need for significant financial investment.

Keywords: Lean Manufacturing, 5S, SMED, Unplanned Downtime, Productivity, Corrugated Board

Resumo

A presente dissertação foi desenvolvida no âmbito do Mestrado em Engenharia Mecânica, com especialização em Gestão da Produção, na Faculdade de Engenharia da Universidade do Porto (FEUP). Este projeto foi realizado na unidade da DS Smith em Guilhabreu, uma fábrica de placas e embalagens de cartão canelado (CAE 17211).

O enquadramento industrial de crescente competitividade, onde a melhoria contínua da produtividade se torna decisiva para sustentar a eficiência operacional e responder às exigências do mercado, motivou a seleção da linha UP02 para o presente projeto. Esta linha tem como máquina principal uma Emba Casemaker que transforma placas de cartão canelado em caixas através de operações de impressão, slotting, corte, dobragem e colagem. Devido à sua importância estratégica dentro da unidade e à sua dificuldade persistente em atingir os objetivos de produtividade definidos pela empresa, esta linha tornou-se o foco do projeto, sendo o aumento da sua produtividade através da aplicação de ferramentas de Lean Manufacturing o objetivo principal.

Foi realizado um diagnóstico inicial que permitiu identificar as principais causas de perda de produtividade e definir quatro áreas de intervenção: a organização do espaço de trabalho, a redução das paragens não planeadas, a redução do tempo de preparação e o estudo dos fatores que limitam a velocidade de execução. Na sequência deste diagnóstico, as quatro áreas foram abordadas de forma sequencial, começando a intervenção pela organização e normalização do espaço de trabalho através da metodologia 5S. As paragens não planeadas foram depois combatidas através de intervenções centradas no *pre-feeder* e no *counter stacker*, identificados como os principais responsáveis pelos encravamentos da linha, enquanto o tempo de preparação foi reduzido pela aplicação da metodologia SMED. Finalmente, a análise da velocidade de execução da linha revelou que a dificuldade em manter a qualidade de impressão e em assegurar uma inspeção visual fiável a velocidades elevadas constituía a principal barreira ao seu aumento.

Estas intervenções produziram os seguintes resultados: a percentagem média de tempo em paragens não planeadas baixou de 30% para 19%, uma redução de aproximadamente 37%; o tempo médio de preparação diminuiu de 19 para 17 minutos, uma redução de aproximadamente 11%; a velocidade média de execução aumentou de 4.637 para 5.386 folhas/h, um aumento de aproximadamente 16% impulsionado tanto pelas melhorias nas paragens não planeadas como pela atualização dos objetivos de velocidade de vários produtos; a produtividade média subiu, em conformidade, de 1.522 para 2.024 m^2/h, um aumento de aproximadamente 33% que ultrapassou o objetivo de 31% do projeto e que se traduz num ganho estimado de aproximadamente 6.285 euros por mês para a unidade.

Todos os objetivos definidos para a dissertação foram cumpridos, confirmando que a aplicação estruturada de ferramentas de Lean Manufacturing pode elevar o desempenho de uma operação industrial e proporcionar ganhos substanciais de produtividade sem a necessidade de um investimento financeiro significativo.

Palavras-chave: Lean Manufacturing, 5S, SMED, Paragens Não Planeadas, Produtividade, Cartão Canelado

Acknowledgements

To Professor Jonas André Rodrigues Henriques de Lima, my supervisor at FEUP, for his guidance, his availability and the valuable feedback offered throughout the development of this dissertation;

To Eng. Isabel Bozzato, my supervisor at the company, for welcoming me to the DS Smith Guilhabreu unit, for her constant support and for everything she taught me during the internship;

To Nuno, responsible for continuous improvement at the unit, a particular word of thanks for his help, his readiness to assist and the knowledge he shared at every stage of the project;

To the operators of the line, who taught me a great deal about the day-to-day reality of the process and were always willing to help; and to the maintenance team, whose work was essential to many of the interventions carried out;

To everyone at DS Smith who contributed, in one way or another, to the success of this work;

To my friends, for their support over these years, with a special word for those who shared this academic journey with me from the very beginning and became an essential part of it;

To my parents, my sisters and my whole family, for their unconditional support;

To all of them, my most sincere gratitude.

Contents

Acronyms and Symbols

HTR	Hit the Rabbit
IP	International Paper
JIPM	Japan Institute of Plant Maintenance
JIT	Just-in-Time
KPI	Key Performance Indicator
OEE	Overall Equipment Effectiveness
OPL	One Point Lesson
PDCA	Plan-Do-Check-Act
PPWR	Packaging and Packaging Waste Regulation
SMED	Single-Minute Exchange of Die
TPM	Total Productive Maintenance
TPS	Toyota Production System
UDT	Unplanned Downtime
WIP	Work in Progress

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Chapter 1

Introduction

The corrugated board packaging industry has shown sustained growth, with its market size estimated to reach approximately 205.74 billion dollars in 2026, compared to the 198.34 billion recorded in 2025, and projections indicating 247.1 billion dollars by 2031 (Mordor Intelligence, 2025).

This growth is driven by relevant structural trends on a global scale, notably the increasing regulatory and social pressure to replace materials such as plastics, with particular emphasis on the implementation of the European Union's Packaging and Packaging Waste Regulation (PPWR), which begins to apply in August 2026 (European Commission, 2025). This legislative framework imposes significant restrictions on the use of single-use plastics, in favour of more sustainable alternatives such as corrugated board.

In this context, the corrugated board packaging industry establishes itself as a strategic sector, not only for its economic growth but also for the central role it plays in the transition towards more sustainable production and consumption models.

1.1 Company Presentation

DS Smith is a British company founded in the 1940s as a box manufacturing business in East London, United Kingdom (DS Smith, 2026). Since then, the company has expanded to provide complete solutions, including paper manufacturing and recycling, becoming a leading supplier of sustainable packaging in Europe, with a turnover in the 2024 fiscal year of approximately 6.822 billion pounds (DS Smith, 2024).

In January 2025, DS Smith was acquired by the American company International Paper, in a deal worth around 7.2 billion dollars, creating a global leader in sustainable packaging solutions, as can be seen in Figure 1 (Packaging Dive, 2025). In January 2026, International Paper announced its intention to separate the combined business into two independent publicly traded companies, forming a new entity through a spin-off expected to be completed in the next few months (International Paper, 2026).

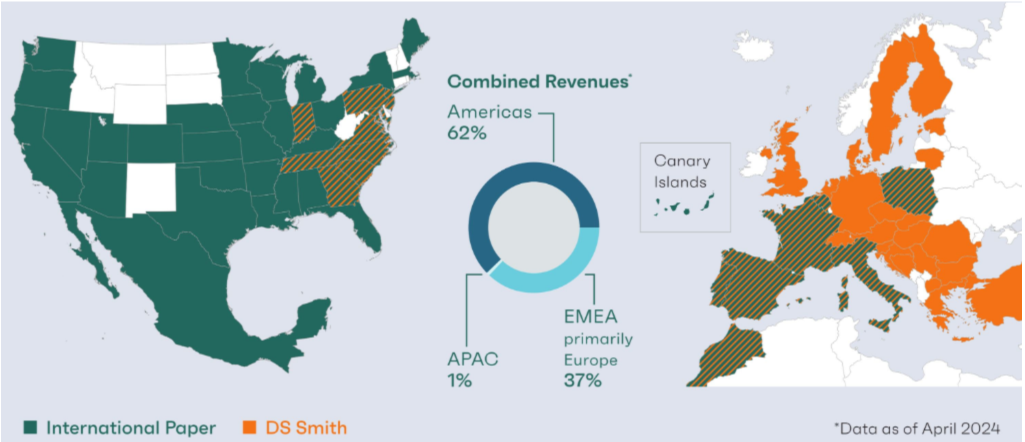

Figure 1: DS Smith and IP plants around the world (DS Smith, 2026).

This project was developed at the DS Smith unit in Guilhabreu, Vila do Conde, designated *Nova DS Smith Embalagem, SA*. The unit is part of the group's European industrial network and of a broader presence in Portugal, which includes other corrugated board sheet and packaging manufacturing units, a paper mill in Viana do Castelo and two paper and board recycling and waste management units, in Porto and Figueira da Foz.

The Guilhabreu unit, illustrated in Figure 2, stands as one of the most relevant in the North region, with its main focus on producing packaging for the food, beverage and industrial sectors. This unit operates in two main stages: the production of corrugated board sheets in the corrugator, and their subsequent conversion into corrugated board packaging in the conversion area.

Figure 2: DS Smith unit in Guilhabreu (DS Smith, 2020).

1.2 Project Framework and Motivation

The DS Smith Guilhabreu unit has a conversion line, the Emba Casemaker line (UP02), responsible for converting corrugated board sheets into finished cases. By bringing together most of the conversion operations and by integrating one of the most complete and advanced machines in the unit, it holds a prominent position in the production flow, with significant weight in the factory's overall performance.

This relevance becomes even more pronounced when the production model is considered. Production follows a make-to-order model, in which each order initiates the production process. The just-in-time philosophy, combined with increased competition in the sector, has shortened product life cycles and broadened the product range, leading to more frequent and smaller orders. Under these conditions, any loss of time on the line, whether due to a stoppage or a product changeover, has an increased impact on the factory's responsiveness.

Despite its central role, the UP02 line is also one of those recording the highest amount of unplanned downtime (UDT) in the unit, with the consequent increase in waste. Alongside this, the execution speed is below what is intended and the setup process is in need of improvement, being outdated and resulting in high changeover times. Added to this is the fact that the automation systems recently introduced on the line do not yet operate optimally, which limits the expected return on this investment.

It is within this framework that the motivation for this project arises: to intervene in a structured way on this line, in order to stabilise the operation, reduce waste and increase its overall performance, with a direct effect on the unit's productivity.

1.3 Objectives

The central objective of this project is to increase the productivity of the Emba conversion line, measured in square metres per working hour (m^2/h), the main indicator used by the company to assess the performance of its lines.

This depends on acting on the factors that limit the line's performance. Reducing unplanned downtime increases equipment availability, while reducing setup time lowers the unproductive time spent on product changeovers, which matters in a production model marked by frequent, smaller orders. The study of the factors conditioning execution speed, in turn, provides the diagnostic basis for future improvements to the production rate.

These factors translate into the following specific objectives:

- Improving productivity by 31%;
- Reducing unplanned downtime by 27%;
- Reducing setup time by 11%;
- Study of the factors conditioning line execution speed.

These objectives are interdependent, forming a structured intervention aimed at raising the overall performance of the line. Clearly defining them from the outset was essential to guide the project and to provide a solid basis for evaluating its success.

1.4 Methodology

To achieve the objectives set out above, this work follows a structured methodology.

The research is applied, as it addresses a concrete problem in a real industrial setting, combining quantitative production data, such as productivity, unplanned downtime and setup times, with qualitative methods based on direct observation of the line and root cause analysis of the identified problems.

In line with this approach, the work is structured as a single case study, focused on the Emba Casemaker conversion line at the DS Smith Guilhabreu unit. The aim is to understand one specific line in depth, with its operational particularities, rather than to generalise from multiple cases.

Beyond observation, the work follows an action research logic. The line was not merely studied: it was directly subject to interventions in the conversion process aimed at improving it, and the effects of those interventions were then assessed. This approach suits continuous improvement projects, where knowledge is built through successive cycles of diagnosis, intervention and evaluation.

To put this logic into practice, the research was organised into five phases. The preliminary phase covered the initial diagnosis of the line: the definition of the project scope, the identification of the relevant KPIs, the analysis of the PC-Topp platform and the collection of real production data. This characterised the initial state and revealed the main improvement opportunities. The next three phases were the improvement interventions, applying the 5S methodology, reducing unplanned downtime and applying the SMED methodology, each followed by a period of monitoring and standardisation. Finally, the factors conditioning the line's execution speed were studied, in order to identify what limits it.

To evaluate the impact of these interventions, the performance of the line was assessed by comparing two periods of equal length. The initial state corresponds to the first eight weeks of the year, prior to the start of the project. The diagnosis of the line was carried out in the following weeks, after which the improvements were implemented in a progressive and continuous manner, in the order described above. The final state corresponds to weeks 14 to 21, an eight-week window of the same length as the initial period. Although improvement work continued throughout these weeks, by this stage the effects of the interventions were already consistently reflected in the indicators, ensuring a valid comparison between the two periods.

1.5 Dissertation Structure

This work is organised into six chapters.

Chapter 1 briefly presents and characterises the industrial unit where the project was developed, along with the general context, the motivations, the objectives and the methodology applied.

Chapter 2 corresponds to the theoretical framework, covering the fundamental concepts that support the development of the project, namely the principles of Lean Manufacturing, the main Lean tools used and the fundamentals of corrugated board production.

Chapter 3 presents the unit's production process and the detailed description of the conversion line under study, together with the initial diagnosis of its performance, identifying the main problems associated with the conversion process.

Chapter 4 presents the work carried out on the line, covering the interventions in the organisation of the workspace, the reduction of unplanned downtime and the optimisation of the setup process, as well as the study of the factors conditioning the execution speed.

Chapter 5 presents the analysis of the results obtained, comparing the final state with the initial diagnosis across all the key performance indicators.

Finally, Chapter 6 sets out the project's conclusions and future work.

Chapter 2

Theoretical Framework

This chapter presents the theoretical framework that underpins the approach to the problem studied throughout the project. It begins with the principles of Lean Manufacturing, with emphasis on the Toyota Production System, the Kaizen philosophy and the seven wastes of lean.

It then presents the main Lean tools used in the project, namely the 5S methodology, Standard Work, Visual Management, Total Productive Maintenance (TPM) and its associated indicator Overall Equipment Effectiveness (OEE), Pareto analysis, layout analysis through the spaghetti diagram and the Single-Minute Exchange of Die (SMED) methodology.

Finally, it covers the fundamentals of corrugated board, the central raw material of the process under study, and how it is produced.

2.1 The Lean Concept

Lean Manufacturing emerged in post-Second World War Japan, in a context marked by resource scarcity and an urgent need for industrial reconstruction. It was in this environment that Toyota, largely through the work of Taiichi Ohno, developed over the following decades the Toyota Production System (TPS), through a long process of trial, error and organisational learning (Fujimoto, 1999), whose central principle rests on the systematic elimination of everything that does not add value to the final product (Ohno, 1988).

Decades later, Womack, Jones and Roos popularised the term Lean Manufacturing in the work The Machine That Changed the World, making the principles of TPS accessible and applicable far beyond the automotive industry (Womack et al., 1990).

2.1.1 Toyota Production System and the Kaizen philosophy

The Toyota Production System (TPS) is more than a production system; it is a management philosophy whose central principle rests on the elimination of waste, with the aim of reducing costs and increasing efficiency (Liker, 2021). To achieve this, the TPS relies on two fundamental pillars: Just-in-Time (JIT) and Jidoka.

Just-in-Time is based on a simple principle: each step of the process should produce only what is needed, in the quantity needed and at the right time, thereby eliminating overproduction and excess inventory. Jidoka, in turn, builds intelligence into the line, so that whenever an anomaly is detected, production is immediately halted, preventing defective products from advancing along the chain (Monden, 2012).

The Kaizen philosophy, a Japanese term meaning "continuous improvement", is the mechanism that ensures the permanent evolution of the TPS. Following the PDCA cycle (Plan-Do-Check-Act), this philosophy requires all employees, regardless of their hierarchical level, to participate actively in identifying and eliminating waste. While Western approaches often rely on radical and disruptive changes, Kaizen follows a different path, favouring small incremental improvements that, when accumulated over time, produce significant results (Wilson, 2010).

2.1.2 Seven Wastes of Lean

In developing the TPS, Ohno identified seven types of waste, collectively known as muda, covering all activities that consume resources without adding any value to the final product (Ohno, 1988):

- **Overproduction**: producing in excess or before it is needed, considered the most serious of the seven wastes, as it feeds and worsens all the others;
- **Waiting**: time during which operators or equipment stand idle, waiting for materials, information or the completion of previous operations;
- **Transport**: unnecessary movement of materials or products between process steps;
- **Over-processing**: carrying out operations beyond what the customer actually requires;
- **Inventory**: holding raw materials, work in progress or finished products in greater quantities than needed;
- **Motion**: unnecessary movement of operators while carrying out their tasks;
- **Defects**: producing non-conforming parts that require rework or scrap.

The identification of these seven wastes provides the conceptual basis for any Lean intervention, since reducing them is the means through which performance is improved, a principle put into practice by the tools presented in the following section, which act precisely on these sources of waste.

2.2 Lean Tools

The principles of Lean Manufacturing are put into practice through a set of tools that translate its concepts into concrete actions on the shop floor. The following sections present the tools applied in this project, describing their purpose and the way they support continuous improvement.

2.2.1 5S Methodology

The 5S methodology is one of the most widely used Lean tools, and is often the starting point for any continuous improvement initiative. Its name comes from five Japanese words that describe the stages of the method, and its main aim is to create and maintain an organised, clean and standardised work environment that serves as a basis for implementing other Lean tools. The five stages are (Michalska and Szewieczek, 2007):

1. **Sort** (Seiri): identifying and removing all unnecessary materials, tools and equipment from the workstation, keeping only what is essential for the tasks;

2. **Set in order** (Seiton): defining an accessible and clearly identified place, so that any employee can find an item and return it without difficulty. Each tool should be kept close to where it will be used, supporting an efficient workflow;

3. **Shine** (Seiso): the systematic cleaning of the workstation and equipment as part of the daily routine, an activity that also keeps the equipment under regular observation and the work area in consistent condition;

4. **Standardise** (Seiketsu): consolidating the gains of the first three stages by creating visual standards and procedures that ensure Seiri, Seiton and Seiso are carried out consistently by all employees. The aim is to keep the workstation in good condition every day;

5. **Sustain** (Shitsuke): the most challenging stage, as it requires internalising the previous four S's as a habit and organisational culture. Shitsuke also assumes that employees adopt the principles defined by the organisation autonomously and continuously, without the need for constant supervision.

Taken together, these five stages make 5S more than a simple cleaning exercise: they establish the conditions required for other Lean tools to be effective.

2.2.2 Standard Work

On a production line, the way each operator carries out a task is rarely exactly the same. Standard Work addresses this problem by documenting and standardising the best known way of performing each operation, based on the sequence of steps, the task time and the inventory required at each workstation.

More than a simple instruction manual, Standard Work is a living tool that should be updated whenever an improvement is implemented, becoming the baseline for each new Kaizen cycle. In practice, it eases the integration of new operators, makes deviations from the process easier to detect, and creates the conditions for continuous improvement to be sustainable over time (Fin et al., 2017).

2.2.3 Visual Management

In a well-run factory, anyone walking onto the production line should be able to tell at a glance whether everything is running smoothly or there is a problem. This is what Visual Management seeks to ensure, making the state of the process immediately clear to any employee, without the need to consult computer systems or reports.

In practice, this tool takes shape through simple but effective elements: floor markings, production boards, light signals (andons), tool boards and work instructions posted at the workstations. Together, these elements create an environment where deviations from the normal process are immediately visible, allowing a quick and effective response.

Visual Management is closely linked to 5S and Standard Work, since without an organised space and standardised processes any visual system loses effectiveness. The three tools work together, reinforcing one another in creating a controlled work environment suited to continuous improvement (Tezel et al., 2016).

2.2.4 Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM), developed in Japan by Seiichi Nakajima (Nakajima, 1988), goes far beyond a simple maintenance policy. It is a structured continuous improvement process that aims to maximise equipment effectiveness throughout its entire life cycle, eliminating losses and relying on the active involvement of all employees, from line operators to top management (McKone and Weiss, 1998). Reaching this goal rests on three fundamental targets:

1. zero defects;
2. zero accidents;
3. zero breakdowns.

Within the Lean context, TPM is closely connected to two ideas already covered, Just-in-Time and Kaizen. The reliability it ensures supports Just-in-Time, which depends on stable equipment to operate with minimal inventory, while its continuous, employee-driven nature aligns directly with the Kaizen philosophy. Its implementation requires long-term commitment, management support and teamwork.

The spread and structuring of TPM are largely due to the JIPM (Japan Institute of Plant Maintenance, 1996), the Japanese organisation responsible for formalising the methodology. It was the JIPM that organised TPM into eight pillars, shown in Figure 3, with the aim of increasing productivity, reducing costs and lowering stoppage and setup times (Zlatić, 2019):

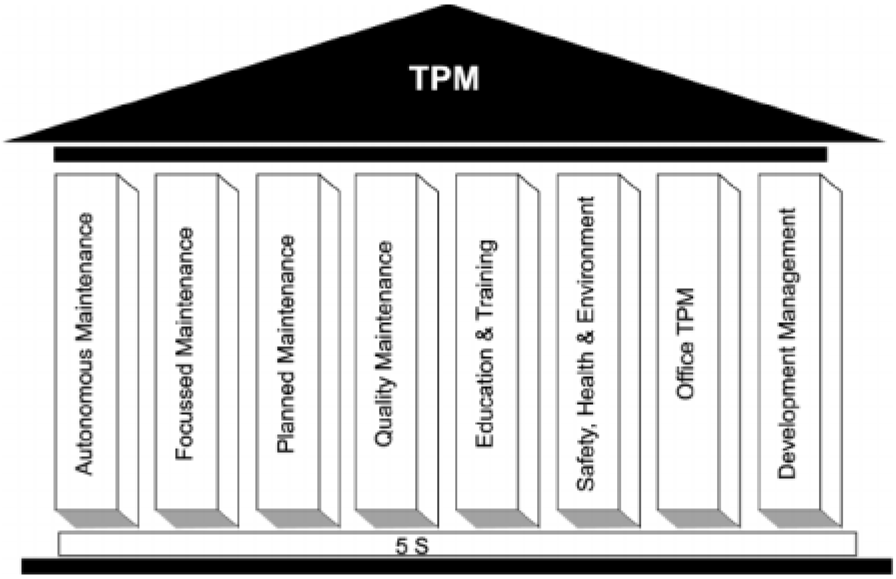

Figure 3: The eight pillars of TPM (Zlatić, 2019).

1. **Autonomous Maintenance (Jishu Hozen):** operators take on simpler maintenance tasks, freeing up technicians for more demanding interventions;

2. **Focused Improvement (Kaizen):** small continuous improvements, at no additional cost, applied both in production and in administrative functions;

3. **Planned Maintenance:** divides maintenance into: preventive, corrective, condition-based and prevention-based maintenance;

4. **Quality Maintenance:** detects and prevents errors in production processes through root cause analysis;

5. **Education and Training:** develops employees' skills for independent work;

6. **Safety, Health and Environment:** pursues zero accidents, zero injuries and zero fires, and is present across all the other pillars;

7. **Office TPM:** extends the TPM logic to administrative functions, eliminating losses in productivity and efficiency;

8. **Development Management:** reduces the start-up time of new equipment.

These eight pillars show the breadth of TPM, which extends well beyond the maintenance function to involve the whole organisation in the pursuit of equipment effectiveness. The level of that effectiveness is measured through a specific indicator, the Overall Equipment Effectiveness, presented in the following section.

2.2.5 Overall Equipment Effectiveness (OEE)

OEE (Overall Equipment Effectiveness) is one of the metrics used to evaluate the performance of a manufacturing system, measuring the percentage of productive time relative to the planned production time, with a higher percentage indicating a more productive process.

Beyond providing this overall measurement, OEE also makes it possible to systematically identify the main sources of productivity loss, allowing resources to be directed more effectively towards improving performance. Its calculation rests on the following three factors (Ghafoorpoor Yazdi et al., 2018):

1. **Availability**: the ratio between the actual runtime and the planned production time;

2. **Performance**: the ratio between the total quantity produced and the quantity that should have been produced over the same period, had the equipment operated continuously at the nominal cycle rate;

3. **Quality**: the ratio between conforming output and total output.

OEE is the product of these three parameters, as expressed in Equation 2.1:

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \tag{2.1}$$

An OEE value of 85% or more is generally regarded as the ideal benchmark. However, subsequent studies show that this standard varies considerably across industries, depending on their specific operational characteristics. A comparison of typical OEE values across different manufacturing sectors is presented in Table 1, illustrating how factors such as the level of automation, the frequency of changeovers and the complexity of the production process influence the values achieved (Koç and Eryürük, 2025).

Manufacturing sector	**OEE (%)**	**Key insight**
Automotive Industry	85-95	High levels of automation and robotics.
Food and Beverage	70-80	Process optimisation and hygiene standards.
Pharmaceutical	65-75	Strict standards and quality control.
Other discrete production	50–65	Frequent changeovers and partial automation.
Apparel Manufacturing	40-60	Manual labour and limited automation.

Table 1: OEE comparison between different manufacturing sectors (Koç and Eryürük, 2025).

Ultimately, these variations highlight that OEE targets cannot be applied uniformly across industries. As such, OEE should be interpreted according to the specific characteristics of each production environment, while serving as a valuable tool for monitoring equipment performance and identifying improvement opportunities.

2.2.6 Pareto Analysis

Pareto analysis is a widely used tool for prioritising problems in a continuous improvement context. It is a statistical technique based on the Pareto principle, which states that roughly 80% of the problems in a given situation tend to come from around 20% of the causes, an idea commonly expressed as the 80/20 rule.

In practice, the tool consists of ranking the causes of a problem by their relative weight and presenting them in descending order, usually combined with a cumulative percentage line. This makes it possible to separate the few causes responsible for most of the impact from the many that contribute only marginally, directing the improvement effort towards the areas where the greatest gains can be obtained (Natawijaya and Kasih, 2026).

For this reason, Pareto analysis is particularly useful in the diagnosis phase, helping to identify and prioritise the main sources of loss before any intervention is carried out.

2.2.7 Layout and Spaghetti Diagram

The layout of a production facility determines the physical arrangement of equipment, workstations and material flows within the factory space. When this organisation is poor, the result is unnecessary movement of materials and operators, longer transport times and a slower production flow, with a direct effect on lead time and production costs. In a Lean context, the layout should therefore minimise the distances travelled and bring process steps closer together, creating the conditions for a continuous flow (Wilson, 2010).

One of the most widely used tools for analysing it is the spaghetti diagram, which traces the actual paths of materials and operators over the factory floor plan and makes the movement and transport that add no value easy to identify. From this reading, it becomes possible to reorganise workstations, shorten distances and simplify the flow of materials (Senderská et al., 2017).

2.2.8 Single-Minute Exchange of Die (SMED)

SMED (Single-Minute Exchange of Die) is a methodology developed by Shigeo Shingo with the aim of reducing setup times, defined as the preparation period between the end of one product's production and the start of the next. The term "single minute" refers to the goal of achieving changeover times of under ten minutes (Shingo, 1985; Silva and Godinho Filho, 2019).

The methodology, outlined in Figure 4, is structured in three sequential stages:

1. **First Stage**: classifying all operations into two types: internal setup, covering operations that can only be carried out with the machine stopped, and external setup, covering operations that can be performed while the machine is still running;

2. **Second Stage**: analysing the internal setup operations with the aim of converting as many as possible into external ones, thereby reducing the actual machine stoppage time;

3. **Third Stage**: optimising all operations, both internal and external, seeking to eliminate or simplify tasks and reduce their duration to the minimum possible.

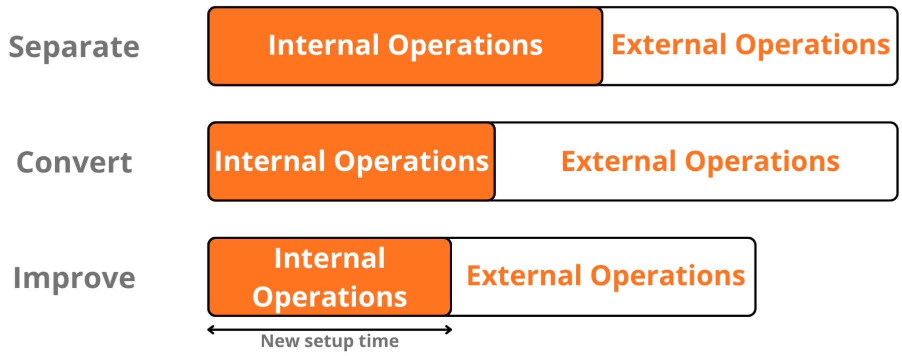

Figure 4: SMED methodology.

The application of SMED makes it possible, in a systematic and progressive way, to reduce the stoppage time associated with production changeovers, freeing up production capacity without the need to invest in additional equipment. By shortening the time the machine remains stopped between orders, it becomes economically viable to produce in smaller batches, which in turn reduces stock levels and shortens the overall lead time.

This greater agility in switching between products gives the line additional flexibility to respond to demand, making SMED a central tool in any productivity improvement project in a Lean context (Wilson, 2010).

2.3 Fundamentals of Corrugated Board Production

Corrugated board is produced from two main paper components: the liner and the fluting. The liner consists of the flat paper sheets that form the outer layers of the board, while the fluting, also called the medium or flute, is the intermediate paper sheet given a wavy shape, which gives the assembly its mechanical strength. These layers are bonded together with starch glue, creating a sandwich structure whose strength increases with the number and configuration of the layers.

The manufacturing of corrugated board takes place on a continuous production line called the corrugator, shown in Figure 5, which combines several integrated modules. Several paper reels are fed in at the same time and, as they pass through the machine, are shaped and bonded together to form the final board.

The fluting passes through heated, fluted rolls under pressure, which give it its characteristic wavy shape. Starch is then applied to the crests of the flutes to bond the inner liner to the fluted sheet, forming what is known as a single face. The outer liner is then glued to the opposite side, completing the structure.

The board is finally cut to the required dimensions and exits the corrugator as a flat sheet, ready to be dispatched to the conversion stage (FEFCO, 2024).

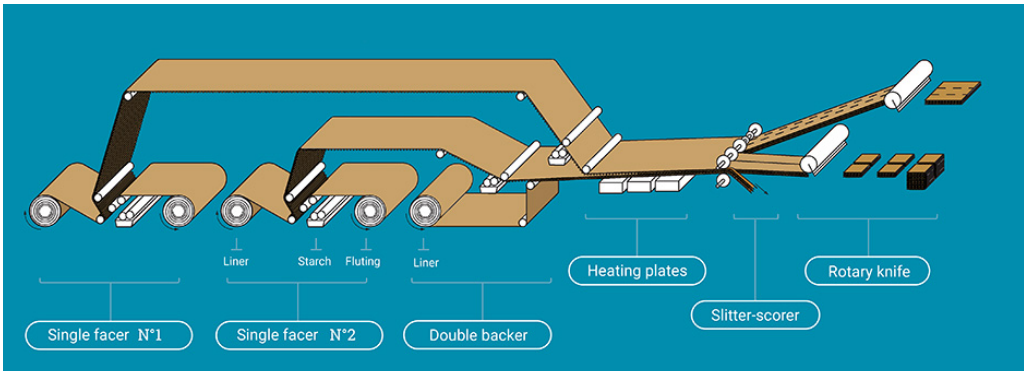

Figure 5: Corrugated board production process in a corrugator (FEFCO, 2024).

The resulting board can be classified by the number of layers and by the flute profile, factors that directly affect its mechanical properties. In terms of layer configuration, there are four types, shown in Figure 6: single face, with one liner and one fluting; single wall, with two liners and one fluting; double wall, with three liners and two flutings; and triple wall, with four liners and three flutings, for more structurally demanding applications (FEFCO and CCB, 2015).

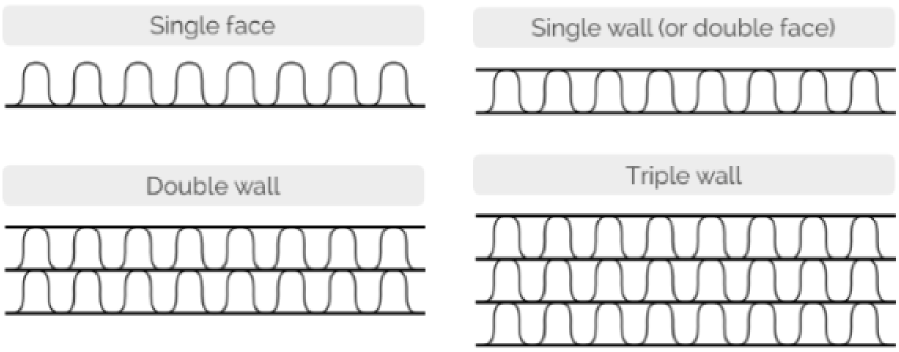

Figure 6: Types of corrugated board (FEFCO and CCB, 2015).

As for the flute profile, the most common types are identified by the letters A, B, C and E, alongside the smaller F, G and N profiles, each defined by a characteristic height. Their reference heights, given for the fluting alone, are listed in Table 2 (FEFCO and CCB, 2015).

Flute	**Height (mm)**
A	4.8
B	2.4
C	3.6
E	1.2
F, G, N	0.5-0.8

Table 2: Flute profile height (liners excluded) (FEFCO and CCB, 2015).

The choice of layer configuration and flute profile determines the mechanical properties of the board and, consequently, its suitability for each type of packaging. Understanding these fundamentals is essential to follow the conversion process studied in this work, in which these boards are transformed into finished cases.

With the theoretical concepts now established, the following chapter characterises the production unit and the line under study, and presents the diagnosis of its initial state.

Chapter 3

Description and Initial Diagnosis of the Conversion Line

This chapter describes and characterises the conversion line under study, forming the diagnostic basis for the improvement work presented later. It begins with a general overview of the company's production process and of the conversion process carried out on the line, followed by a detailed diagnosis of its operational performance using relevant KPIs. It should be noted that the average values presented for the KPIs throughout this project correspond to weighted averages calculated from the underlying production data rather than arithmetic averages of the weekly values shown in the charts.

The aim is to identify and quantify the main sources of productivity loss, so that the subsequent improvement work can target the factors with the greatest impact.

3.1 Production Process at DS Smith Packaging Guilhabreu

The production process at the Guilhabreu unit runs from the arrival of the raw material to the dispatch of the finished product, across a factory floor organised into five main areas. The first is the paper reel storage area, where the reels used in corrugated board production are kept. Next comes the corrugator area, where the paper is transformed into board sheets. These are then held in the intermediate product warehouse, or Work in Progress (WIP), from where they are fed to the conversion lines by forklift. The conversion area is responsible for turning the board into packaging and is equipped with nine machines for printing, creasing, slotting, cutting, folding and closing operations; this is where the conversion line covered by the project is located. Finally, the finished product storage area handles the management and dispatch of the packaging and board produced.

It is also worth noting that, once produced on the corrugator, the board can follow two different paths depending on the type of order: it can go to the conversion area, for customers ordering finished board cases, or straight to the finished product warehouse, for customers who only want board sheets to make their own cases.

The nine machines in the conversion area, each forming its own conversion line, are grouped into five distinct types:

- **Integrated machines:** able to carry out most conversion operations;
- **Printing machines:** able to produce high-quality printing;
- **Presses:** flatbed or rotary, able to perform simple printing, die-cutting and creasing operations;
- **Gluing machines:** used to close more complex models, such as cases with partitions or cases with an automatic bottom;
- **Stitchers:** dedicated to closing large cases, using staples or glue, for models too large to close on the integrated machine or the gluer.

The complete production process of the unit, from the arrival of the raw material to dispatch, is summarised in the diagram in Figure 7.

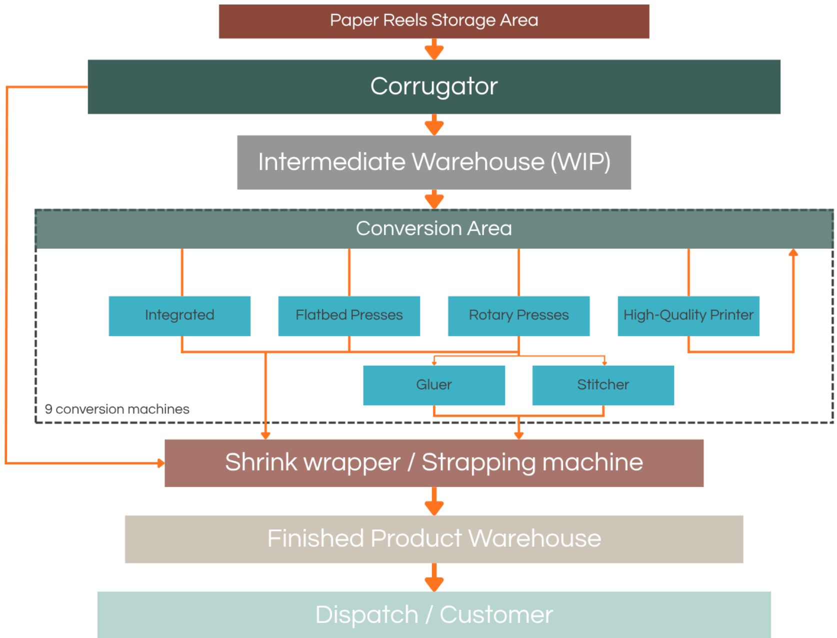

Figure 7: Production process.

Having characterised the unit's production process as a whole, the analysis now focuses on the line central to this project. The following section presents a detailed description of its conversion process, covering each of its stages.

3.2 Conversion Process at UP02

The UP02 line is centred on the Emba 245 Quick Set Casemaker, a conversion machine manufactured in 2004 that converts corrugated board sheets into finished cases at a rate of one case per sheet. Of the nine machines in the factory's conversion area, only two are integrated: the Emba, which carries out all operations except creasing, and the Simon, which carries out all operations. The Emba is a considerably more advanced machine and therefore has a higher production capacity.

In recent years, the line has undergone several changes at the level of the auxiliary equipment upstream and downstream of the machine, namely with the addition of a pre-feeder, composed of a robot and a transfer section, from Ducker Robotics, as well as two robots and a pallet dispenser downstream, also from the Italian brand. The layout of the UP02 conversion line is shown in Figure 8.

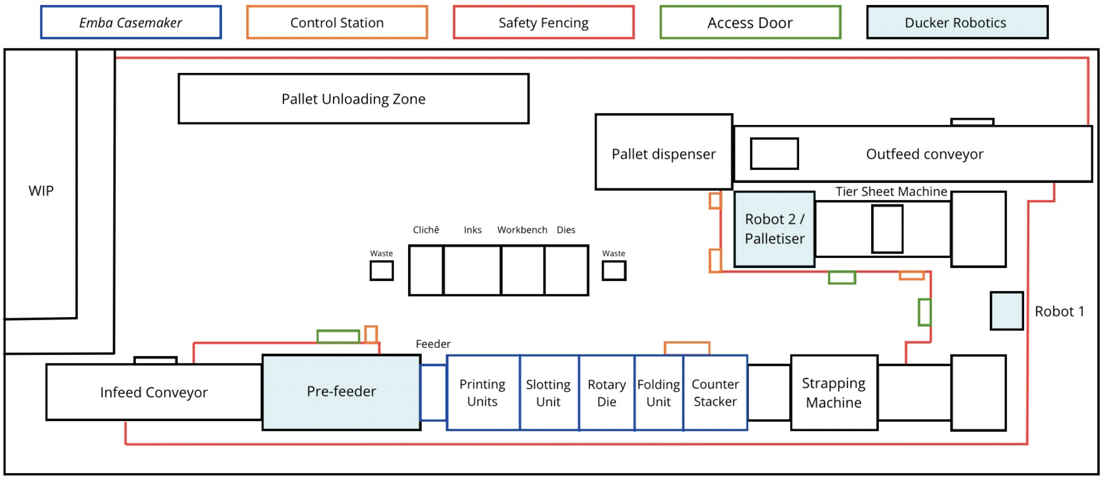

Figure 8: Schematic diagram of conversion line UP02.

The conversion process on the line begins with board sheets entering the infeed conveyor, after being transported by forklift from the WIP. The sheets arrive in stacks, already creased, with the face to be printed facing downwards, as is the case on all other lines in the factory. However, since the Emba Casemaker is the only line where printing is carried out on the top face, the sheets are turned over by the pre-feeder robot and placed on the pre-feeder transfer section, which stacks them and distributes them one by one onto the feeder, correctly aligned for entry into the machine. The pre-feeder is unique in the factory and is one of the most relevant factors in the present study.

The sheets then enter the Emba machine individually through the feeder of the machine, at a speed controlled by the operator. This speed serves as the reference value for calculating the actual execution speed of the entire line, expressed in sheets per hour.

Inside the machine, the sheets pass through five sequential printing units, each fitted with clichés specific to each order, allowing up to five simultaneous impressions in different colours. The printing process used is flexography, the predominant technique in the corrugated board industry, in which ink is transferred to the substrate through photopolymer clichés mounted on rotating cylinders. At this stage, the proximity of the doctor blades (metering blade) to the anilox roll can be adjusted, controlling the amount of ink retained on the anilox roll. The cylinder carrying the cliché can also be brought closer to the board, increasing the printing pressure applied to the substrate, which allows the colour intensity to be regulated. A diagram of the printing system on the machine under study is shown in Figure 9.

At the start of each order, during the setup process, the operator adjusts the printing to ensure that the shade and intensity of the printed colour are within the tolerance defined relative to the order's reference colour. This check is carried out using a spectrophotometer, a device that allows the deviation between the obtained colour and the target colour to be objectively quantified.

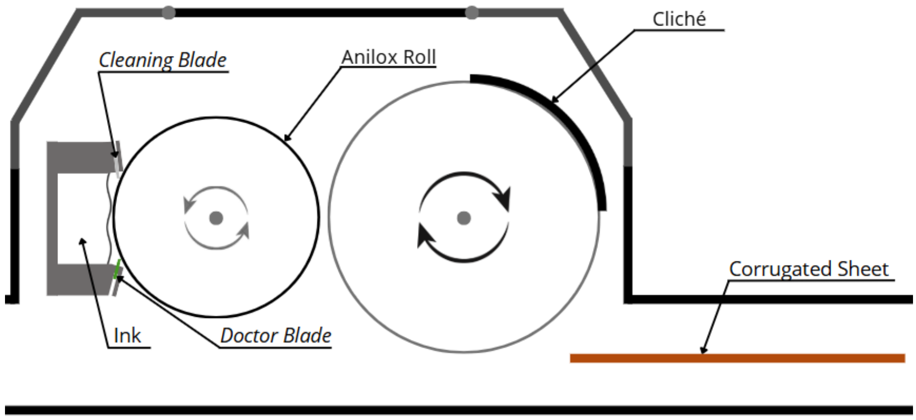

Figure 9: Schematic of the flexographic printing process on the Emba Casemaker.

After printing, the sheets may or may not undergo the slotting process, depending on the specifications of each order. When carried out by the slotting unit, the slot width is fixed at 8 mm, with only its position being configurable. If the order requires a slot with a different size or shape, such as a round-cornered slot, this can be performed by the rotary die, since the machine's blades do not have that capability. There are also orders, namely for large cases, where the sheets are cut on another conversion line and only then printed, folded and glued on the UP02 line, in which case the machine's blades are removed to avoid any additional slotting.

The rotary die allows all external and internal cutting operations of the case to be performed. However, there is always a variation of ± 2 mm when cutting with the die, which is why cutting with the machine's blades is the preferred option and is used whenever possible.

After all cutting operations have been completed, the cases are folded and glued, with glue applied to the tab and the case folded into its final shape. Figure 10 shows the most common case model produced on the line, the American-style case.

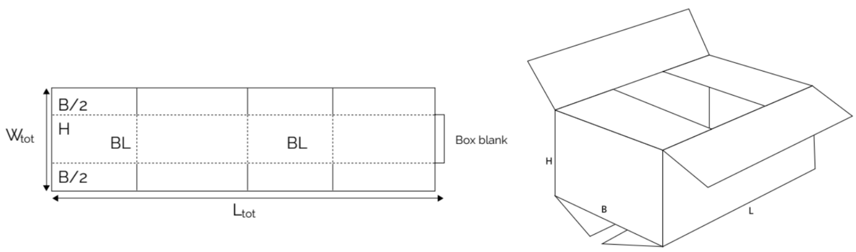

Figure 10: Example of an American-style case (FEFCO and CCB, 2015).

After this process, the produced cases reach the counter stacker, where they are stacked according to the desired bundle height, before passing through the strapping machine, where they may or may not undergo the strapping process.

After the strapper, the bundles, strapped or loose depending on the customer's requirements, reach Robot 1 via a conveyor. Robot 1 is responsible for picking up the bundles and arranging them according to the desired pallet configuration, with 27 possible arrangements available. Before moving on to Robot 2 (Palletiser), the bundles may also receive a tier sheet on top, placed by the tier sheet machine. This board sheet provides greater stability to the pallet and is applied in most orders, either on every bundle or alternately, depending on requirements. The bundles then move on to Robot 2, which acts as the palletiser and places the cases onto the pallet. The pallets are fed automatically through the pallet dispenser, requiring only that a stack of pallets be placed in the pick-up location.

Once palletising is complete, the operator checks the pallet, applies the label identifying it and, if necessary, adds the sample cases. The pallet is then transferred out of the line by the outfeed conveyor, where it is collected by a transfer car shared by seven of the nine lines in the conversion area. This car moves along the lines, picking up the finished pallets and carrying them to a common outfeed line for dispatch, completing the conversion process.

This sequence shows how the UP02 line brings together a large number of operations and pieces of equipment in a single integrated flow. The resulting complexity, combined with the high degree of automation, makes the line both one of the most capable in the unit and one of the most sensitive to disruptions at any individual stage.

3.3 Order Variability

In recent years, increased competitiveness in the business sector has contributed to shorter product life cycles and a greater variety of products. Added to this is the just-in-time philosophy, which by reducing stock levels leads customers to order smaller quantities more frequently, directly affecting the number of setups that need to be carried out daily.

On the conversion line under study, cases are produced with minimum dimensions of 630×305 mm and maximum dimensions of 2,450×1,400 mm, with printing of up to five different colours. In the case of consecutive orders with a high number of different colours, the setup time increases considerably, since the time spent cleaning the printing units and fitting new clichés is significantly higher.

This variability does not affect only the setup time. The dimensions of the cases, the type of board and the operations each order requires also condition the speed at which the line can run and the area it produces per hour. As a result, the line's performance depends not only on its own efficiency but also on the characteristics of the orders being processed at any given time.

3.4 Initial Situation Analysis

The Emba Casemaker conversion line operates on three shifts (morning, afternoon and night), that is, 24 hours a day, with a two-person crew: an operator responsible for the line and an assistant. Despite its high degree of automation, the line remains heavily dependent on the work of these two, whose role remains vital to its performance, from the setup of each order to the constant monitoring of the process. At the time the project began, the line was operating below its capacity, making the increase of its average productivity a priority. Understanding the causes behind this underperformance was therefore the necessary first step.

To this end, an initial diagnosis was carried out, based on direct observation of the line on the shop floor and on the analysis of the PC-Topp platform, the system used by the group to record and centralise all the information generated in the factory. The quantitative analysis of the initial state covers the first eight weeks of the year, prior to any intervention on the line. From this diagnosis, the problems identified were grouped into four distinct areas, described below.

First, poor organisation of the workspace was found throughout the line, with particular emphasis on the lack of tools, the disorganisation of the workbench, the general line layout and the control desk. Second, the unplanned downtime per working hour was high, one of the highest recorded across all lines in the conversion area. Additionally, the line execution speed was significantly below the defined target, directly compromising the line's productivity. Finally, several improvement points were identified in the setup process, with the potential to consistently reduce the time spent on this operation.

3.4.1 Workspace Organisation and Condition

The conversion line under study has two main work areas: the workbench and the control desk.

The workbench, shown in Figure 11, is where all manual operations on the line are carried out, namely updating the daters, small rubber pieces glued to the clichés with double-sided tape that record the production week of the product, and the preparation of the clichés. At the start of the study, the workbench was in a considerable state of disorganisation, with obsolete tools and materials accumulated, and the tool boards and support material boards out of date.

The workbench also has a support drawer intended for the storage of various materials, such as spare cutting blades and glue machine nozzles, also in a disorganised state. In the lower section there is an area reserved for storing the liquids that can be added to the ink, such as anti-foam, whose labelling showed considerable wear, with some liquids incorrectly identified.

The main control desk concentrates the line's primary controls, including the Emba controls, the spectrophotometer, the computers providing access to PC-Topp, the glue detection system, which analyses the cases as they pass and flags any in which the glue falls outside the defined pattern, and the footage from the surveillance cameras placed at critical points on the line.

Since this is where the operator spends most of their time, it must be well organised and have everything needed for efficient work within reach. As can be seen in Figure 12, this area was also in a disorganised state, both on the desk surface and in the lower section, where the printer and storage cabinets are located.

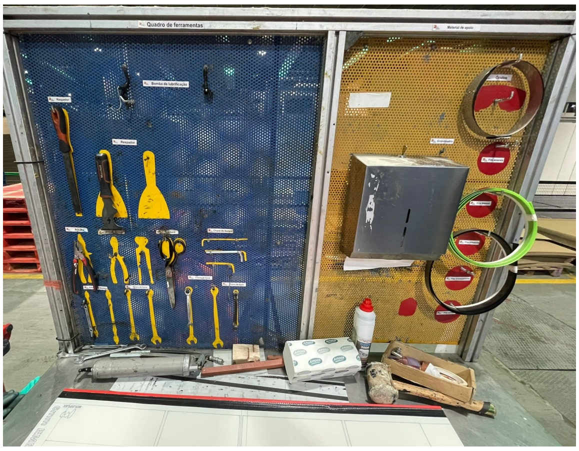

Figure 11: Initial state - Workbench.

Figure 12: Initial state - Control desk.

In addition to these areas, other parts of the line were identified as requiring intervention: the pallet unloading zone, where materials had accumulated without any organisation criteria and pallets were stacked at a height that did not comply with the applicable safety regulations; the ink area, which was disorganised; the die storage area, whose labelling was incorrect; and the cliché trolley, whose identification labels were worn.

3.4.2 Unplanned Downtime Analysis

Unplanned downtime (UDT) was one of the main problems of the line at the start of the study, considered by the production team as the priority issue to address and the main obstacle to improving productivity. During the first eight weeks of the year, the line was stopped for an average of 30% of its working time exclusively due to unplanned downtime, a value well above the defined target of 22%, as can be seen in Figure 13.

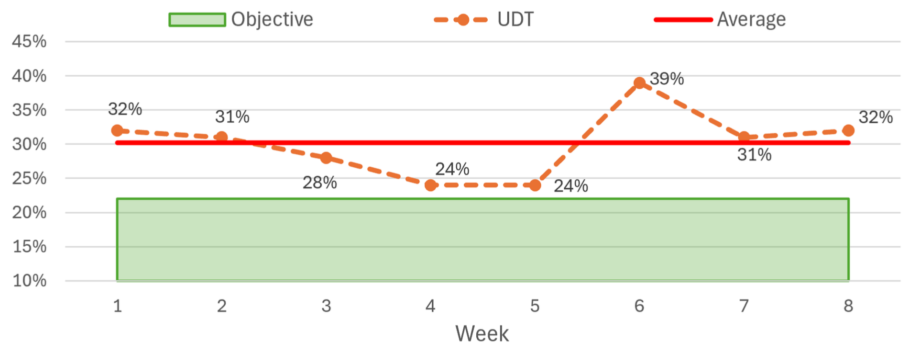

Figure 13: Initial state - Unplanned downtime (%).

Whenever an unplanned downtime event occurs, the operator records the corresponding cause in PC-Topp, with the downtime duration calculated automatically based on the machine's operating status. Based on the data collected over the same period, a Pareto diagram was produced to identify the main causes of downtime, shown in Figure 14.

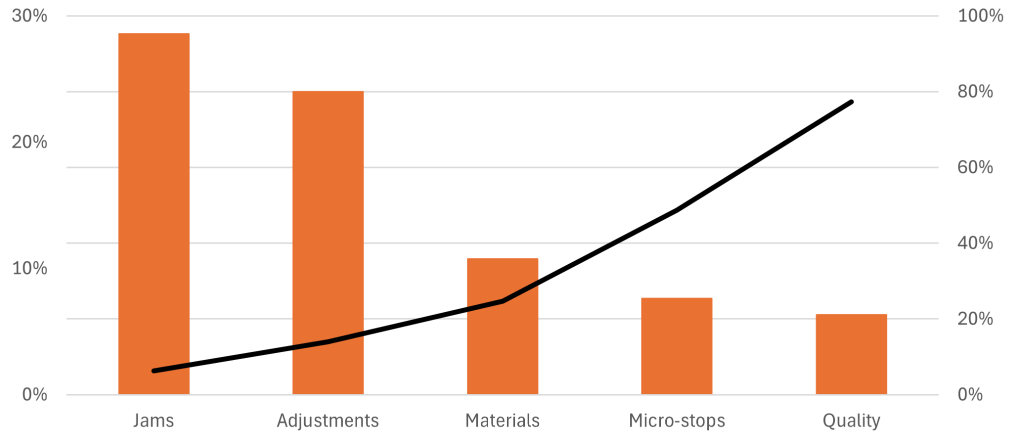

Figure 14: Pareto diagram of unplanned downtime causes.

These five causes account for almost 80% of total unplanned downtime. However, since material and quality issues are not the direct responsibility of the line under study, the analysis will focus on the remaining three causes: jams, adjustments and micro-stops.

Regarding jams, identified as the main cause of downtime on the conversion line, a more detailed analysis was carried out to determine which ones occur most frequently. The results are shown in the Pareto diagram in Figure 15.

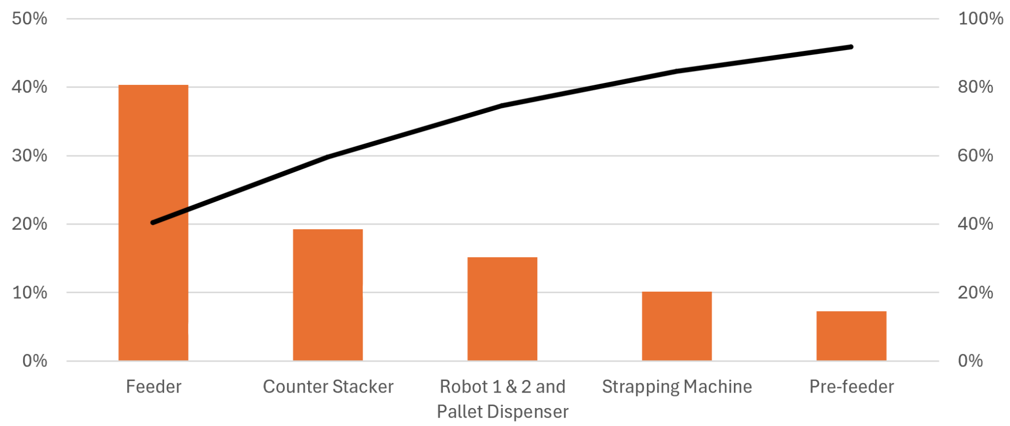

Figure 15: Pareto diagram by jam type.

The diagram shows that the main cause of jams is associated with the infeed section of the line, namely the feeder. The counter stacker is also a major source of downtime.

Direct observation of the line, however, points to a different root cause. Although jams are recorded mostly at the feeder and the counter stacker, their origin lies not in the operation of those areas but in the pre-feeder. This piece of equipment, by damaging the board sheets during the turning process, introduces defects that, even without causing an immediate jam, propagate downstream, leading to failures at the feeder and the counter stacker. In the case of the latter, the board frequently arrives torn, which directly compromises its operation and contributes significantly to the number of jams recorded.

In addition to the pre-feeder, other areas of the line were identified as having a relevant contribution to the number of jams, occurring mostly at the strapping machine, Robot 1 and Robot 2.

At the strapping machine, jams result from the arrival of skewed bundles or from the top case falling at the counter stacker exit. At Robot 1, they occur mostly when bundles leave the strapping machine loose with the top case tipped backwards, preventing the photocell responsible for detecting the bundles at the conveyor entry from identifying them correctly. At Robot 2, the main cause is cases falling during palletising, as a result of errors in the manual setting of the drop height by the operator, a value that serves as an incremental reference for the robot and changes with each order.

It should also be noted that reducing jams will have a direct impact on the number of microstops recorded, since most of these occur precisely as a consequence of the jams identified.

Regarding the second largest cause of downtime, adjustments, an identical analysis was carried out to identify which adjustments take up the most time. The results of this analysis are shown in the Pareto diagram in Figure 16.

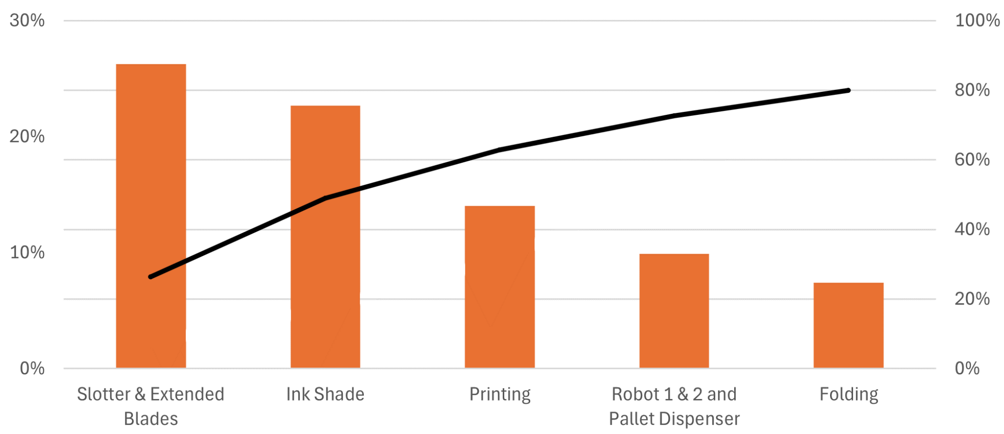

Figure 16: Pareto diagram by adjustment type.

From the analysis of the diagram, it can be seen that the largest cause of adjustments is due to the slotter and extended blades installation or removal, an operation required to fit or remove the blades responsible for carrying out the case cuts.

As for ink shade adjustments, these are mostly caused by shade deviations, requiring intervention to correct the printed colour. Depending on the deviation, the operator can dilute the ink, add ink without varnish to darken the shade, or add pigment of the corresponding colour.

Printing adjustments, in turn, stem mainly from the anilox rolls, the doctor blades and the clichés. The anilox rolls caused problems mostly due to scoring on their surface. On the doctor blades, dried ink would build up and disrupt ink transfer, forcing the line to stop. The clichés, in turn, sometimes needed rectification, which also added to these adjustments.

Finally, adjustments to Robots 1 and 2 are mostly associated with drop height issues, already mentioned above. It should be noted that these adjustments are recorded by the operator when they are able to identify and correct the problem before a jam actually occurs, thus representing a preventive intervention that avoids longer stoppages.

3.4.3 Setup Process Analysis

The setup process on the line under study encompasses a diverse set of operations, including the completion of the previous order, calling up the new product in the system, changing the inks and washing the printing units, changing and preparing the clichés, fitting the rotary die, setting up the pre-feeder and the two robots, among others. The duration of this process varies depending on the differences between consecutive orders, with the cliché change and printing unit washing operations having the greatest impact on the total setup time. Orders requiring a higher number of colours also take longer, as each colour must be individually adjusted to meet the required print standard.

The setup process, documented and posted at several points on the line, was out of date at the start of the study. The target defined was 17 minutes; however, during the first eight weeks of the year an average of 19 minutes per setup was recorded, as can be seen in Figure 17. Of the eight weeks covered by the analysis, only one recorded a time equal to the target.

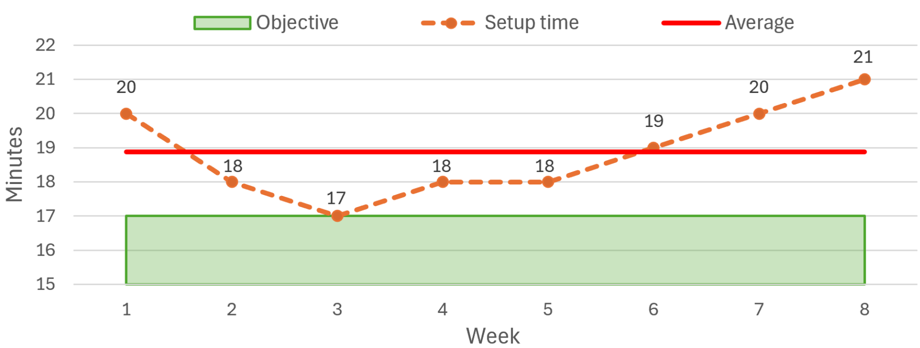

Figure 17: Initial state - Setup time (min).

The visual signage on the machine, in addition to indicating an outdated setup process, displayed an alternative target of 10 minutes plus 2 minutes per cliché to be fitted. However, this reference value was not sufficiently clear to the operators and was therefore not taken into account in practice.

It is also important to note that during this period, the UP02 line recorded the second highest number of setups of all the lines in the conversion area, totalling 397 setups, which corresponds to approximately 126 hours spent exclusively on changeovers. Although the production team did not identify this as the most critical problem, this figure confirms that a reduction in setup time will have a significant impact on the line's overall performance.

In order to gain a deeper understanding of the process, setup recordings were made, direct observations were carried out and the operators were consulted. Spaghetti diagrams were also produced to map the movements carried out during the changeover, presented in Appendix A.

3.4.4 Analysis of the Factors Conditioning Line Execution Speed

The execution speed of the conversion line is a key parameter for ensuring productivity improvement. The Emba Casemaker has a theoretical maximum speed of 16,000 sheets per hour; as an initial reference value, the target set for a new product corresponds to half that value, 8,000 sheets per hour. This value is defined per product and retained across different orders, but can be adjusted by a supervisor in PC-Topp according to the specific characteristics of each order.

During the first eight weeks of the year, the average execution speed recorded was 4,637 sheets per execution hour, a value below the internal target of 5,400 sheets per execution hour, as can be seen in Figure 18.

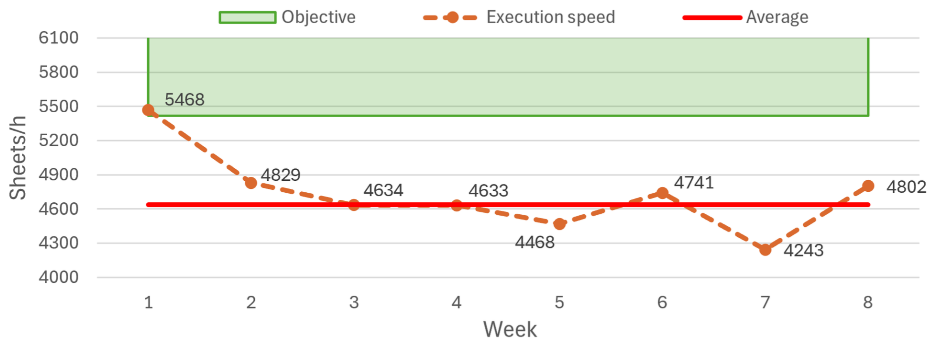

Figure 18: Initial state - Execution speed (sheets/h).

This gap highlights a clear improvement opportunity. It should be noted, however, that the speed the line can actually reach is not constant: it depends on the characteristics of each order, such as the board type, the number of colours and the cutting operations required, which condition the rate at which the line can run. Identifying and acting on the factors that condition the line's execution speed is therefore necessary, and is the subject of analysis in the following chapter.

3.4.5 Productivity Analysis

Productivity in m^2 per working hour (m^2/h) is the main KPI used by the company to assess the performance of all production lines in the unit. During the first weeks of the year, productivity was below the target in every week, with an average of approximately 1,522 m^2/h, as can be seen in Figure 19, significantly below the defined target of 2,000 m^2/h.

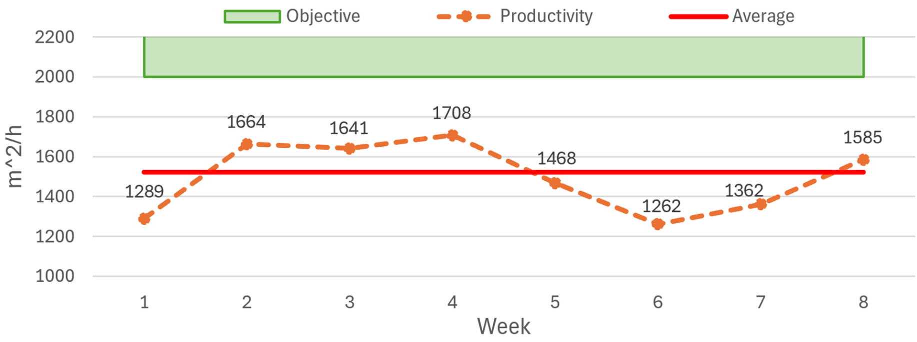

Figure 19: Initial state - Productivity (m^2/h).

Since this indicator is expressed in m^2/h, meeting it depends not only on the line's other KPIs, but also significantly on the order profile, in particular the area of each case produced. For orders of larger cases, the execution speed does not need to be as high for the target to be met, unlike smaller cases, which require a higher production rate. The number of cases per order is also a determining factor, since weeks with fewer setups, resulting from higher-volume orders, naturally benefit the line's performance.

3.4.6 OEE Analysis

To complement the productivity analysis and obtain a broader view of the line's performance, the OEE indicator was also used.

During the first weeks of the year, the average OEE value recorded on the line was 16%, as can be seen in Figure 20, a low value when compared against the benchmarks used in the industry.

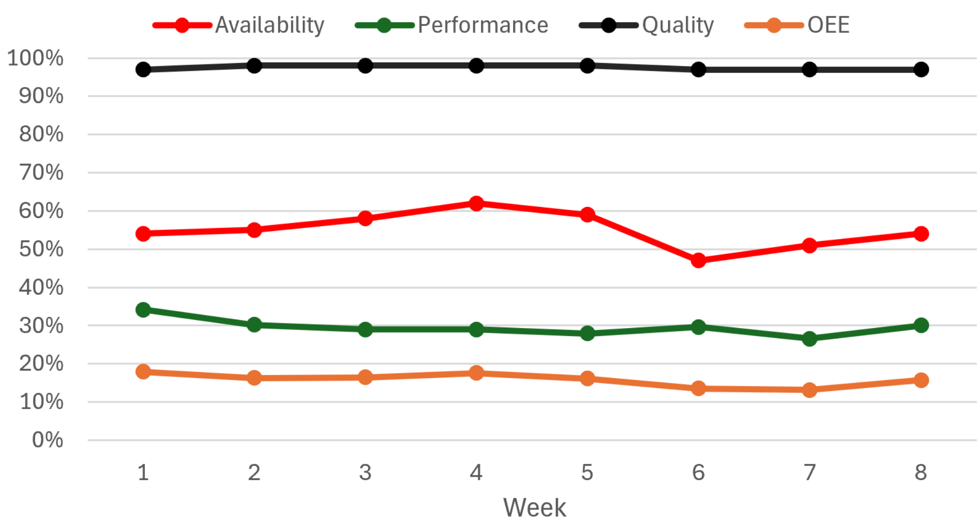

Figure 20: Initial state - OEE (%).

This figure reflects the difficulties identified throughout the diagnosis, namely in terms of availability, compromised by unplanned downtime and high setup times, and performance, conditioned by the execution speed being below the target.

Together, the analysis carried out in this chapter characterised the initial state of the line and identified the main sources of productivity loss, defining the four areas on which the improvement work was focused.

Chapter 4

Improvement Actions and Execution Speed Limitations Study

Following the analysis of the line's initial situation and the identification of improvement opportunities, this chapter presents the methodologies applied and the solutions implemented. The 5S methodology is addressed first, as it created the organisational conditions that supported the subsequent interventions. The reduction of unplanned downtime and the application of SMED are then presented, each targeting the main causes identified in Chapter 3. Finally, unlike the previous sections, the study of the factors conditioning the line's execution speed is presented as a characterisation study rather than a direct intervention.

4.1 5S Implementation

In a first phase, a general clean-up of the work area was carried out and unnecessary tools and materials were removed from all areas of the line, with particular focus on the workbench and the control desk.

At the workbench, as shown in Figure 21, the tool and support boards were painted and reorganised, with the most frequently used tools repositioned for easier access by the operator, missing tools added, and labels placed to identify each position. Cleaning the bench surface also freed up space to set down clichés before fitting them to the machine, which had been particularly difficult in the case of larger clichés, while in the liquids area beneath the workbench, also visible in the same figure, the labelling was renewed and the layout reorganised.

In the drawer intended for cutting and replacement materials, as can be seen in Figure 22, a new structure was created, with a dedicated space for the daters and an additional one for a glue nozzle and spare blades.

Together, these improvements contributed to a more functional workspace and a reduction in the time spent searching for tools.

Figure 21: Final state - Workbench.

Figure 22: Final state - Workbench drawer.

The control desk was also fully reorganised, both in the upper section and in the storage area, as can be seen in Figure 23. In the upper section, all unnecessary material was removed and the clear working space was maximised, since the operator needs room to place and adjust the cases, among other tasks. In the lower section, a thorough clean-out was carried out, removing all material that was not needed. In addition, the plywood support was extended to reduce the dead space that existed and to increase the available storage space.

Figure 23: Final state - Control desk.

In the die storage area, the entry and exit zones were re-identified, since the old signage was wrong: the exit sign sat where operators were placing incoming dies. A space was also created here for the die revision labels and the problem-flagging stickers, which used to be kept elsewhere and are now stored at the point of use.

In the ink area, similar work was carried out. The retention tanks where the inks are placed had no identification, even though two of them already existed, one for incoming and one for outgoing inks, so both were labelled. The incoming area was also split into zones, so that operators can find the inks and substances they need more quickly, and so that the team responsible for the inks can place the incoming material in an organised way.

Next to this area, in the printing units, a recording space was added at each unit for operators to log when the doctor blades are changed and when the ink trays are cleaned, as can be seen in Figure 24. This allows them to see at a glance which doctor blade has been in use the longest and when a tray is due for cleaning.

Further downstream, after the counter stacker, two graduated scales were installed: one before, and one after, the strapping machine. The first, as can be seen in Figure 25, measures the height of the loose bundles, while the second measures it once strapped. This makes the task quicker and easier, allowing the bundle height to be set correctly at Robot 2.

Figure 24: Recording sheet for doctor blade replacement and ink tray cleaning.

Figure 25: Graduated scales installed at the strapping machine.

At the strapping machine, a sign was put up, shown in Appendix B, instructing operators to request more strapping band as soon as the last roll is in use. This prevents extended stoppages, since running out with no replacement forces operators to leave the line to fetch more.

Away from the main production flow, the cliché trolley used to store and move clichés between the printing units and the storage area was also updated, with new labels added to its entry and exit zones, as well as to the sample cases zone.

In the pallet unloading zone, the space was reorganised and each pallet type's zone was clearly identified, as shown in Figure 26. A green marking was also added to indicate the maximum stack height for each pallet type, ensuring compliance with safety regulations.

Adjacent to this zone, the pallet intake area, where pallets are placed on arrival before being moved to their correct storage location, was also identified, and a dedicated space was created and labelled next to the pallet dispenser for the pallets of the next order, as can be seen in Figure 27. In this same area, a space was also set aside for the tier sheets, used both as a base, placed directly on top of the pallet to protect the order, and between layers.

Figure 26: Pallet unloading zone correctly identified.

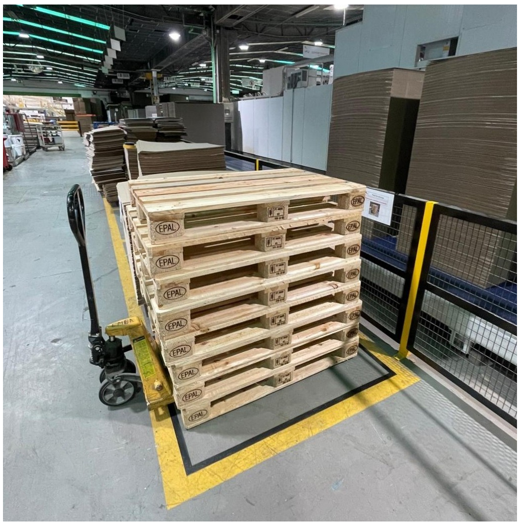

Figure 27: Dedicated space created for pallets of the next order.

Finally, several label and sheet holders were added throughout the line. The main ones are at the infeed section, with a holder for provisional labels, and at the outfeed section, where a holder was installed at the pallet approval point for the labels required to track the pallets through to dispatch. Near this same point, further holders were created for the non-conforming product sheets and for sheets displaying other relevant information.

4.2 Reduction of Unplanned Downtime

Following the implementation of the 5S methodology, the focus shifted to reducing unplanned downtime. As noted in the initial diagnosis, jams and adjustments are the main causes of downtime, so the critical points on the line with the greatest impact on these indicators were identified and addressed, with smaller measures also adopted for other less significant causes of downtime.

4.2.1 Jams

Pre-feeder robot

On the pre-feeder robot several changes were made to its gripper, the area in direct contact with the board sheets, which are listed below:

- Removal of support screws from the upper section of the gripper;
- Adjustment of the inclination of the lower section of the gripper;
- Addition of two movable supports to the lower section of the gripper.

The upper section of the gripper has a rough surface responsible for lifting the board sheets so they can be transported onto the feeder belt. Since this area was already sufficiently rough, seven screws that had been fitted with the intention of increasing support at the top of the gripper were removed, because they were causing damage to the sheets.

Another critical point was the lower section of the gripper, consisting of a steel part that provides support to the sheets during transport. At the start of the study, the inclination of this part was excessive, causing the gripper to collide with sheets still waiting to be picked up, damaging them. After several tests, an optimised inclination was determined, defined by the reference distance between the gripper's upper and lower sections. This range was recorded directly on the gripper in the form of a label attached to it, and documented in Appendix C, serving as a reference for maintenance in the event of future warping.

Finally, two movable supports were added to the lower section of the gripper, with two objectives: to provide greater stability and rigidity to this area, which was prone to warping, and to improve the pre-feeder's behaviour with longer sheets. When needed, these two bars could be deployed outwards from the robot's control screen at the start of each new order, extending the support area beneath the sheet and preventing damage to it.

The gripper can be seen before and after the intervention in Figures 28 and 29.

Figure 28: Initial state - Gripper.

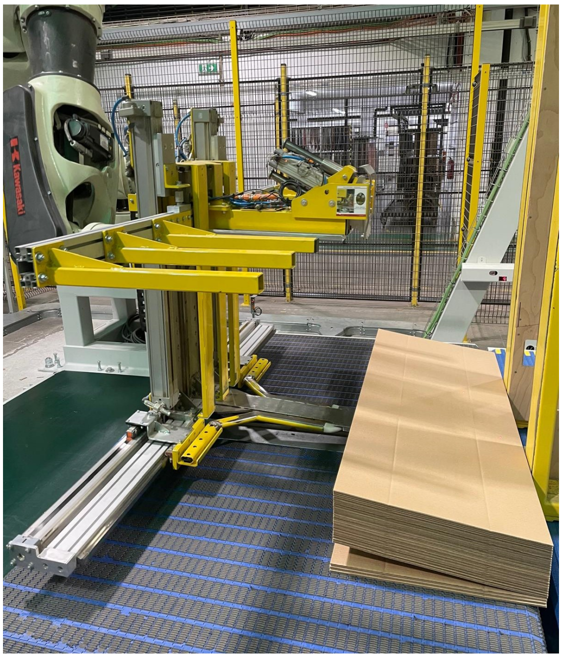

Figure 29: Final state - Gripper.

Pre-feeder transfer

Minor adjustments were made to the pre-feeder transfer to ensure better operation. The front guides of the fork, the area where the pre-feeder drops the sheets, were moved outwards on both sides, so that for larger orders the sheets would be properly supported without risk of falling, as can be seen in Appendix D.

Regarding the sheet separator, the component responsible for distributing the sheets onto the transfer belt, it was found not to be level, which was causing damage to the sheets and to the feeder belt, as can be seen in Figure 30. Since this damage was a direct cause of jams at the feeder of the Emba, the sheet separator was levelled, thereby eliminating the problem at its source.

In the final zone of the pre-feeder, in the Emba feeder section, the component responsible for aligning each sheet before it enters the conversion machine was tilted, with its upper part further forward than its lower part. This prevented the correct alignment of the sheets and caused jams. As can be seen in Figure 31, this component was realigned, ensuring that the sheets enter the conversion machine correctly positioned.

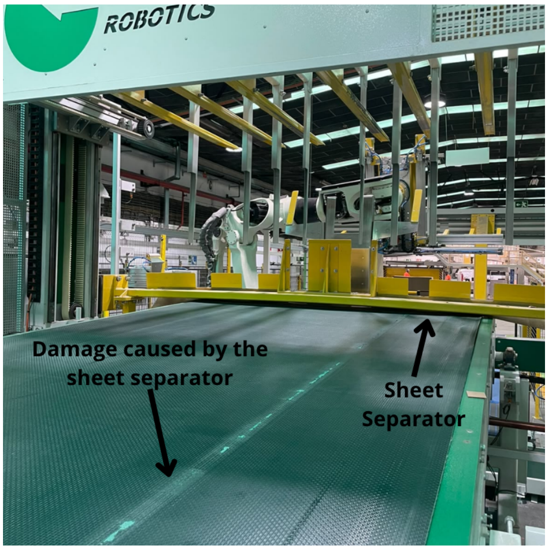

Figure 30: Damage caused by the sheet separator.

Figure 31: Component responsible for sheet alignment, after adjustment.

Counter stacker

At the counter stacker, as already mentioned, the top case falling from the bundle was a frequent cause of jams, both at the counter stacker and downstream. After a detailed analysis of the operation of this unit, it was identified that the component responsible for pushing the cases at the counter stacker exit, before the bundle enters the guide belts, was not functioning correctly. Although it was performing the pushing movement, it was not doing so quickly enough to keep up with the bundle's forward speed on the belts.

Two interventions were carried out to correct this problem: the replacement of the servo valve controlling this component and the straightening of the pusher itself, which was warped. This warping meant that the actuator was wasting force against the structure instead of applying it fully to the intended movement, thus compromising its performance.

After these interventions, the problem was fully resolved, as can be seen in Figures 32 and 33, which show the state before and after the correction.

Figure 32: Initial state - Counter stacker.

Figure 33: Final state - Counter stacker.

Robots 1 and 2

At the Robot 1 and 2 section, the problem described above was addressed using the two graduated scales installed at the strapping machine (Figure 25), also introduced earlier in this chapter as a 5S improvement. By measuring the bundle height directly, whether loose at the entry or strapped at the exit, operators can determine the value to enter into Robot 2 more quickly and accurately at the start of each order, reducing errors and the resulting stoppages.

Pallet dispenser

The pallet dispenser, responsible for feeding pallets into the outfeed section so that Robot 2 can carry out palletising, is also a key element of the line. Initially, the system was found to be unable to transport pallets thicker than standard, causing pallet stacks to fall, representing a safety hazard in addition to the associated unplanned downtime, as can be seen in Figure 34. The equipment was adjusted to reach a lower height, allowing it to pick up the pallet more effectively and eliminating this occurrence.

There was also a recurring problem with the photocell responsible for detecting pallets before Robot 2 begins palletising. Being in an exposed position, this component was frequently struck by operators passing by and also by cases falling from pallets, causing it to become systematically misaligned. To mitigate this problem, a protective cover was designed and installed, as shown in Figure 35.

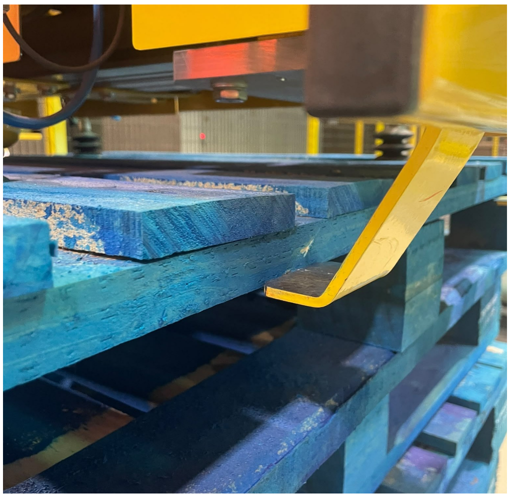

Figure 34: Pallet dispenser before adjustment.

Figure 35: Protective cover fitted to the pallet detection photocell.

Together, these interventions tackled the main sources of jams along the line, correcting the defects at their origin rather than at the points where they were recorded. The following section addresses the second largest cause of unplanned downtime, the adjustments.

4.2.2 Adjustments

Regarding downtime due to adjustments, the stoppage associated with the removal or installation of the slotter and extended blades was left unchanged, as it is a simple but necessary operation, conditioned by the type of order, with no scope for improvement.

Regarding ink shade adjustments, some stoppages stem from shade deviations and are treated as downtime rather than setup, for example when correcting the shade requires requesting a pigment from the ink team. To make this adjustment more precise, two measuring cups were made available, allowing operators to measure the ink to be added accurately.

Printing adjustments, in turn, were addressed in greater depth. It was found that the *doctor blades*, the lower blade in the chamber of the printing units, responsible for metering the ink on the anilox roll, were being fitted the wrong way round, with the bevel facing outwards instead of inwards. Since the bevel must face inwards to correctly meter the ink, mounting it the wrong way round disrupted the ink metering on the anilox roll, degrading print quality and accelerating wear of the blade.

The line uses two types of blade holder, and in both the bevel was being mounted the wrong way round. In the newer type, present in three printing units, this caused a second problem: because the rubber seal sits on the same side as the bevel, mounting the blade backwards left the chamber unsealed, allowing ink to seep into the fitting area. As one operator was also unaware that this holder could be dismantled, the fitting area was not cleaned and the blade was left poorly fixed.

To standardise the procedure, a One Point Lesson (OPL), a brief visual instruction sheet, was developed and displayed on the conversion line, as presented in Appendix E.

4.3 SMED Methodology Implementation

The implementation of the SMED methodology was based on the analysis of the setup process carried out during the diagnosis, which formed the basis for the subsequent stages of the methodology. Given the high variability of the setups on the line, the SMED was applied to the most common situation: a setup involving a die change and the change of three clichés, representative of a typical changeover of medium difficulty.

Separation of internal and external activities

Following this analysis, all activities carried out by the operator and the assistant during the changeover process were identified, along with the average time taken by each task. They were then classified as internal or external, with this classification presented in Table 3.

Task	Resp.	Type	Dur. (min)
Having the next order recipe ready on the computer	Op.	Ext.	0.5
Pre-positioning of the die	Op.	Ext.	0.5
Setting palletiser to end of production mode	Op.	Int.	0.5
Completion of the previous order	Op.	Int.	3
Labelling the last pallet of the previous order	Op.	Int.	1.5
Loading the recipe onto the Emba	Op.	Int.	0.5
Die change	Op.	Int.	3.5
Cleaning of printing units outer surfaces and ink loading	Op.	Int.	2.5
Case adjustment (slotting, folding and colours)	Op.	Int.	7.5
Storage of previous die	Op.	Ext.	0.5
Removal of tier sheets and labels from piles	Ass.	Ext.	1
Pre-positioning the inks and clichés	Ass.	Ext.	0.5
Setting up the pre-feeder	Ass.	Int.	1
Removing inks and setting units to wash	Ass.	Int.	1.5
Cliché fitting	Ass.	Int.	5
Manual loading of the feeder	Ass.	Int.	1.5
Setting up robots 1, 2 and pallet dispenser	Ass.	Int.	2.5
Placing pallets in pallet dispenser	Ass.	Int.	3
Setting up the strapping machine	Ass.	Int.	0.5
FIT test	Ass.	Int.	1.5
Cliché washing	Ass.	Ext.	1
Placing clichés on trolley	Ass.	Ext.	0.5

Table 3: Identification and classification of setup tasks before improvement.

Converting internal activities into external ones

In the context of converting internal activities into external ones, it was identified that the labelling of the last pallet of the previous order can be carried out by the assistant, instead of the operator, while the machine is already in production, at the start of the next order, thus converting it from an internal to an external activity. This change required no technical intervention, being exclusively a change in behaviour and work organisation during the setup.

Continuous improvement of internal and external operations

In the final stage of the SMED methodology, a set of improvements was implemented with the aim of optimising both internal and external operations, reducing unnecessary time and movements during the setup process.

The first line addressed the movement of the operators during the changeover. Regarding the infeed section, as can be seen in Figure 36, whenever operators needed to make manual adjustments in this area, the control was available on the pre-feeder screen but only with automatic mode deactivated. Since this was normally active, operators were required to move to the specific infeed section control to deactivate it before making any manual adjustment. To eliminate this unnecessary movement, a button was added to the pre-feeder controller, as shown in Figure 37, allowing automatic mode to be deactivated directly from this point.

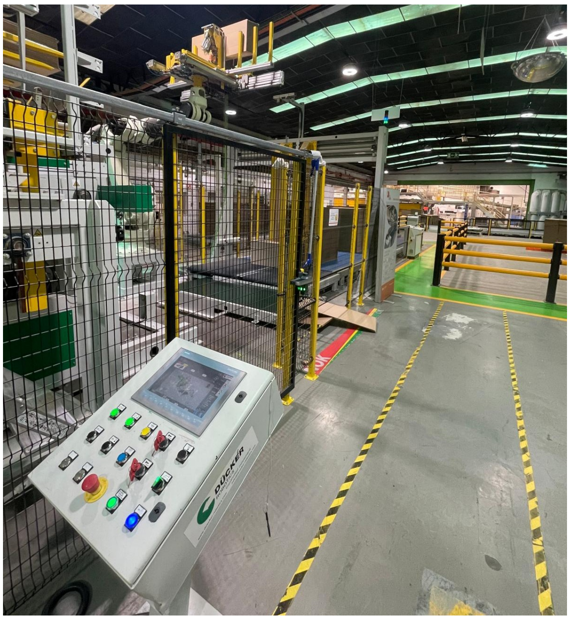

Figure 36: Pre-feeder control system.

Figure 37: Modification made to the pre-feeder control system.

Also along this line, and as mentioned before, a dedicated space for the next order's pallets was created next to the pallet dispenser, reducing the distance travelled by operators during setup and the time spent placing the pallets.

The second line focused on reducing the time taken by individual setup tasks. Regarding the die change, the existing screwdriver was replaced with a more powerful pneumatic one, allowing this task to be carried out more quickly. The measuring cups and the graduated scales before and after the strapping machine, already mentioned in the unplanned downtime section, likewise contribute to greater efficiency in the case adjustment task.

Finally, a laminated record sheet was created and posted on the control desk to track the last replacement of the doctor blades on each printing unit, as shown in Figure 38. Since new doctor blades offer greater resistance to ink flow to the anilox roll, resulting in less ink being transferred to the print, this record allows operators to be aware of the blade wear state and adjust the pressure accordingly, contributing to greater consistency in print quality and a reduction in the time spent on adjustments during setup.

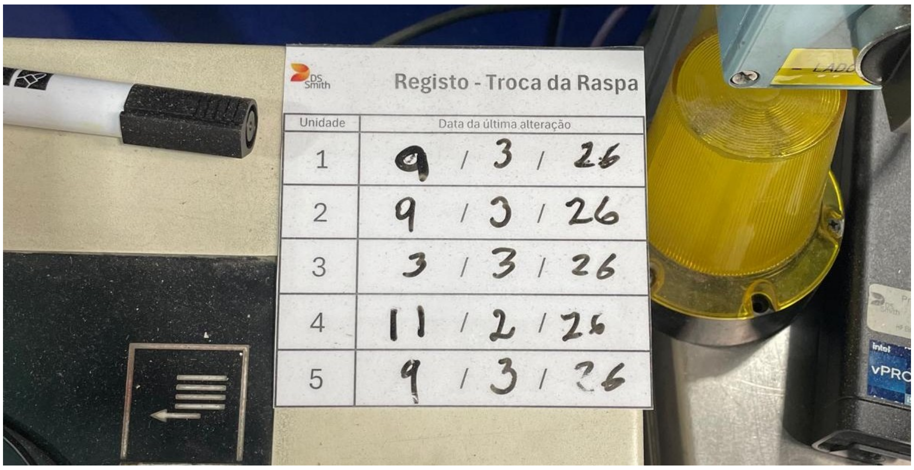

Figure 38: Doctor blade replacement record.

The effect of these interventions can be traced back to the task classification in Table 3. Before the application of the SMED methodology, the setup time was determined by the operator, whose internal tasks added up to 19 minutes and therefore defined the duration of the machine stoppage, since the operator and the assistant work in parallel and the assistant's internal tasks summed to 16.5 minutes.

By converting the labelling of the last pallet from an internal to an external task, 1.5 minutes were removed from the operator's critical path. The remaining optimisations of the internal operations, namely the faster die change enabled by the new pneumatic screwdriver, brought the projected setup time down to 17 minutes, matching the company's official target while creating additional margin to absorb the difficulties of more complex setups.

An internal target of 15 minutes was nonetheless adopted on the line. Given the high variability of the setups carried out on the line, this more ambitious figure was set to create margin for more complex setups and to discourage operators from underperforming on simpler ones, addressing the natural tendency to relax when the task feels straightforward.

With this in mind, the setup process signage was renewed through two documents: a simplified process table with this internal target clearly defined, and a separate sheet listing the external tasks to be carried out before and after the machine stoppage, both available in Appendix F. The process table also reinforces the importance of completing all tasks prior to the case adjustment step as quickly as possible. Since the case adjustment is the most variable and unpredictable operation in the entire setup, the faster the preceding tasks are completed, the more time is available to handle any difficulties that may arise during this step without exceeding the overall target.

Both documents were posted in clearly visible locations on the line, giving all line personnel access to the information at any point during the process. Beyond standardising the process, they make both the operator and the assistant accountable for following the defined procedure, preventing deviations and helping sustain the improvements implemented.

4.4 Study of the Factors Conditioning Line Execution Speed

Based on the initial diagnosis, a systematic study was carried out of the causes limiting the line's execution speed. For this purpose, the HTR (Hit the Rabbit) method was applied, used internally by the company, which consists of progressively increasing the line execution speed until a constraint is reached that prevents further increase. The cause is then recorded for later analysis. The method was applied over two weeks, during which 26 different orders were observed, with the results presented in Figure 39.

In the course of this process, the speed targets for several products were also updated, as they had become outdated. This factor is particularly relevant: when the defined target is low, operators tend not to go beyond it, which in itself limits the speed achieved regardless of the line's actual capacity.

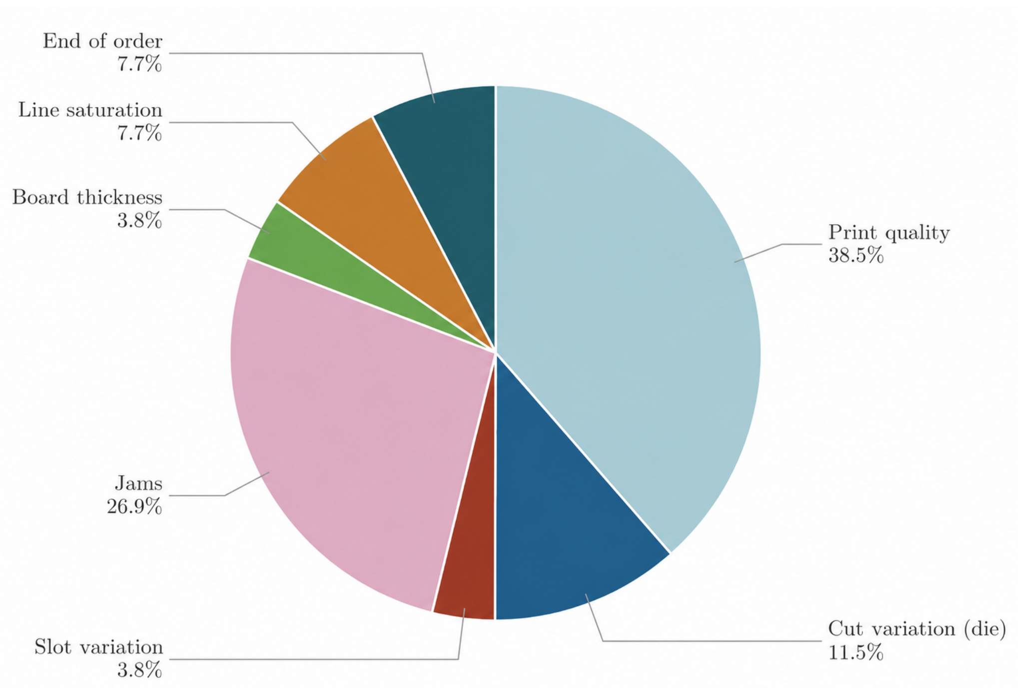

Figure 39: Factors conditioning the increase in execution speed.

From the analysis of the results, two main factors were identified that accounted for approximately 65% of the limitations to increasing speed: jams, responsible for 26.9% of recorded occurrences, and print quality, responsible for 38.5%.

Regarding jams, the diagnosis proved particularly difficult, as they occurred at different points on the line within the same order, without a clear pattern that would allow a specific cause to be identified.

The print quality limitation, in turn, can be attributed to two closely related factors that are difficult to separate in practice. At higher speeds, the printing tends to lose quality, while at the same time its conformity becomes harder to verify. Unlike cutting or folding defects, which are easily visible in the bundles, print defects can only be detected by inspecting each case individually, an approach that becomes impractical at high speed. As a result, operators were unable to guarantee the conformity of the printed cases at high rates and tended to reduce the speed as a precaution. Isolating the exact contribution of each aspect was not possible with the means available, since the line has no system capable of objectively assessing print quality in real time.

The remaining factors, namely cut and slot variation, board thickness, line saturation and the end of order, had a smaller individual impact on the execution speed. Although less significant, they also contribute to the overall limitation and may justify attention in future improvement efforts.

Unlike the previous sections, this part of the project focused on diagnosis rather than direct intervention, in line with the objective of identifying the factors conditioning the line's execution speed. The identified limitations were characterised but not addressed within the scope of this dissertation, and are therefore considered opportunities for future improvement.

Chapter 5

Results Analysis

This chapter compares the final state with the initial diagnosis across the KPIs defined earlier. The final state covers weeks 14 to 21, an eight-week period of the same length as the initial baseline. The two periods have a comparable order profile: the average case area was 0.59 m^2 in both, and the final period had slightly more setups (430 against 397). A higher number of setups makes the final period's profile, if anything, slightly less favourable, so it does not flatter the productivity comparison. Some week-to-week variation in the order profile still exists, and it is discussed where it matters in the sections below.

5.1 Unplanned Downtime

Unplanned downtime was one of the main focuses of the project, and the improvements described in the previous chapter produced a clear reduction in this indicator.

As can be seen in Figure 40, the average unplanned downtime in the final period stood at 19%, a reduction of 11 percentage points from the 30% recorded in the initial diagnosis. This represents a decrease of approximately 37%, exceeding the 27% reduction target defined for the project.

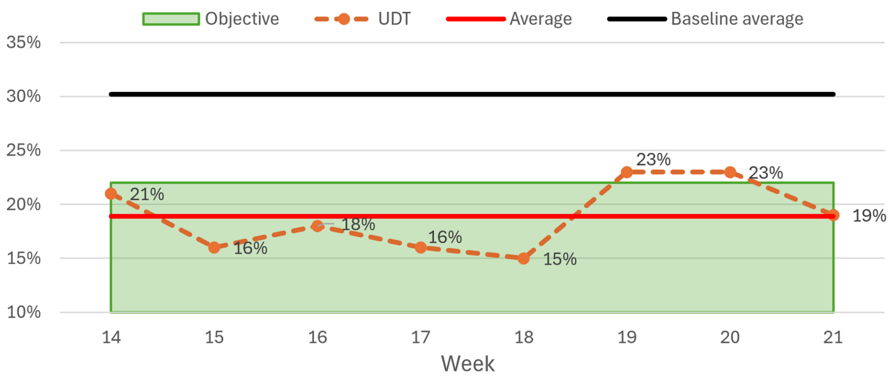

Figure 40: Final state - Unplanned downtime (%).

This reduction resulted mainly from the interventions on the jams, the largest cause of downtime, with particular emphasis on the pre-feeder gripper and the counter stacker. By correcting the damage the pre-feeder caused to the sheets, the defects that propagated downstream to the feeder and the counter stacker were eliminated at their source. The work on the adjustments also contributed, namely the correct fitting and positioning of the doctor blades.

Weeks 19 and 20 recorded values of 23%, above the target, due to issues external to the line that were identified and resolved. Even so, in the worst weeks the values obtained still represent a substantial improvement over the initial state.

5.2 Setup Time

Regarding setup time, as shown in Figure 41, the average for the final period stood at 17 minutes, a reduction of 2 minutes from the 19 minutes recorded in the initial diagnosis, corresponding to a decrease of approximately 11%, thereby meeting the defined objective. The target of 17 minutes was met in seven of the eight weeks analysed, compared to only one week in the initial period.

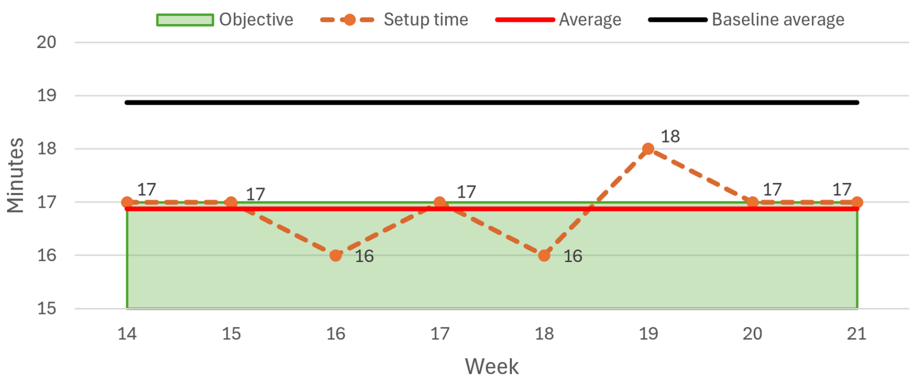

Figure 41: Final state - Setup time (min).

This reduction resulted mainly from the application of the SMED methodology, namely the conversion of a single internal task into an external one and the optimisation of the internal operations. The 5S interventions also contributed, by reducing the distances travelled and the time spent searching for material during the changeover.

Beyond the reduction in the average value, the results show greater consistency between weeks, with the setup time staying close to the target throughout the period analysed. This stability is relevant because it makes the duration of the changeovers more predictable, which supports more reliable production planning.

The impact of the reduction also becomes clear when considered over the full period: during the eight weeks of the final state, 430 setups were carried out on the line, so the average reduction of two minutes per setup corresponds to an estimated saving of approximately 14 hours that would otherwise have been spent on changeovers, time that becomes available for production.

5.3 Execution Speed

Although the focus of this project was the identification of the factors conditioning the line's execution speed, the improvements implemented to address unplanned downtime also contributed to an increase in the average value, from 4,637 to 5,386 sheets per hour, as shown in Figure 42, an increase of approximately 16% that fell just short of the internal target of 5,400 sheets per hour. The update of the speed targets for several products also contributed significantly to this increase.

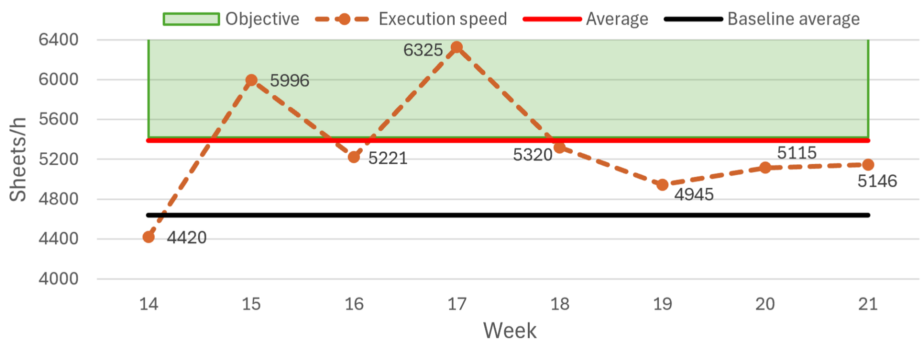

Figure 42: Final state - Execution speed (sheets/h).

Despite the positive results, this indicator still has room for significant improvement, namely through the resolution of the print quality constraint and continuous improvement regarding jams. This margin will allow the line to compensate for weeks in which external factors, such as a higher number of unplanned downtime events outside the line's control or a higher number of setups resulting from lower-volume orders, may compromise the achievement of the productivity target.

The contribution of the target update also highlights the importance of revising the speed targets regularly, since outdated targets limit the speed operators aim for, regardless of the line's actual capacity.

5.4 Productivity

Regarding productivity, the line's main KPI, as can be seen in Figure 43, the average productivity in the final period reached 2,024 m^2/h, an increase of 502 m^2/h over the 1,522 m^2/h recorded in the initial diagnosis, corresponding to a growth of around 33% that exceeded the 31% improvement target defined as the project's main objective.

It is worth highlighting also that even the worst-performing week of the final period significantly outperformed the best week recorded during the initial state.

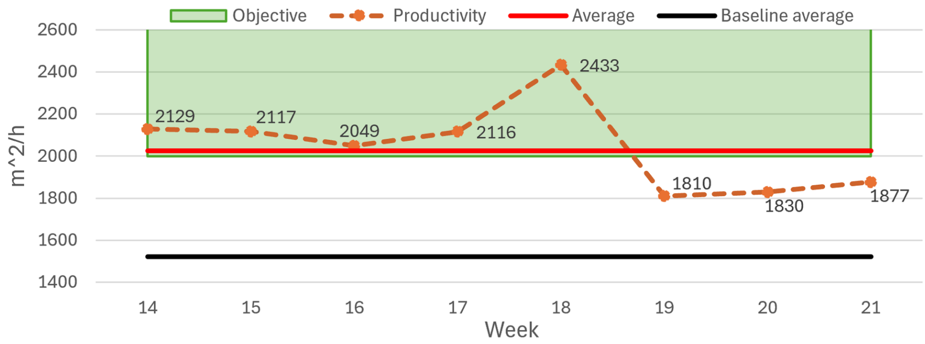

Figure 43: Final state - Productivity (m^2/h).

Weeks 19, 20 and 21 recorded values between 1,810 and 1,877 m^2/h, below the target. This drop is examined in more detail in the OEE analysis that follows, which isolates the factors behind it.

5.5 OEE

Regarding OEE, although it was not a defined objective of the project, it was also analysed as a global indicator of the line's performance. As can be seen in Figure 44, the average value for the final period was 22%, compared to the 16% recorded in the initial diagnosis, representing an increase of 6 percentage points. Despite this improvement, the value remains well below the typical industry benchmarks, which points to the considerable margin for improvement that still exists on the line.

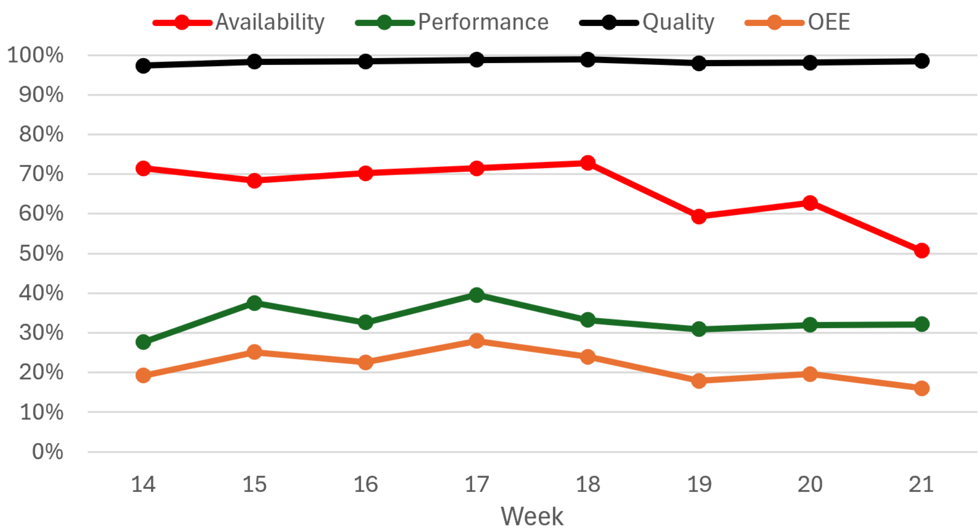

Figure 44: Final state - OEE (%).

Beyond the average value, the OEE provides additional insights into the final weeks of the analysis period, where a clear reduction in the availability component can be observed. This drop is not explained by the indicators usually associated with availability. A comparison between weeks 14 and 21 illustrates this well: week 14 recorded a higher unplanned downtime than week 21, 21% against 19%, and the average setup time was the same in both, at 17 minutes. Despite this, week 14 achieved a higher productivity than week 21.

The difference between the two weeks is explained by two factors not captured by the individual KPIs: the frequency of setups and the average case area. In week 21, a larger share of the working time was spent on changeovers rather than on production, around 18% against 13% in week 14, as a result of smaller and more frequent orders. Here the OEE proves useful, since its availability component captures this effect, something that the unplanned downtime and setup time KPIs do not reveal on their own, as both were more favourable in week 21.

The productivity in $m2/h$, however, remains harder to interpret. Because it depends directly on the area of the cases produced, a week with larger cases can show a higher value regardless of the line's actual efficiency. In week 14, the average case area was 0.74 m^2, against 0.58 m^2 in week 21, which partly explains its higher productivity. Smaller cases usually run at a higher speed, in sheets per hour, but this does not necessarily translate into a higher area produced per hour. The speed that can actually be reached is further constrained by factors such as printing, slotting and cutting, which are difficult to control. This dependence on the order profile is not corrected by any of the indicators, including the OEE, which means that comparisons of m^2/h between weeks must be made with caution.

This analysis reinforces the importance of addressing production planning and setup reduction as key levers for improving the stability and efficiency of the line. It also demonstrates the relevance of the OEE as a global indicator, capable of revealing operational constraints that the individual KPIs do not capture, while making clear that no single indicator fully describes the line's performance on its own.

Chapter 6

Conclusion

6.1 Final Conclusions

This project, developed at the DS Smith Guilhabreu unit, aimed to increase the productivity of the UP02 conversion line through the application of Lean Manufacturing tools. The work followed an action research methodology, starting from the diagnosis of the line's initial state, followed by the implementation of targeted measures and the evaluation of their effects. In addition, a study of the line's execution speed limitations was carried out as a complementary part of the work.

The initial diagnosis identified the main problems and their respective causes: unplanned downtime caused mainly by jams and adjustments, an outdated and unoptimised setup process, the disorganisation of the workspace, and an execution speed below the defined target caused mainly by the degradation of print quality at high speed and the resulting difficulty for operators to guarantee the conformity of the printed cases. These were grouped into four areas of intervention, addressed throughout the project.

In the implementation phase, the 5S methodology was the starting point and proved decisive. Beyond organising and standardising the line, it created the conditions for the remaining interventions, reducing distances travelled and time spent searching for material and making the workspace more predictable. The reduction of unplanned downtime was then achieved mainly through interventions at the pre-feeder and the counter stacker. Identifying that the damage caused by the pre-feeder gripper propagated downstream and originated most of the jams was one of the main contributions of this work, since correcting it eliminated these defects at their source rather than treating their symptoms. The setup process, in turn, was optimised through the SMED methodology, by converting an internal task into an external one and streamlining the internal operations, which both reduced and stabilised the changeover times.

As for the study of the factors conditioning the execution speed, it was carried out through the application of the HTR method over 26 orders, which identified jams and print quality at high speed as the main limitations. The diagnosis of the jams proved particularly difficult, since they occurred at different points on the line within the same order, without a clear pattern that would allow a specific cause to be identified. Print quality, in turn, combines two connected aspects: at higher speeds the printing tends to lose quality, while its conformity becomes harder to verify, as print defects can only be detected by inspecting each case individually, which led operators to reduce the speed as a precaution. Although this part consisted mainly of a diagnosis rather than a direct intervention, it still contributed actively to the results, since the speed targets of several products were found to be outdated and updated, helping to raise the line's execution speed. The print quality constraint, however, was characterised but not fully resolved, and remains the most relevant opportunity for future gains in execution speed.

Taken together, these measures were reflected in the line's key performance indicators. The average unplanned downtime fell from 30% to 19%, a reduction of approximately 37% that exceeded the 27% target. The average setup time decreased from 19 to 17 minutes, an 11% reduction that met its target, with the added benefit of greater consistency between weeks. The execution speed rose from 4,637 to 5,386 sheets per hour, an increase of approximately 16%, and the OEE improved from 16% to 22%. These gains converged on the line's main indicator, productivity, which rose from 1,522 to 2,024 m^2/h, a growth of approximately 33% that surpassed the 31% target defined as the project's main objective.

This increase of 502 m^2/h represents an estimated gain of approximately 6,285 euros per month for the unit, illustrating the economic relevance of the work and showing that a structured Lean intervention can translate into a tangible return without significant financial investment.

Looking at the objectives defined at the outset, all of them were achieved: the increase in productivity and the reduction of unplanned downtime and setup time met their respective targets, and the factors limiting execution speed were studied and characterised.

Beyond the quantitative results, this work left on the line a set of tools and standards that did not exist before, of which the following stand out: the One Point Lesson for the doctor blade replacement, the record sheet for blade and ink tray maintenance, the scales installed at the strapping machine, the reference range marked on the pre-feeder gripper and the standardised and documented setup process. These elements help sustain the improvements, keeping them durable beyond the project's duration.

These results, however, were not achieved without obstacles. The high variability of the orders made it difficult to define standard conditions and to isolate the causes of some problems. The fact that the line operates 24 hours a day limited the window available for more significant interventions, and the preventive maintenance not always being carried out on schedule occasionally conditioned the work. Overcoming these constraints required adapting the interventions to the real operating conditions of the line, and they may also represent some limitations of this project, since they constrained the depth of the analysis and the scope of the interventions that could be carried out.

Finally, it is worth highlighting that this project drew directly on concepts and tools developed throughout the master's programme, namely from the curricular units of Production Management, Process Engineering and Continuous Improvement, and Asset Management. The 5S, SMED and broader Lean methodologies were applied as continuous improvement tools, while the OEE analysis drew on asset management principles.

6.2 Future Work

Despite the results achieved, several opportunities remain open to take the work further. The main one concerns print quality at high speeds, identified as the greatest constraint on the line's execution speed. On one hand, the difficulty operators face in validating print conformity at high production rates, without resorting to an individual inspection of each case, points to the need for an automatic quality control system capable of detecting print defects in real time. On the other hand, the printing system itself would benefit from a deeper analysis to understand why its performance degrades at high speed, identifying the specific causes behind this loss of quality.

Another relevant point concerns the jams which, despite the improvements implemented, continue to occur in a dispersed manner without a clear pattern, making it difficult to identify their causes. Continuous monitoring of these events is recommended in order to collect sufficient data for a more in-depth root cause analysis.

Equally important is sustaining the gains already achieved. The organisation of the line must be maintained and the standardised setup process consistently followed, since improvements of this nature tend to erode over time if they are not actively preserved. The continuous improvement effort therefore cannot stop: the methodologies applied here should remain part of the line's daily routine, ensuring that the results are not only maintained but progressively built upon.

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Appendix A

Spaghetti Diagrams

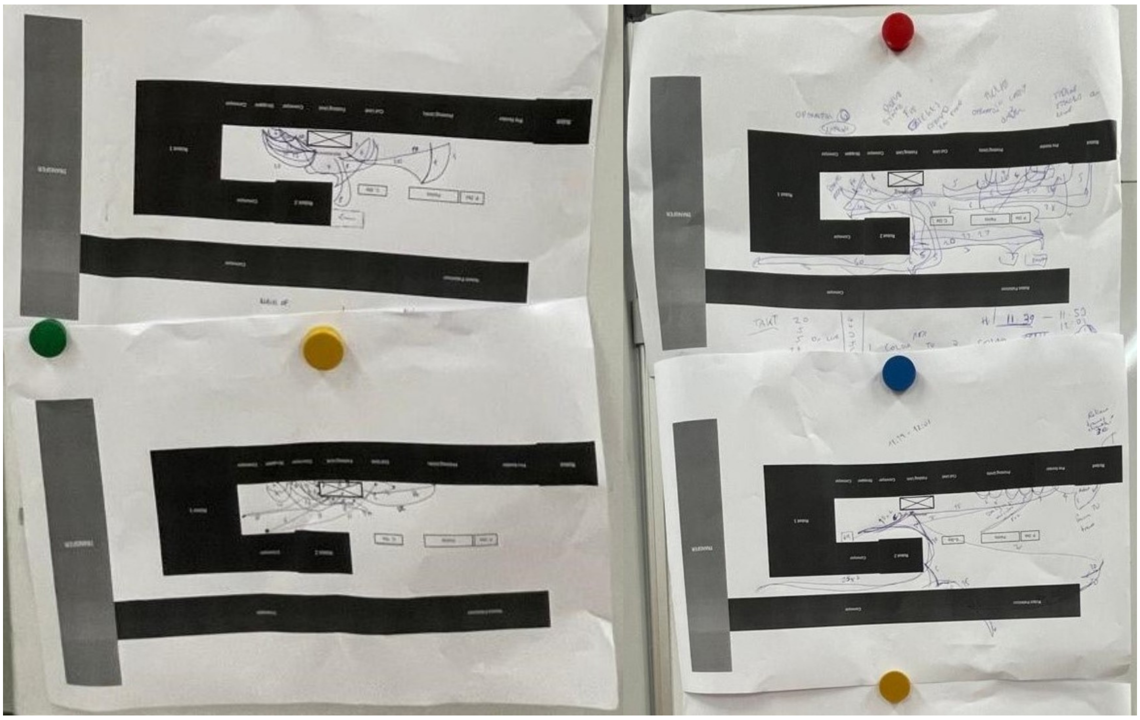

Figure 45: Spaghetti diagrams of the initial setup process: operator during Setup 1 (top left), operator during Setup 2 (bottom left), assistant during Setup 1 (top right) and assistant during Setup 2 (bottom right).

Appendix B

Sign in the Strapping Machine

Figure 46: Sign instructing operators to request more strapping band.

Appendix C

Reference Distance Range of the Gripper's Lower Section

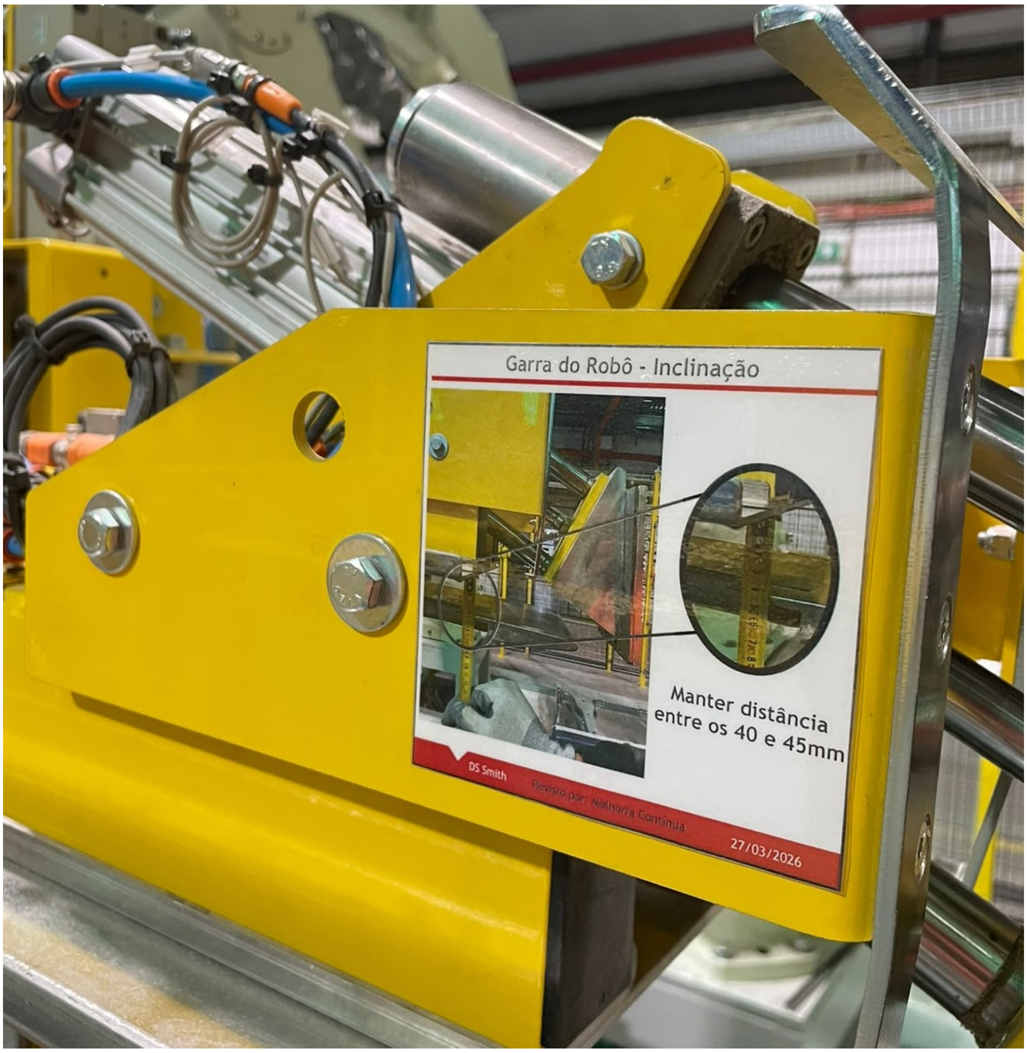

Figure 47: Reference range between the two parts of the gripper.

Appendix D

Front Guides of the Fork

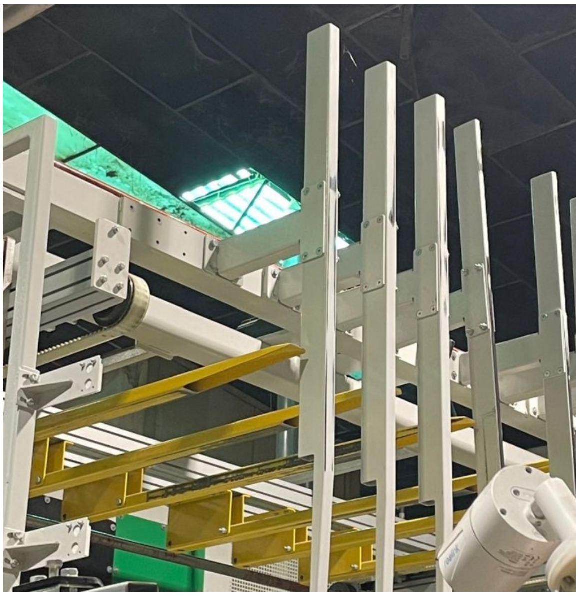

Figure 48: Initial state - Front guides of the fork.

Figure 49: Final state - Front guides of the fork.

Appendix E

OPL for Doctor Blade Replacement

Figure 50: OPL for doctor blade replacement.

Appendix F

Setup Process Displayed on the Line

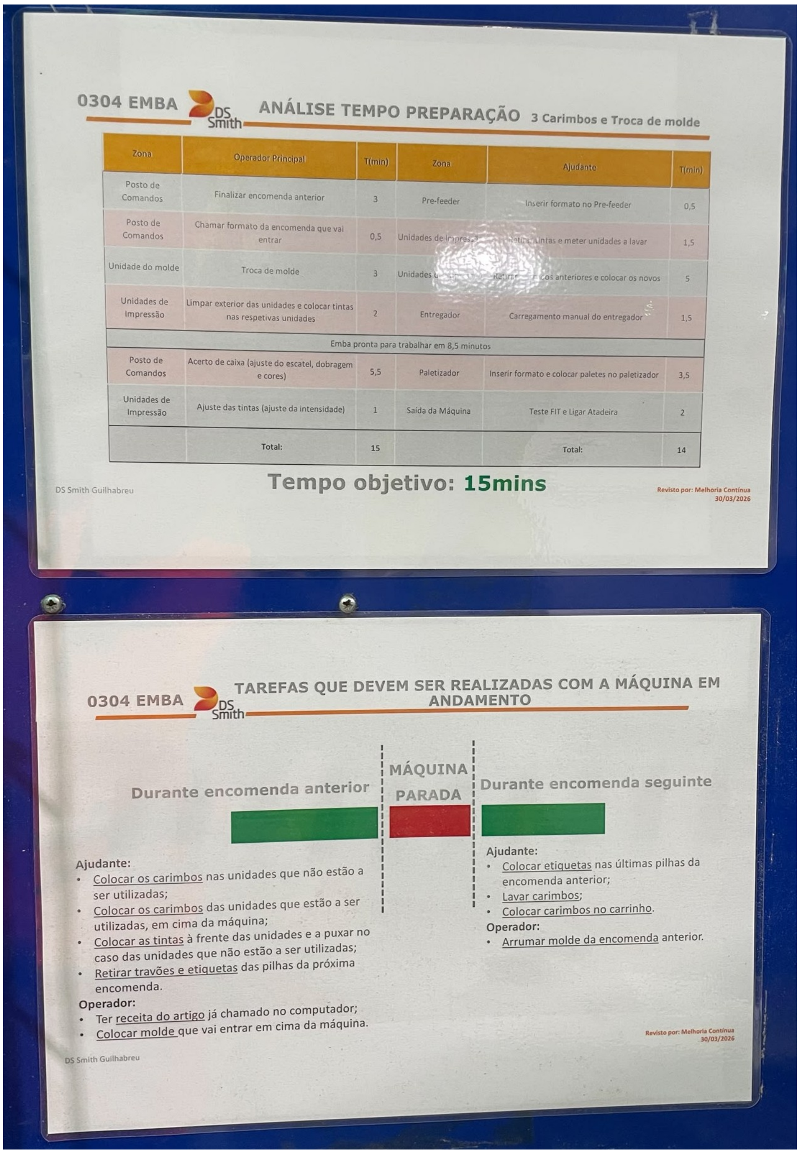

Figure 51: Setup process and external tasks displayed on the line.