

Improving Productivity of a Flatbed Die-Cutting Press Through Lean Manufacturing: A Case Study in the Corrugated Cardboard Packaging Industry

Rodrigo Borges Braga

Master's Dissertation

Orientador na FEUP: Prof. Armando Luís Ferreira Leitão



Master's in Industrial Engineering and Management

2026-06-25

Abstract

The corrugated cardboard packaging industry operates under sustained pressure to maximise productive output, driven by the expansion of e-commerce and tightening environmental regulations that are accelerating the transition away from non-recyclable plastics. Within this context, converting machinery must operate as efficiently as possible to meet growing demand. This dissertation presents a case study conducted at Nova DS Smith Packaging Guilhabreu, a corrugated packaging production unit in Vila do Conde, Portugal, focused on the Bobst SPO 1600, a flatbed die-cutting press manufactured in 1980 that, despite its age, continues to play a significant role in the factory's converting operations.

During the baseline period, the machine operated at 639 m² of processed board per worked hour, against a company-defined target of 900 m²/worked hour. Overall Equipment Effectiveness (OEE) analysis, structured around the Six Big Losses framework, was employed to diagnose and quantify the sources of this underperformance, decomposing productivity losses across the Availability, Performance, and Quality components. The baseline OEE of 35.4% reflected significant losses in both Availability (57.8%) and Performance (61.8%). Quality was excluded from targeted analysis due to the absence of reliable measurement data and its observed non-critical contribution to overall losses.

Improvement actions were structured according to the Six Big Losses framework and preceded by a 5S implementation that established an organised and standardised working environment as the foundation for subsequent interventions. Availability losses were addressed through a SMED-based reduction of changeover time and a structured downtime reduction programme targeting the priority stoppage categories identified by Pareto analysis. Performance losses were addressed through a systematic speed constraint study and improvements to machine utilisation across the line.

The implemented actions yielded an OEE improvement of 8.9 percentage points, rising from 35.4% to 44.3%. Availability improved by 4.5 percentage points to 62.3%, and Performance improved by 10.1 percentage points to 71.9%. Productivity increased by 32.1%, from 639 to 844 m²/worked hour, establishing a clear upward trajectory towards the company target and demonstrating that structured lean practice can deliver significant productivity gains on ageing equipment without capital investment.

Resumo

Melhoria da Produtividade de uma Unidade de Impressão, Corte e Vinco Através de Metodologias Lean: Um Caso de Estudo na Indústria de Embalagens de Cartão Canelado

A indústria de embalagens de cartão canelado enfrenta uma pressão crescente para maximizar a produção, impulsionada pela expansão do *e-commerce* e pelo reforço das regulamentações ambientais que aceleram a transição para soluções alternativas às embalagens de plástico. Neste contexto, as máquinas de transformação devem operar com a maior eficiência possível para responder ao aumento da procura. Esta dissertação apresenta um projeto desenvolvido na Nova DS Smith Packaging Guilhabreu, uma unidade de produção de embalagens de cartão canelado em Vila do Conde, Portugal, centrado na Bobst SPO 1600, uma prensa plana fabricada em 1980 que, não obstante a sua antiguidade, continua a desempenhar um papel relevante nas operações de transformação da fábrica.

Durante o período de referência, a máquina operou a 639 m² de cartão processado por hora de trabalho, face a um objetivo interno de 900 m²/hora de trabalho. A análise do Overall Equipment Effectiveness (OEE), estruturada com base nas Six Big Losses, foi utilizada para diagnosticar e quantificar as fontes desta ineficiência, decompondo as perdas de produtividade nas componentes de Disponibilidade, Desempenho e Qualidade. O OEE de referência de 35,4% reflete perdas significativas tanto na Disponibilidade (57,8%) como no Desempenho (61,8%). A componente de Qualidade foi excluída da análise por ausência de dados fiáveis e por ter sido observado que a sua contribuição não era crítica para as perdas globais.

As ações de melhoria foram estruturadas de acordo com as Six Big Losses e precedidas por uma implementação de 5S, que estabeleceu um ambiente de trabalho organizado e padronizado como base para as intervenções subsequentes. As perdas de Disponibilidade foram abordadas através de uma redução do tempo de troca entre encomendas, assente na metodologia SMED, e de um programa estruturado de redução de paragens não planeadas, direcionado para as categorias prioritárias identificadas pela análise de Pareto. As perdas de Desempenho foram abordadas através de um estudo sistemático das restrições de velocidade e de melhorias na utilização das máquinas ao longo da linha.

As ações implementadas resultaram numa melhoria do OEE de 8,9 pontos percentuais, passando de 35,4% para 44,3%. A Disponibilidade aumentou 4,5 pontos percentuais para 62,3% e o Desempenho melhorou 10,1 pontos percentuais para 71,9%. A produtividade aumentou 32,1%, de 639 para 844 m²/hora de trabalho, demonstrando que a aplicação estruturada de metodologias Lean permite obter ganhos de produtividade expressivos em equipamentos sem recurso a investimento de capital.

Agradecimentos

Em primeiro lugar quero agradecer aos meus pais pelo apoio incondicional, por acreditarem sempre em mim e por terem moldado a pessoa que sou hoje. Agradecer também à minha irmã, madrinha e avós pelo carinho e motivação que me ajudaram a ultrapassar as barreiras mais difíceis. Um agradecimento especial à Marta por ouvir os meus desabafos e por estar sempre ao meu lado quando eu mais preciso.

Em segundo lugar, agradecer a todo o corpo docente e não docente do Departamento de Engenharia e Gestão Industrial da FEUP por colaborarem para um curso tão bem estruturado e útil, em especial ao professor Armando Leitão pelo acompanhamento e ajuda no desenvolvimento desta dissertação.

Gostaria também de agradecer aos colaboradores da DS Smith, em particular à minha orientadora Isabel Bozzato por todo o apoio e disponibilidade, e também aos operadores Vítor Maia e Francisco Rui pela proatividade e por me terem ensinado tudo o que necessitei para conseguir desenvolver com sucesso o presente projeto.

Por último, agradecer aos meus amigos e colegas de curso por terem tornado esta passagem pela FEUP inesquecível. Sem eles não teria conseguido passar a mecânica dos fluidos, quanto mais chegar até aqui.

*"A espantosa realidade das coisas
É a minha descoberta de todos os dias."*

Alberto Caeiro

Contents

1	Introduction	1
1.1	Project Overview and Motivation	2
1.2	Project Objectives	3
1.3	Methodology	3
1.4	Dissertation Structure	4
2	Literature Review	5
2.1	The Toyota Production System	5
2.2	Lean Manufacturing	6
2.3	The 5S Methodology	8
2.4	Single Minute Exchange of Dies	8
2.5	Total Productive Maintenance	9
2.6	Overall Equipment Effectiveness and the Six Big Losses	10
2.7	OEE in the Packaging Industry	12
3	Current State Analysis	13
3.1	The Bobst SPO 1600 – Machine Characterisation and Productive Process	13
3.2	Data Collection Methodology	15
3.3	Current State Overview	16
3.4	Overall Equipment Effectiveness Analysis	18
3.5	Downtime Analysis	19
3.6	Changeover Analysis	21
4	Implementation	23
4.1	5S Implementation	23
4.2	Availability Improvements	27
4.2.1	Setup & Adjustment – SMED	27
4.2.2	Breakdowns – Downtime Analysis and Reduction	30
4.3	Performance Improvements	34
4.3.1	Idling & Minor Stops	35
4.3.2	Reduced Speed – Speed Constraints	35
5	Results and Discussion	39
5.1	Results: Company Objectives Perspective	39
5.1.1	Weekly Evolution of Productivity	39
5.1.2	Final Results Against Company Targets	40
5.2	Results: OEE Perspective	42
5.2.1	Weekly OEE Evolution	42
5.2.2	Final OEE Results	43

5.3	Results Overview	46
5.3.1	Economic Impact	47
6	Conclusion	49
6.1	Future Work	50
	References	51
	Sustainable Development Goals	52

Acronyms and Symbols

CAGR	Compound Annual Growth Rate
EU	European Union
JIT	Just-in-Time
KPI	Key Performance Indicator
MES	Manufacturing Execution System
OEE	Overall Equipment Effectiveness
SMED	Single Minute Exchange of Dies
TPM	Total Productive Maintenance
TPS	Toyota Production System
WIP	Work in Progress

List of Figures

1	Production flow at Nova DS Smith Packaging Guilhabreu.	2
2	Gantt Chart of the Project.	4
3	Manual feeding area and Flexo 1575 printer.	14
4	Bobst SPO 1600 flatbed die-cutting press.	14
5	EasyBreak separator and palletising area.	15
6	Pareto chart of downtime categories – Bobst SPO 1600, January–February 2026.	20
7	Changeover task breakdown for the Bobst SPO 1600 – current state.	21
8	Replacement of hammers with a purpose-built metal support at the introductor table.	24
9	Shadow board for Bobst tools.	24
10	Reorganised drawers for die-fixing materials adjacent to the Bobst SPO 1600. . .	25
11	Previous pallet zone layout around the palletising station.	25
12	Revised pallet zone layout around the palletising station.	26
13	Second metal bar enabling external preparation of the blanking plate for the next order.	28
14	Replacement of worn positioning pins on the flat die table.	28
15	Replacement of the allen key with a T-shaped key for bolt fastening operations. .	29
16	Replacement of a standard bolt with an easy-open bolt inside the Flexo 1575 printer.	29
17	Visual work instruction tables installed at the Bobst SPO 1600 line.	30
18	Flexo 1575 introductor showing the pneumatic press and moving plate.	31
19	Metal guide at the claw entry point of the Bobst press introductor.	32
20	Blanking tool and <i>guillotine</i> area of the Bobst SPO 1600 press.	33
21	Drawer with pre-prepared plastic strips for counter plate adjustments.	33
22	EasyBreak separation timer before and after installation of the centimetre conversion reference.	34
23	Press speed conversion reference installed next to the speed dial.	36
24	EasyBreak operating instructions installed at the machine.	37
25	Weekly evolution of productivity indicators on the Bobst SPO 1600 line, weeks 6–23 (2026).	40
26	Weekly evolution of Overall Equipment Effectiveness and its components on the Bobst SPO 1600 line, weeks 6–23 (2026).	42

List of Tables

1	The Six Big Losses and their correspondence to OEE components (Nakajima, 1988).	11
2	Key performance indicators for the Bobst SPO 1600 – January and February 2026 baseline.	17
3	OEE results for the Bobst SPO 1600 – January and February 2026 baseline. . . .	18
4	Speed constraint observation template.	36
5	Operational KPI comparison: baseline versus results period.	41
6	OEE component comparison: baseline versus results period.	43
7	Downtime category comparison: baseline versus results period (% of worked hours).	44
8	Performance indicator comparison: baseline, results period, and company targets.	46
9	Sustainable Development Goals addressed by this project.	54

Chapter 1

Introduction

The present project was conducted at Nova DS Smith Packaging Guilhabreu, a corrugated cardboard packaging production unit located in Guilhabreu, Vila do Conde, Portugal. The factory has more than 50 years of history in the packaging industry and was acquired by DS Smith in 2018.

DS Smith is a British multinational packaging company founded in 1940 in London, which grew into one of the leading providers of sustainable fibre-based corrugated packaging solutions in Europe. A defining characteristic of its business model is its commitment to the circular economy, having developed an integrated supply cycle in which recovered paper is recycled into new corrugated packaging within approximately 14 days (DS Smith, 2017). In January 2025, DS Smith was acquired by International Paper, creating a global leader in sustainable packaging with over 65,000 employees and operations across more than 30 countries (DS Smith, 2025).

The Guilhabreu factory's production flow begins with the reception of paper rolls, which are fed into the corrugator to produce corrugated cardboard sheets. These are then directed from the Work in Progress (WIP) warehouse to one of seven transformation machines (*Emba*, *Gopfert*, *Mastercut*, *Martin*, *Ward*, *Bobst* and *Simon*), each with distinct printing and cutting capabilities. Certain products subsequently pass through a gluing stage before all goods converge at the shrink wrap and palletising stage, as illustrated in Figure 1. The factory serves a diverse and demanding client base across the food and beverage, retail, and industrial sectors.

The European corrugated packaging industry produces approximately 49 billion square metres of board annually, with the market valued at USD 53.76 billion in 2025 and projected to grow at a CAGR of 4.61% through 2034 (Market Data Forecast, 2025). This growth is driven primarily by the expansion of e-commerce and EU regulations phasing out non-recyclable plastic packaging (FEFCO, 2024). In this context of sustained demand growth, Nova DS Smith Guilhabreu operates under continuous pressure to maximise output, making the efficiency of each transformation machine a critical operational concern and the central motivation for the present project.

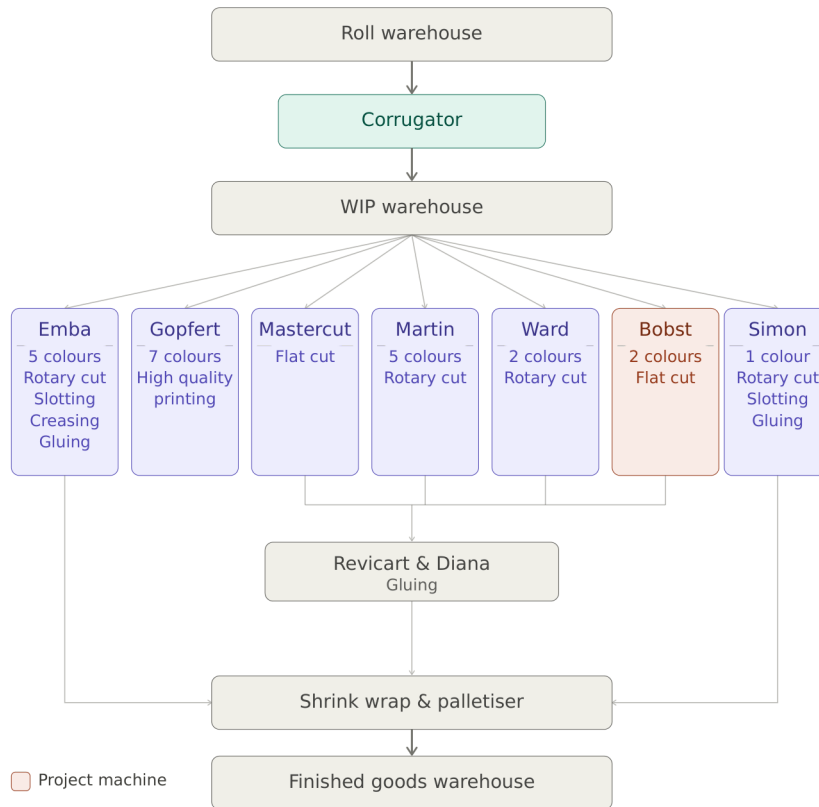


Figure 1: Production flow at Nova DS Smith Packaging Guilhabreu.

1.1 Project Overview and Motivation

The present project was conducted within the Continuous Improvement department of Nova DS Smith Packaging Guilhabreu. The unit benefits from an already established Lean culture, with both workers and management familiar with Lean principles and tools, creating a favourable environment for the implementation of improvement initiatives. This project is part of a broader continuous improvement strategy for the factory's transformation machines, following similar projects previously carried out on other machines within the unit. The machine at the centre of this project is the Bobst SPO 1600, a flatbed die-cutting machine equipped with two-colour printing capability. Manufactured in 1980, the machine is over 40 years old and is one of the seven transformation machines represented in Figure 1. Despite its role in the factory's production flow, the Bobst SPO 1600 has consistently underperformed relative to the company's internal objectives. This underperformance is observed in three key dimensions: the total square metres of corrugated board produced, the operating speed of the machine, and the level of downtime recorded. The persistence of these gaps against established targets, combined with the high demand environment in which the factory operates, makes the Bobst SPO 1600 a priority target for productivity improvement. It is within this context that the present dissertation is situated. By applying lean manufacturing methodologies to address the root causes of underperformance on the Bobst SPO

1600, this project aims to contribute to the factory's continuous improvement strategy and bring the machine's performance in line with the company's operational objectives.

1.2 Project Objectives

The primary objective of this project is to improve the productivity of the Bobst SPO 1600 through the application of lean manufacturing methodologies. During the observation period of January–February 2026, the machine operated at an average of 639 m² of corrugated board per worked hour, against a company-defined target of 900 m²/worked hour, representing a gap of approximately 29% below the established objective.

Main Objective: Achieve 900 m² of processed corrugated board per worked hour on the Bobst SPO 1600, representing an improvement of approximately 41% over the observed baseline.

In order to achieve this primary objective, the following sub-objectives were defined:

- Reduce unplanned downtime on the Bobst SPO 1600;
- Improve machine run speed by identifying and eliminating operational speed constraints;
- Improve setup operations through the reduction of changeover time;
- Establish a more organised and standardised working environment.

The lean manufacturing methodologies selected to address each of these objectives are presented in the following section and discussed in detail in Chapter 2.

1.3 Methodology

The methodological approach adopted in this project combines lean manufacturing tools applied in a coordinated manner. 5S methodology is implemented first, establishing an organised and standardised working environment as a foundation for subsequent improvements. The Overall Equipment Effectiveness (OEE) framework is then employed as the primary analytical lens, decomposing machine performance into availability, performance rate, and quality, allowing the root causes of productivity losses to be systematically identified and quantified (Dal et al., 2000). Building on this analysis, SMED methodology is applied to reduce changeover times, downtime reduction initiatives are implemented to improve machine availability and speed constraints are addressed. As illustrated in Figure 2, the work was structured sequentially, beginning with familiarisation and current state analysis, followed by objective definition and project planning.

The improvement phases follow a logical progression, with 5S implementation preceding the analytical phases of downtime analysis and speed constraints, followed by the SMED implementation. The project concludes with a validation and results monitoring phase to assess the impact of the implemented improvements.

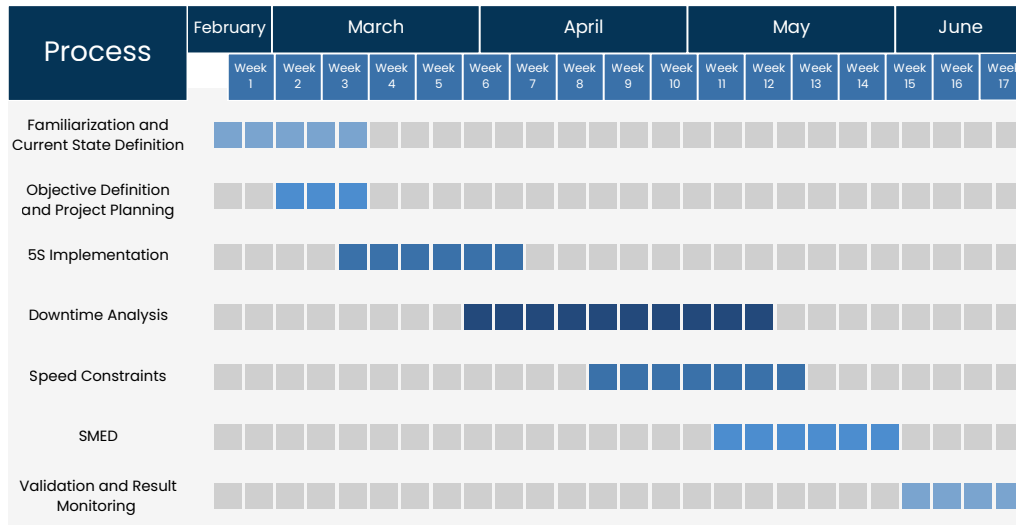


Figure 2: Gantt Chart of the Project.

1.4 Dissertation Structure

This dissertation is organised into six chapters. The present chapter has introduced the industrial context of the project, the company and production unit where it was conducted, the project objectives, and the planned methodology.

Chapter 2 presents the literature review, covering the theoretical foundations underpinning the work. It begins with the Toyota Production System and Lean Manufacturing as the overarching philosophical framework, before addressing the specific methodologies applied in this project: 5S and SMED. Total Productive Maintenance is also introduced as the broader framework from which OEE is derived. The chapter places particular emphasis on OEE and its six big losses framework, which serves as the primary analytical lens through which machine performance is assessed.

Chapter 3 presents the current state analysis of the Bobst SPO 1600, beginning with a characterisation of the machine and its productive process. The data collection methodology is described, followed by a comprehensive baseline assessment of the machine's performance using the OEE framework, including a detailed downtime analysis and changeover analysis that establish the foundation for the improvement work.

Chapter 4 details the implementation of the improvement initiatives, structured around the OEE components they address. It covers the 5S implementation, availability improvements through SMED and downtime reduction, and performance improvements through the elimination of speed constraints and minor stops.

Chapter 5 presents the results and discussion, evaluating the impact of the implemented improvements against both the company's operational targets and the OEE baseline established in Chapter 3.

Chapter 6 presents the conclusions of the project, summarising the key findings, assessing the degree to which the defined objectives were achieved, identifying directions for future work.

Chapter 2

Literature Review

This chapter reviews the theoretical foundations underpinning the present work, beginning with the Toyota Production System and Lean Manufacturing as the overarching philosophical framework, before addressing the specific methodologies applied in this project.

2.1 The Toyota Production System

The Toyota Production System (TPS) stands as one of the most influential manufacturing philosophies of the twentieth century, fundamentally reshaping how industries worldwide conceptualise production efficiency. Developed in the decades following World War II by Taiichi Ohno, an engineer and executive at Toyota Motor Corporation, the TPS emerged as a direct response to the economic constraints facing Japan at the time. Unlike the mass production model prevalent in Western manufacturing, most visibly associated with Ford's assembly line, Toyota operated in a context of scarce resources, limited capital, and a fragmented domestic market that could not absorb the volume-oriented output that characterised American industry (Ohno, 1988; Toyoda, 1987). These constraints, rather than hindering innovation, acted as the catalyst for a fundamentally different approach to manufacturing.

At the philosophical core of TPS lie two foundational pillars: Just-in-Time (JIT) and *Jidoka*. Just-in-Time is the principle that each process in a production system should produce only what is needed, in the quantity required, and at the exact moment it is required, eliminating the need for large inventories and the inefficiencies they conceal (Ohno, 1988). *Jidoka*, often translated as “autonomation” or “intelligent automation,” refers to the capacity of machines and workers to detect abnormalities and stop production immediately, preventing the propagation of defects downstream (Liker, 2004). Together, these pillars establish a system that is simultaneously lean in its resource consumption and robust in its quality assurance, a duality that would prove highly adaptable across diverse manufacturing environments.

Central to the operationalisation of TPS is the concept of *muda*, the Japanese term for waste. Ohno (1988) identified seven categories of waste that TPS seeks to systematically eliminate: over-production, waiting, unnecessary transportation, over-processing, excess inventory, unnecessary

motion, and defects. The identification and elimination of *muda* became a discipline in itself within Toyota, with workers and managers trained to observe production flows critically and surface inefficiencies that would otherwise remain invisible. This focus on waste is not merely technical but deeply cultural: TPS embeds a mindset of continuous improvement, known as *kaizen*, throughout the organisation, expecting every employee to contribute to the ongoing refinement of processes (Imai, 1986; Toyoda, 1987).

The broader significance of TPS beyond Toyota's own factories was brought into sharp focus by Womack et al. (1990) in their landmark study *The Machine That Changed the World*, which drew on extensive research conducted through the International Motor Vehicle Program at MIT (Massachusetts Institute of Technology). The study provided the first systematic, data-driven comparison of manufacturing performance across the global automotive industry, demonstrating that Toyota's plants consistently outperformed their Western counterparts on key metrics including productivity, quality, and flexibility. Womack et al. (1990) attributed this superiority not to superior technology or scale, but to the organisational and managerial principles embodied in TPS, principles that they argued were transferable to any manufacturing context. This finding marked a turning point in Western industrial thinking, triggering a widespread re-evaluation of production philosophies and laying the intellectual groundwork for what would subsequently be formalised as Lean Manufacturing.

In the context of this thesis, TPS provides the foundational philosophical framework within which subsequent tools and methodologies, including Lean Manufacturing, the Six Big Losses, SMED, and Overall Equipment Effectiveness, are grounded. The emphasis on waste elimination, continuous improvement, and the disciplined analysis of production losses is not simply a methodological choice, but reflects the enduring relevance of TPS principles to modern manufacturing challenges. As will be discussed in the following sections, the application of these principles to capital-intensive converting equipment such as the Bobst SPO 1600 flatbed die-cutter represents a direct continuation of the thinking pioneered by Ohno and his colleagues at Toyota.

2.2 Lean Manufacturing

While the Toyota Production System provided the conceptual and operational blueprint for a new paradigm of manufacturing, its formal introduction to a global audience required translation into a vocabulary accessible to Western industry. This translation was largely accomplished by Womack and Jones (1996) in *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*, which built directly on the findings of their earlier study (Womack et al., 1990) to present a universal framework for applying TPS principles across industries and organisational contexts. The term "Lean," first coined by Krafcik (1988), was adopted to capture the central ambition of the approach, to achieve more with less: less human effort, less equipment, less time, and less space, while delivering ever greater value to the customer (Womack and Jones, 1996). In doing so, Lean Manufacturing established itself not merely as a set of tools borrowed from Toyota, but as a coherent management philosophy with broad industrial applicability.

At the heart of Lean thinking is the concept of value, defined exclusively from the perspective of the end customer. Womack and Jones (1996) argue that the starting point of any Lean initiative must be a precise understanding of what the customer considers valuable, a specific product or service that meets their needs at a specific price and time. Everything within a production system that does not contribute to this definition of value constitutes waste, or *muda*. This value-centric perspective gives rise to the concept of the value stream, the complete sequence of activities required to bring a product from raw material to finished good in the hands of the customer. Mapping this stream reveals three categories of activity: those that add value, those that add no value but are currently unavoidable, and those that add no value and should be eliminated immediately (Womack and Jones, 1996). Value stream mapping thus becomes one of the most powerful diagnostic tools available to the Lean practitioner, enabling organisations to visualise and systematically attack waste across the entire production flow.

Building on Ohno's original seven categories of waste, Lean thinking extended the classification to include an eighth form: the underutilisation of human talent and knowledge (Liker, 2004). The eight wastes of Lean, overproduction, waiting, unnecessary transportation, over-processing, excess inventory, unnecessary motion, defects, and unused talent, provide a comprehensive taxonomy that practitioners can apply systematically to identify and prioritise improvement opportunities. In the context of high-throughput converting equipment such as the Bobst SPO 1600, these categories translate directly into observable operational losses: idle machine time, excessive setup durations, material defects, and underutilised operator knowledge are all recognisable manifestations of waste that Lean thinking seeks to eliminate.

Among the suite of tools that Lean Manufacturing employs to create the conditions for waste elimination, the 5S methodology occupies a foundational role (Imai, 1986; Liker, 2004), providing the organised and standardised workplace environment upon which more advanced improvement initiatives, including SMED and preventive maintenance, can be effectively built and sustained. The methodology and its five sequential disciplines are discussed in detail in Section 2.3.

Although Lean Manufacturing emerged from the automotive sector, its principles have proven highly transferable to a wide range of manufacturing industries. Womack and Jones (1996) documented early applications across aerospace, consumer goods, and industrial equipment, arguing that wherever waste exists, Lean thinking offers a structured path to improvement. In the packaging and converting industry, adoption has been driven by competitive pressures for shorter lead times, greater product variety, and tighter cost control (Liker, 2004). The principles of flow, pull, and continuous improvement are as applicable to a converting press as to an automotive assembly line, and it is within this context that the subsequent tools explored in this literature review (SMED, Total Productive Maintenance, and Overall Equipment Effectiveness) find their industrial relevance.

Despite its widespread adoption, Lean Manufacturing is not without limitations. Successful implementation requires sustained management commitment and a genuine cultural shift at all organisational levels, conditions that are frequently underestimated in practice (Liker, 2004). Furthermore, Lean's emphasis on flow and waste elimination assumes a degree of demand stability

that may not always hold in high-variety environments, where frequent product changes can undermine the standardisation upon which Lean gains depend (Womack and Jones, 1996). These limitations do not diminish the relevance of Lean to the present project, given the stable demand environment and established lean culture at Nova DS Smith Guilhabreu, but they underscore the importance of contextual alignment.

2.3 The 5S Methodology

The 5S methodology is one of the most widely adopted tools within Lean Manufacturing, providing the foundational workplace organisation upon which all other improvement initiatives depend. Originating within the Toyota Production System, 5S is a structured, sequential approach to creating and sustaining a clean, orderly, and standardised working environment (Imai, 1986; Liker, 2004). Its name derives from five Japanese terms, each representing a distinct and progressive discipline, described below.

Seiri – Sort: The first step involves identifying and removing all items from the workplace that are not necessary for current operations. Tools, materials, and equipment that are unused, obsolete, or redundant are either discarded or relocated, eliminating clutter that can obscure problems and impede workflow.

Seiton – Set in Order: Once only necessary items remain, they are arranged logically so that each has a clearly defined and labelled location. The guiding principle is that any item should be retrievable and returnable in the shortest possible time, minimising motion waste and reducing the risk of errors during operations and changeovers.

Seiso – Shine: The workplace and equipment are thoroughly cleaned and inspected on a regular basis. Beyond aesthetics, this discipline serves as an early detection mechanism: routine cleaning exposes leaks, wear, loose components, and other anomalies that might otherwise go unnoticed until they cause unplanned downtime, directly supporting the preventive maintenance goals of TPM.

Seiketsu – Standardise: The gains achieved through the first three steps are codified into written standards, visual controls, and documented procedures. Standardisation ensures that the improved workplace condition does not deteriorate over time and that all operators follow consistent practices, reducing variability in process execution.

Shitsuke – Sustain: The final and most challenging discipline involves embedding the previous four steps as lasting organisational habits through training, regular audits, and management commitment. Without Sustain, 5S programmes tend to regress; with it, the methodology becomes self-reinforcing and forms a durable foundation for continuous improvement (Liker, 2004).

2.4 Single Minute Exchange of Dies

The Single Minute Exchange of Die (SMED) methodology was developed by Shigeo Shingo, a Japanese industrial engineer whose systematic analysis of machine setup operations at Toyota and

in the Japanese steel industry led to one of the most impactful contributions to manufacturing practice of the twentieth century. First conceived in 1950 and formally codified in 1969, SMED takes its name from Shingo's ambition to achieve setup times expressible in a single digit, that is, under ten minutes, a target dramatically demonstrated when a 1,000-tonne press changeover at Toyota was reduced from four hours to three minutes (Shingo, 1985).

At its core, SMED addresses the time during which a machine is stopped to be reconfigured from one product to another. This changeover time encompasses all activities required to transition from the last good part of one run to the first good part of the next (Shingo, 1985). In high-variety manufacturing environments such as cardboard packaging, frequent changeovers represent a critical constraint on machine availability: extended setups reduce productive time and incentivise longer batch runs, reintroducing the inventory waste that Lean Manufacturing seeks to eliminate (Womack and Jones, 1996).

The central insight of SMED is the distinction between internal and external setup activities. Internal setup comprises tasks that can only be performed whilst the machine is stopped, such as mounting dies or adjusting mechanical components. External setup comprises tasks that can be completed whilst the machine is still running, such as retrieving tooling, preparing documentation, or pre-staging materials (Shingo, 1985). In practice, most activities are performed internally by default, meaning the machine remains idle for longer than necessary.

Shingo (1985) formalised SMED as a three-stage process: first, separating internal and external activities through observation and time study; second, converting internal tasks to external ones wherever possible, for instance through pre-assembly of tooling or standardised mounting systems; and third, streamlining all remaining activities by eliminating adjustments, using functional clamps, and standardising tool dimensions. Applied systematically, these stages have been shown to reduce changeover times by 50 to 95 per cent across a wide range of manufacturing contexts (Shingo, 1985; Liker, 2004).

In the context of the Bobst SPO 1600 flatbed die-cutter, SMED is directly applicable to the frequent changeovers between packaging specifications, each requiring the exchange of cutting and creasing tools and mechanical adjustments before production can resume. These changeovers constitute a significant share of total non-productive time and represent one of the most actionable targets for improving the Availability component of OEE, as discussed in Section 2.6.

2.5 Total Productive Maintenance

Total Productive Maintenance (TPM) was developed in Japan during the 1970s by Seiichi Nakajima, drawing on American preventive maintenance concepts and integrating them with the operational philosophy of the Toyota Production System. Prior to TPM, maintenance in most manufacturing environments was predominantly reactive in nature and equipment was repaired after failure, with little systematic effort to prevent breakdowns from occurring in the first place. Nakajima (1988) argued that this approach was fundamentally incompatible with the goals of Lean Manufacturing, as unplanned downtime constitutes one of the most disruptive and costly forms

of waste a production system can experience. TPM established a company-wide framework for equipment management that sought to maximise the productive life and operational reliability of machinery through proactive, disciplined maintenance practices.

The defining characteristic of TPM is the active involvement of machine operators in equipment care. Rather than treating maintenance as the exclusive responsibility of a dedicated technical department, TPM assigns routine inspection, cleaning, lubrication, and minor repair tasks to operators themselves, a discipline formalised as **Autonomous Maintenance** (Nakajima, 1988; Liker, 2004). This shift brings those with the most direct contact with the equipment into the maintenance process, enabling earlier detection of anomalies and deterioration. It also develops a sense of ownership among operators, fostering the sustained attention to equipment condition that underpins long-term performance improvement. This principle closely echoes the *Seiso* discipline of 5S discussed in Section 2.3, where routine cleaning simultaneously serves as an inspection activity.

TPM is structured around five organisational pillars, each addressing a distinct dimension of equipment and production performance: Autonomous Maintenance, Planned Maintenance, Focused Improvement, Early Equipment Management, and Education and Training (Nakajima, 1988). In the context of equipment-intensive manufacturing operations, the pillars of **Autonomous Maintenance**, **Planned Maintenance**, and **Focused Improvement** (*Kobetsu Kaizen*) are particularly relevant. These pillars directly address the reduction of unplanned downtime, the involvement of operators in the day-to-day care of machinery, and the systematic elimination of specific equipment-related losses, all factors with a direct impact on equipment availability and overall OEE performance.

A further contribution of Nakajima's work was the introduction of Overall Equipment Effectiveness (OEE) as the primary metric for quantifying the impact of TPM activities on equipment performance, explored in detail in Section 2.6. In the context of the Bobst SPO 1600 flatbed die-cutter, TPM provides the maintenance and organisational framework within which the improvement initiatives of this thesis are situated. The application of Autonomous Maintenance and Planned Maintenance disciplines to this machine directly supports the reduction of breakdown-related downtime and contributes to the stable operating conditions that both SMED and OEE-based improvement require.

2.6 Overall Equipment Effectiveness and the Six Big Losses

Overall Equipment Effectiveness (OEE) was introduced by Nakajima (1988) as the primary metric for quantifying the impact of Total Productive Maintenance on equipment performance. Since its introduction, OEE has been widely adopted beyond the TPM context as a standalone key performance indicator in manufacturing industries worldwide, valued for its ability to provide a single, comprehensive measure of how effectively a piece of equipment is being utilised relative to its full potential (Dal et al., 2000; Hansen, 2002). Unlike simple productivity ratios, OEE captures losses across three distinct dimensions of equipment performance, making it simultaneously a

measurement tool and a diagnostic framework that directs improvement efforts towards their most impactful targets.

OEE is composed of three multiplicative factors, each capturing a distinct category of equipment loss. **Availability** measures the proportion of planned production time during which the equipment is actually operating, accounting for losses due to breakdowns and setup & adjustment time. **Performance** measures the speed at which the equipment operates relative to its theoretical maximum, capturing losses from idling, minor stoppages, and reduced running speed. **Quality** measures the proportion of output that meets specification on the first pass, accounting for losses from defects, rework, and start-up waste (Nakajima, 1988; Hansen, 2002). The three components are combined multiplicatively to yield the OEE score:

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

The resulting OEE score is expressed as a percentage, where a score of 100% would represent perfect production, no downtime, full speed, and zero defects. In practice, Nakajima (1988) established a widely cited world-class benchmark of 85%, corresponding approximately to Availability of 90%, Performance of 95%, and Quality of 99%. This benchmark provides a meaningful reference point against which the current performance of a given piece of equipment can be assessed, and the magnitude of potential improvement estimated (Dal et al., 2000).

To make OEE actionable as a diagnostic tool, Nakajima (1988) decomposed equipment losses into six categories, known as the **Six Big Losses**, each mapping directly to one of the three OEE components. This classification provides practitioners with a structured lens through which observed production losses can be identified, categorised, and prioritised for improvement. Table 1 presents the Six Big Losses and their correspondence to each OEE component.

Component	Loss Category	Description
Availability	1. Breakdowns	Unplanned stoppages due to equipment failure.
	2. Setup & Adjustment	Time lost during changeovers and adjustments.
Performance	3. Idling & Minor Stops	Brief interruptions that do not require maintenance.
	4. Reduced Speed	Equipment running below its designed ideal cycle time.
Quality	5. Defects & Rework	Output not meeting specification during stable production.
	6. Start-up Losses	Waste generated during warm-up and initial production.

Table 1: The Six Big Losses and their correspondence to OEE components (Nakajima, 1988).

Identifying and classifying losses using the Six Big Losses framework is, however, only the first step, as determining which losses to prioritise for improvement requires an additional analytical tool. The **Pareto analysis** applies the 80/20 principle, first articulated by the Italian economist Vilfredo Pareto and later adopted in quality management by Joseph Juran, to identify the relatively

few loss categories or failure modes that account for the majority of total production loss (Hansen, 2002). By ranking losses in descending order of frequency or impact and overlaying a cumulative percentage curve, a Pareto chart makes immediately visible which losses deserve priority attention. In the context of this thesis, Pareto analysis is applied to OEE loss data collected on the Bobst SPO 1600 to direct improvement efforts towards the highest-impact opportunities, ensuring that resources are allocated where they will generate the greatest gain in equipment effectiveness.

2.7 OEE in the Packaging Industry

Whilst OEE originated within the automotive sector as a TPM metric, its applicability as a performance measurement tool extends well beyond this context. Muchiri and Pintelon (2008) conducted a comprehensive literature review of OEE in the *International Journal of Production Research*, concluding that its three-component structure, availability, performance, and quality, is sufficiently generic to accommodate the loss profiles of any capital-intensive production system, and that the gap between theory and practice is most effectively bridged through systematic loss classification and structured improvement initiatives. This cross-industry applicability has driven the growing adoption of OEE in the packaging and converting sector, where high product variety and frequent changeovers make equipment effectiveness a critical competitive variable.

Empirical studies in packaging manufacturing consistently report OEE values significantly below the 85% benchmark, with availability losses driven by breakdowns and changeover time as the dominant constraint. Hadisaputra and Hasibuan (2022) conducted an OEE and Six Big Losses analysis on blow moulding machines in a plastic packaging company, reporting an average OEE of 56%. Pareto analysis identified breakdown losses and setup & adjustment losses as the two dominant contributors at 36.4% and 20.1% respectively, a loss profile consistent with high-variety converting equipment. Following TPM-based interventions including autonomous maintenance and revised preventive maintenance schedules, OEE increased by 10.6%.

Similar findings are reported by Alvarado-Vasquez et al. (2025) in flexible packaging operations, where an initial OEE of 69.47% was attributed to mechanical misalignments, component wear, and setup times of up to 45 minutes. The application of SMED combined with predictive maintenance yielded a projected OEE increase of 15.53 percentage points and a reduction in setup time from 45 to 20 minutes. Taken together, these studies confirm that availability losses driven by breakdowns and changeover time are consistently the dominant constraint in packaging environments, and that TPM and SMED represent a well-evidenced path to measurable improvement in equipment effectiveness.

Chapter 3

Current State Analysis

This chapter presents the current state analysis of the *Bobst SPO 1600*, beginning with a characterisation of the machine and its productive process. The data collection methodology is then described, followed by a baseline assessment of machine performance using the OEE framework, including a detailed downtime analysis and changeover analysis that together establish the foundation for the improvement work presented in subsequent chapters.

3.1 The Bobst SPO 1600 – Machine Characterisation and Productive Process

The Bobst SPO 1600 is a flatbed die-cutting press manufactured in 1980, making it over 40 years old at the time of this project. Equipped with two-colour printing capability, it is one of the seven transformation machines operating at Nova DS Smith Packaging Guilhabreu.

Despite its age, the machine remains in active operation and handles an important part of the factory's converting volume, processing corrugated cardboard sheets into packaging units across a wide range of product specifications.

Sheet preparation and loading: The productive process on the Bobst SPO 1600 line begins upstream, at the corrugator. For each production order, the corrugator produces pre-cut corrugated cardboard sheets of a defined format, incorporating a 10 mm waste margin at both the leading and trailing edges to account for the mechanical requirements of subsequent processing. These sheets are stored in the WIP warehouse and subsequently transported to the machine line by forklift, where they are deposited onto an automatic lift platform. This lift raises the stack of sheets to the loading height of the Flexo 1575 printer, the first processing station of the line.

Flexo 1575 – Printing: The Flexo 1575, shown in Figure 3, is a flexographic printer physically connected to the Bobst SPO 1600 but technically a distinct machine. It is operated by the machine's lead operator, who manually loads the sheet stack for feeding. The printer draws sheets one at a time through a suction mechanism and applies up to two colours of print using *cliché*

plates. Once printing is complete, the printed sheets exit the Flexo 1575 and fall into the introducer of the Bobst SPO 1600 press, where they accumulate in a buffer before being individually fed into the cutting section.



Figure 3: Manual feeding area and Flexo 1575 printer.

Bobst SPO 1600 – Die-cutting: The Bobst SPO 1600, shown in Figure 4, draws sheets from the introducer one at a time, again through a suction system, and subjects them to three successive mechanical stages. In the first stage, a cutting die simultaneously cuts and creases the sheet according to the packaging specification, defining the shape and fold lines of the finished box. The sheet then passes through two counter plates, which apply pressure to expel the surrounding waste material, the offcuts generated by the cutting operation. Finally, a blanking plate acts on the processed sheet to release the finished units, which fall onto a bundle stacker. The stacker accumulates sheets until a predefined count is reached, at which point the completed bundle is released onto a downstream conveyor.



Figure 4: Bobst SPO 1600 flatbed die-cutting press.

EasyBreak – Box separation: The conveyor carries the bundle to the EasyBreak, a separator unit that is permanently integrated into the line. For orders in which multiple box units are nested within a single sheet, the EasyBreak is programmed to separate the individual boxes; for single-unit-per-sheet orders, the unit remains passive and the bundle passes through unaffected.

Palletising and dispatch: Following the EasyBreak, the finished boxes arrive at the palletising area, where an auxiliary operator manually stacks them onto a pallet according to the required configuration. Once the pallet reaches its defined capacity, the operator releases it onto an automatic conveyor belt, which transports it to the shrink wrap and strapping station before the finished pallet is directed to the finished goods warehouse. Figure 5 shows the EasyBreak and the palletising area.



Figure 5: EasyBreak separator and palletising area.

The line therefore involves the coordinated operation of three physically connected units, the Flexo 1575 printer, the Bobst SPO 1600 press, and the EasyBreak separator, together with manual material handling at both the infeed and the palletising stages. This configuration means that the productive output of the line is jointly determined by the mechanical performance of the machines and by the efficiency of the human operations surrounding them, a characteristic that has direct implications for the analysis of downtime and productivity losses presented in the sections that follow.

3.2 Data Collection Methodology

The data underpinning the analysis presented in this chapter was extracted from PC-Topp, the Manufacturing Execution System (MES) used by Nova DS Smith Packaging Guilhabreu. Specifically designed for the corrugated packaging industry, PC-Topp consolidates production order data, output volumes, machine speed records, setup times, and downtime logs across the plant, providing a structured and reliable basis for operational analysis. In the case of a production disruption,

the transformation area supervisor clean any wrongly logged downtime or shift, ensuring the integrity of the data used in this study. For the Overall Equipment Effectiveness metric, however, PC-Topp does not provide a correctly computed OEE value; the indicator was therefore calculated manually from the raw data extracted from the system, following the methodology described in Section 2.6.

The baseline period selected for this analysis corresponds to the months of January and February 2026. This choice reflects a set of operational and contextual considerations specific to the Bobst SPO 1600. In late October 2025, one of the machine's experienced lead operators retired. The transition to a new operator resulted in a marked and sustained decline in machine performance, attributable to reduced operator experience. The months of October, November and December 2025 are therefore considered unsuitable as a baseline: October and November capture the acute phase of the operator transition, while December is affected by the holiday period and the associated reduction in staffing and production regularity. By January 2026, the new operator had completed two full months of active operation on the machine, rendering the data more representative of the current steady-state conditions under which the improvement project is to be evaluated. Furthermore, from March 2026 onwards, the first improvement actions associated with this project began to be implemented, meaning that data from that period no longer reflects the pre-intervention baseline. **January and February 2026** therefore constitute the most reliable and representative window available for characterising the machine's current state.

For historical context, it is worth noting that in the first half of 2025, the Bobst SPO 1600 operated at performance levels close to the company objective of 900 m²/worked hour, confirming that the company's goal is achievable.

3.3 Current State Overview

The current state of the Bobst SPO 1600 is characterised through a set of key performance indicators extracted from PC-Topp for the baseline period of January and February 2026. These metrics were selected to provide a comprehensive picture of the machine's operational performance across its main dimensions: output, speed, availability, and changeover. Together they define the starting point against which the improvements described in the following chapters are to be measured.

The indicators used are defined as follows. **m²/worked hour** measures the total square metres of corrugated board produced per hour of scheduled production time, including all downtime and stoppages, and represents the primary productivity metric against which the company target of 900 m²/worked hour is defined. **Sheets/worked hour** expresses the number of sheets processed per hour of scheduled production time and complements the m²/worked hour metric by removing the influence of sheet format variation. **Run speed** (sheets/hour during execution) captures the average speed at which the machine operates when actively running, excluding stoppages, and provides an indication of the machine's effective processing rate during productive time. **Downtime %** represents the proportion of scheduled production time lost to unplanned stoppages. **Average**

setup time measures the mean duration of changeover operations between production orders, expressed in minutes. Finally, the **Overall Equipment Effectiveness (OEE)** and its three constituent components, Availability, Performance, and Quality, are presented here as summary indicators of the machine's overall operational efficiency, and are analysed in detail in Section 3.4.

Table 2 summarises the values recorded for each indicator over the baseline period, alongside the company-defined targets where applicable.

Table 2: Key performance indicators for the Bobst SPO 1600 – January and February 2026 baseline.

Indicator	Baseline (Jan–Feb 2026)	Target
m ² /worked hour	639	900
Sheets/worked hour	821	1,140
Run speed (sheets/hour)	1,506	1,800
Downtime %	30.4%	21%
Average setup time (min)	24	24
OEE	34.0%	–
OEE Availability	57.8%	–
OEE Performance	61.8%	–
OEE Quality	95.3%	–

The machine's headline productivity indicator, m²/worked hour, stands at 639 against a company target of 900, representing a gap of approximately 29% below the established objective. A closely related metric, sheets/worked hour, records 821 against a target of 1,140, a shortfall of approximately 28%, consistent with the m²/worked hour gap and confirming that the underperformance is not driven by sheet format variation but reflects a broader loss of productive output.

The machine's run speed during active execution stands at 1,506 sheets/hour against a target of 1,800, a gap of approximately 17%. This indicates that even when the machine is running, it is operating below its target speed, contributing to the overall productivity deficit independently of the time lost to stoppages.

Downtime accounts for 30.4% of scheduled production time against a target of 21%, representing a gap of 9.4 percentage points. The composition and root causes of this downtime are analysed in detail in Section 3.5.

Average setup time stands at 24 minutes, in line with the company target. While the mean changeover duration is therefore currently meeting its objective, a more detailed analysis of changeover time is presented in Section 3.6.

The overall OEE score of 34.0% reflects the combined effect of losses across all three dimensions of equipment effectiveness. A full decomposition and analysis of the OEE components is presented in Section 3.4.

3.4 Overall Equipment Effectiveness Analysis

Building on the operational indicators presented in Section 3.3, this section analyses the performance of the Bobst SPO 1600 through the Overall Equipment Effectiveness framework introduced in Section 2.6, decomposing the machine's productivity losses across the three components of Availability, Performance, and Quality.

The three OEE components were calculated from data extracted from PC-Topp. **Availability** was computed as the ratio of actual running time to scheduled production time, with all logged downtime and setup time deducted. **Performance** was computed as the ratio of actual speed to the theoretical maximum of 2,300 sheets/hour, as recommended by a Bobst technical representative during a factory visit approximately one year prior to this study. Since PC-Topp reports run speed excluding minor stoppages, classifying events of two minutes or less separately, minor stoppage time was added to the run time denominator, yielding an adjusted speed of 1,421 sheets/hour for the months of January and February. This reclassification is consistent with the Six Big Losses framework, under which minor stoppages are attributed to Performance rather than Availability. It should be noted that for the operational KPIs reported in Section 3.3, minor stoppages are included in the unplanned downtime figure for monitoring purposes, whereas for OEE they are reclassified into Performance in line with Nakajima's methodology.

Regarding **Quality**, PC-Topp calculates waste as the difference between sheets received from the corrugator and sheets on the finished pallet, yielding a raw Quality figure of 95.3%. However, operational observation revealed that this figure consistently understates the machine's true quality performance: the corrugator deliberately produces more sheets than required to account for downstream losses, meaning that a substantial share of the waste captured by this calculation originates from corrugator overproduction rather than from defects or rework occurring on the Bobst SPO 1600 itself. The true Quality component is therefore expected to be higher than 95.3%, but cannot be reliably isolated from the available PC-Topp data, as the system does not distinguish between waste generated upstream and waste attributable to the machine. Given this limitation, and since operational observation did not identify quality losses as a significant driver of underperformance on this machine, this study assumes a Quality value of 99%, consistent with the world-class benchmark defined by Nakajima (1988), and concentrates the analysis on the Availability and Performance components. The resulting OEE of 35.4% is presented in Table 3, and the assumed Quality value is used throughout the remainder of the dissertation.

Table 3: OEE results for the Bobst SPO 1600 – January and February 2026 baseline.

OEE Component	Value
Availability	57.8%
Performance	61.8%
Quality (assumed)	99.0%
OEE	35.4%

Availability at 57.8% represents the most significant individual loss, indicating that the machine is actively running for less than three fifths of its scheduled production time. The sources of this availability loss, comprising unplanned downtime and setup time, are analysed in detail in Sections 3.5 and 3.6 respectively.

Performance at 61.8% indicates that even when the machine is running, it operates at little more than half of its theoretical maximum speed of 2,300 sheets/hour, reflecting losses from two distinct sub-causes. The first is reduced running speed: during active execution the machine operates at 1,506 sheets/hour, representing a speed efficiency of 65.5% against the theoretical maximum. The second is minor stoppages – brief interruptions of two minutes or less, automatically logged by PC-Topp separately from formal downtime, which on the Bobst SPO 1600 typically manifest as brief jams on the press or blank separator resolved quickly by the operator. Minor stops account for around 3% of worked hours and, when they are incorporated into the Performance calculation, the effective speed drops to 1,421 sheets/hour, yielding the observed Performance of 61.8%.

Quality at the assumed value of 99.0% is not the primary driver of underperformance on this machine and is therefore not analysed further in this study, with the remainder of this dissertation focusing on Availability and Performance.

The resulting **OEE of 35.4%** is substantially below the world-class benchmark of 85% established by Nakajima (1988). However, this benchmark was defined in the context of modern dedicated production lines and is not considered a realistic target for a machine of the Bobst SPO 1600's age and operating context. Equipment age and high product mix are recognised structural factors that result in materially lower OEE benchmarks than those achievable on modern dedicated lines (Dal et al., 2000). The objective of this project is therefore not to reach world-class OEE, but to close the performance gap against the company's operational target of 900 m²/worked hour, which represents the metric of direct business relevance for Nova DS Smith Packaging Guilhabreu. To reach the company's internal targets, the machine would need to operate at an OEE of around 49%.

3.5 Downtime Analysis

Having established in Section 3.4 that Availability at 57.8% represents the most significant contributor to the low OEE score of the Bobst SPO 1600, this section analyses the composition of the recorded downtime to identify which categories are responsible for the majority of availability losses. Following the Pareto principle, improvement efforts should be concentrated on the relatively few categories that account for 80% of the total stoppage time. Figure 6 presents a Pareto chart of all downtime categories recorded during the baseline period of January and February 2026, ranked by their share of total stoppage time.

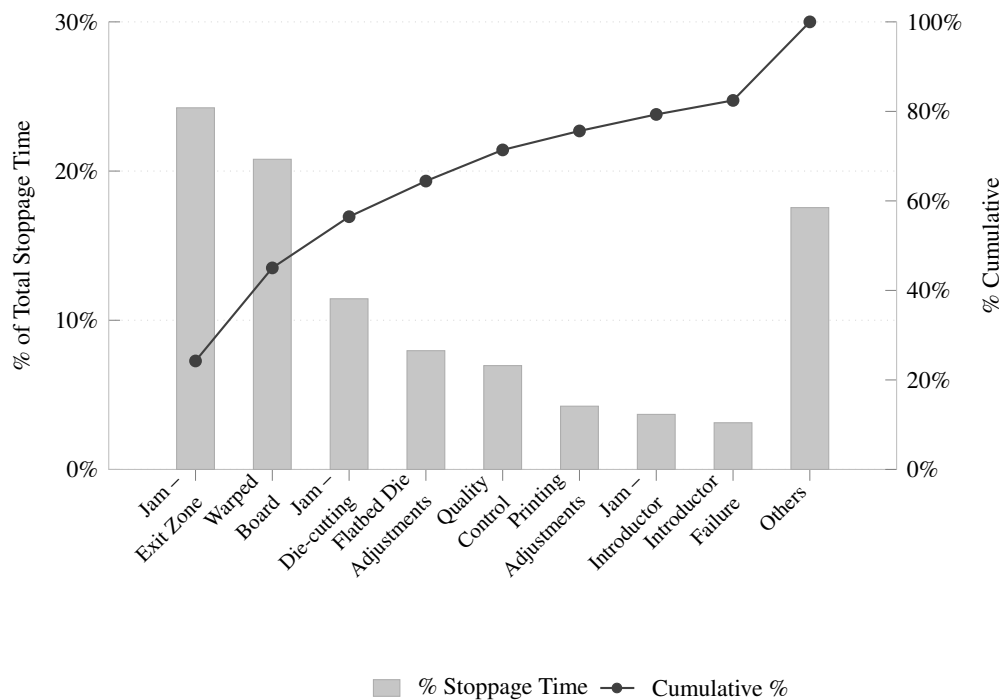


Figure 6: Pareto chart of downtime categories – Bobst SPO 1600, January–February 2026.

The chart reveals that three categories alone account for 56.47% of all recorded stoppage time. **Jam – Exit Zone** is the single largest contributor at 24.24%, representing stoppages caused in the EasyBreak or palletising area. **Warped Board** follows at 20.79%, reflecting stoppages caused by corrugated sheets that arrive at the machine deformed, preventing correct feeding and processing. It is worth noting that warped board is an upstream issue originating in the corrugation and storage process rather than a malfunction of the Bobst SPO 1600 itself; while the machine cannot eliminate this cause entirely, mitigation measures may be possible. **Jam – Die-cutting** accounts for a further 11.44%, corresponding to problems within the cutting section of the press during the die-cutting operation.

Within the 80% Pareto threshold, five additional categories contribute to the remaining share of priority stoppage time. **Flatbed Die Adjustments** at 7.96% represent time lost to mechanical adjustments of the cutting and creasing tools during or between production runs. **Quality Control** stoppages account for 6.96%, reflecting interventions triggered by output quality checks. **Printing Adjustments** at 4.24% correspond to setup and registration corrections on the Flexo 1575 printer. Finally, **Jam – Introducutor** at 3.69% captures stoppages caused by sheets failing to feed correctly into the press at the input stage, while **Introducutor Failure** at 3.13% also reflects problems in the same area. Together, these five categories bring the cumulative total to 82.45% of all recorded stoppage time.

The remaining 17.55%, grouped as Others, comprises a fragmented set of causes that fall below the 80% Pareto threshold and are therefore outside the scope of targeted improvement action in this project.

The Pareto analysis therefore identifies three dominant loss families that collectively drive the majority of availability losses on the Bobst SPO 1600: jamming events across multiple zones of the machine, upstream board quality issues, and mechanical and printing adjustments. The root causes of these categories and the improvement actions implemented to address them are analysed in Chapter 4.

3.6 Changeover Analysis

Changeover operations represent a significant source of availability loss on the Bobst SPO 1600, as each transition between production orders requires the machine to be fully stopped while both operators reconfigure it for the next job. According to PC-Topp, the average setup time recorded during the baseline period was 24 minutes, in line with the company-defined target. However, direct observation and video recording of changeover operations revealed that the actual elapsed time from the last good sheet of the previous order to the first good sheet of the new order averaged approximately 31 minutes in practice.

This discrepancy reflects a systematic practice in which operators manually close the setup event in PC-Topp at 24 minutes and log the remaining time under other stoppage categories – most notably Quality Control and Printing Adjustments – as the startup phase involves trial sheet production and print registration corrections. As a result, the true effective changeover time is approximately 29% higher than reported, and a portion of the stoppage categories identified in Section 3.5 is in reality misclassified setup time.

Figure 7 presents the full breakdown of changeover tasks observed in the current state.

LEAD OPERATOR			AUXILIARY OPERATOR		
ZONE	TASKS	TIME (min)	ZONE	TASKS	TIME (min)
Machine Stop					
Introductor Flexo 1575	Adjust feeder width; Adjust plate height; Load new plate stack; Adjust print roller pressure;	3	Exit	Finish palletising the previous order;	3
Exit	Close previous order;	3	Bobst	Change counter-drawing;	3
Printing	Change cliché plates and inks; Adjust widths and table;	6		Change cutting die;	6,5
Bobst Press Introductor	Adjust sheet joggers; Adjust plate height; Adjust belts;	3		Change counter-plates;	4,5
Printing	Start printing;	2		Change blanking plate;	3
Total:		17	Total:		20
Machine Start					
Exit	Configure EasyBreak	1	Exit	Board FIT test;	2
Bobst	Adjust delivery flap; Extract first bundle;	10			
	Adjust printing; Prepare a quality sample;				
Total: 31 min					

Figure 7: Changeover task breakdown for the Bobst SPO 1600 – current state.

The changeover critical path is determined by the auxiliary operator, who requires 20 minutes to complete the mechanical reconfiguration of the press, followed by an 11-minute startup phase performed by the lead operator, yielding a total observed duration of 31 minutes.

The root causes of this inefficiency and the improvement actions implemented to address them are discussed in Chapter 4.

Chapter 4

Implementation

Building on the current state analysis presented in Chapter 3, this chapter describes the improvement actions implemented on the Bobst SPO 1600 line. The chapter is structured according to the Six Big Losses framework introduced in Section 2.6, which decomposes equipment losses into six categories mapped to the three OEE components. As established in Chapter 3, the machine's OEE of 35.4% reflects significant losses across two of its three components: Availability at 57.8% and Performance at 61.8%, with Quality assumed at 99.0% and not considered a primary driver of underperformance. Improvement actions are accordingly directed at four of the Six Big Losses: Setup & Adjustment and Breakdowns, which drive the Availability gap, and Idling & Minor Stops and Reduced Speed, which drive the Performance gap. Quality losses (Defects & Rework and Start-up Losses) are outside the scope of this project.

Prior to addressing these losses directly, a 5S implementation was carried out on and around the machine line. As discussed in Section 2.3, 5S provides the foundational workplace organisation upon which more advanced improvement initiatives depend, and its implementation here precedes and enables the subsequent actions targeting Availability and Performance. Following the 5S implementation, Availability losses are addressed through two complementary initiatives targeting Setup & Adjustment and Breakdowns respectively, before attention turns to the Performance losses of Idling & Minor Stops and Reduced Speed.

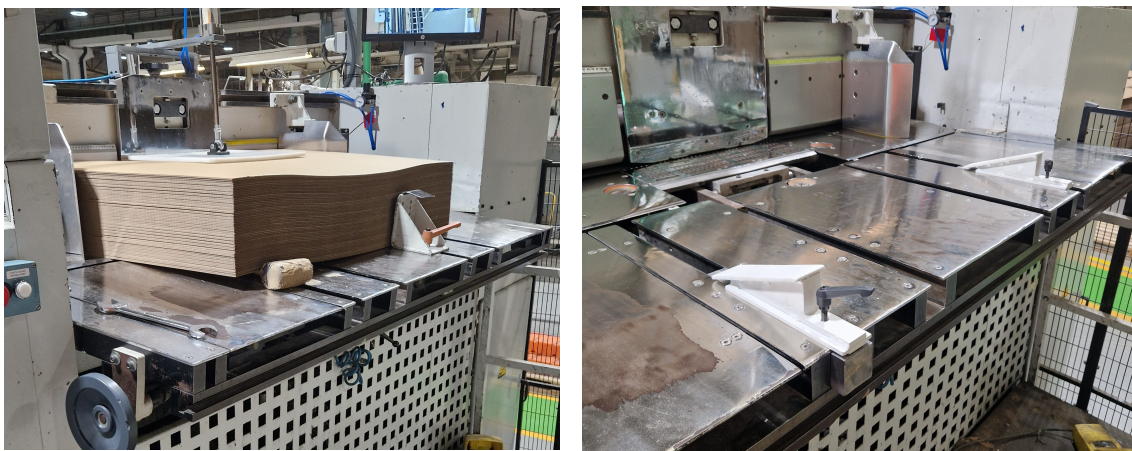
4.1 5S Implementation

The 5S implementation was carried out in close collaboration with the machine operators, whose feedback informed and validated each change, and was structured according to the five sequential disciplines of the methodology.

Seiri – Sort

The first step involved a systematic review of all tools and equipment present in the machine area to identify and remove items that were unnecessary, inadequate, or no longer fit for purpose. Several tools that had fallen out of regular use were removed from the workspace. Two items were identified as inadequate for their intended function and replaced: the introducer ruler, which

had become so worn that its markings were no longer legible, was replaced with a new one to ensure accurate sheet alignment; and the operators' calculator, on which several keys had ceased to function, was replaced to support reliable speed and output calculations during production. Additionally, hammers that operators had been using informally to compensate for warped cardboard at the introducer were replaced with a purpose-built metal support that fits the introducer table and provides the required elevation in a more controlled and appropriate manner, as illustrated in Figure 8. Finally, a review of the tools available at the machine revealed that operators lacked a pair of pliers and cutting pliers, both of which are required for routine operations and minor adjustments. These were procured and added to the workspace, ensuring that operators have all necessary tools immediately at hand.



(a) Before: hammer used for compensation

(b) After: purpose-built metal support

Figure 8: Replacement of hammers with a purpose-built metal support at the introducer table.

Seiton – Set in Order

With only necessary items remaining, the second step focused on reorganising the workspace so that every item has a clearly defined location at or near its point of use. A shadow board was installed for the tools specific to the Bobst SPO 1600 line, providing a dedicated and immediately visible storage location for each item, as shown in Figure 9.

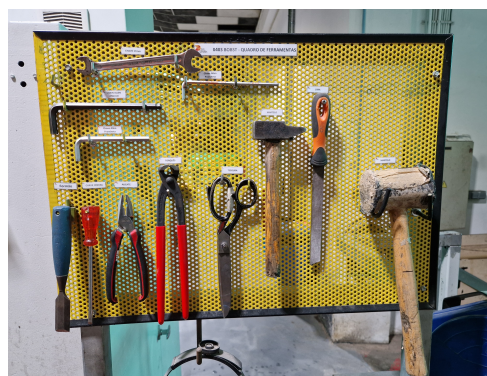


Figure 9: Shadow board for Bobst tools.

The two drawers adjacent to the press, used to store the materials required for fixing cutting dies and counter plates, were reorganised so that their contents are logically arranged, making sure no time is lost looking for materials, as shown in Figure 10.



(a) Reorganised drawer 1

(b) Reorganised drawer 2

Figure 10: Reorganised drawers for die-fixing materials adjacent to the Bobst SPO 1600.

The pallet storage area surrounding the palletising station was redesigned based on direct observation and operator feedback. The previous layout allocated two positions to wooden pallets regardless of size, two to red pallets, two to blue pallets, and two to plastic pallets, as shown in Figure 11.

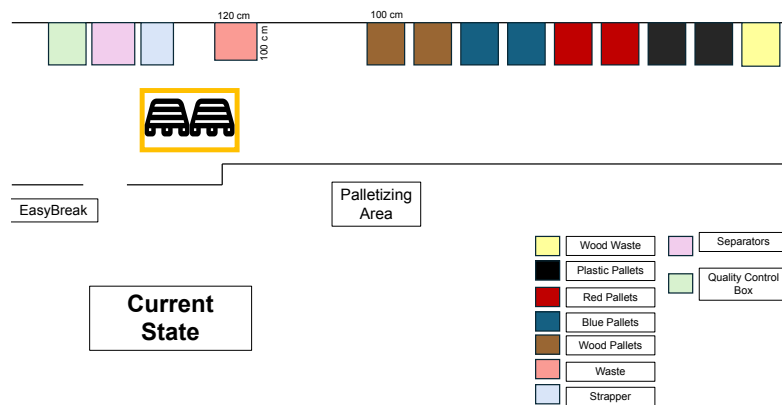


Figure 11: Previous pallet zone layout around the palletising station.

Since wooden pallets are by far the most frequently used, the revised layout doubles their allocated space to four positions (two for 800×1000 mm pallets and two for 1000×1200 mm pallets) by repainting one of the plastic pallet positions, which were rarely used and did not require two dedicated spaces. Red and blue pallet positions were maintained at two each, and plastic pallets reduced to one position. Additionally, the positions for pallets in active use were repainted closest to the palletising station, reducing the physical effort required of the auxiliary operator during production. The revised layout is shown in Figure 12. Dedicated positions were also

labelled for used and unused paint buckets, providing clarity for both machine operators and the replenishment operative.

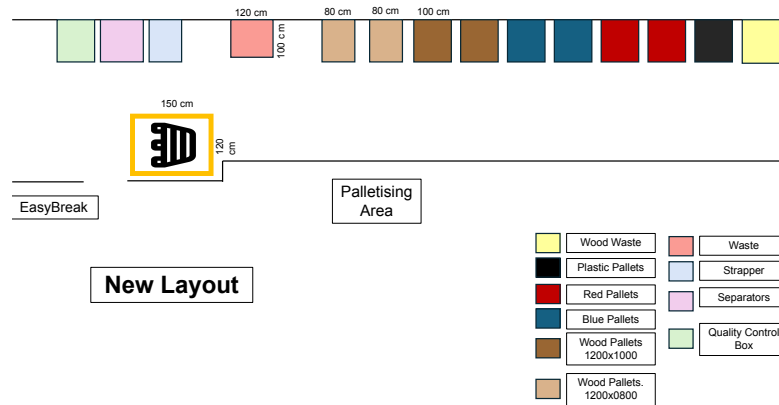


Figure 12: Revised pallet zone layout around the palletising station.

Seiso – Shine

A 30-minute daily cleaning routine had already been established at the machine prior to this project and was maintained throughout. The contribution of the 5S implementation to this discipline was structural: by defining a dedicated floor zone for waste cardboard offcuts generated during production, and by designating a specific location for broken pallets and loose wood, the reorganisation created the physical conditions for operators to maintain a cleaner working environment as a natural consequence of following the new layout, rather than relying solely on individual initiative.

Seiketsu – Standardise

The improvements achieved through the first three steps were codified through visual standards applied consistently across the workspace. Floor zones were painted to demarcate pallet positions by type and size, the waste cardboard area, and the broken pallet location, making the correct state of the workspace immediately visible to any operator. Labels were applied to the shadow board, the reorganised drawers, and all defined floor locations, ensuring that every item and position is unambiguously identified and that the correct arrangement can be restored without reliance on memory or experience.

Shitsuke – Sustain

To verify that the changes implemented were consistently followed, audits were conducted twice a week throughout the remainder of the project. These audits confirmed that all changes were being maintained by the operators, providing evidence that the improvements achieved through the first four disciplines had been successfully embedded into the daily working routine of the machine line.

4.2 Availability Improvements

With the 5S foundation established, attention turns to the two Six Big Losses categories driving the Availability gap identified in Chapter 3. At 57.8%, Availability represents the most significant contributor to the machine's OEE deficit, reflecting losses from both Setup & Adjustment and Breakdowns. The following subsections address each of these categories in turn, beginning with a SMED-based reduction of changeover time and followed by a structured analysis and reduction of unplanned downtime.

4.2.1 Setup & Adjustment – SMED

As established in Section 3.6, the observed changeover time on the Bobst SPO 1600 was around 31 minutes, against a company target of 24 minutes. This gap was compounded by the systematic misclassification of the final 7 minutes of the changeover under the Quality Control and Printing Adjustments downtime categories, obscuring the true cost of Setup & Adjustment losses. Applying the SMED methodology introduced in Section 2.4, the improvement process followed Shingo's three-stage approach to systematically reduce the effective changeover time to the company objective of 24 minutes.

Stage 1 – Separating Internal and External Activities

The first stage involved a detailed mapping of the current state changeover sequence through direct observation and video recording of multiple changeovers on the Bobst SPO 1600 line. Each task performed by both the lead operator and the auxiliary operator was documented, timed, and classified as either internal – requiring the machine to be stopped – or external – capable of being performed whilst the machine is still running. This analysis, presented in Section 3.6 and summarised in Figure 7, established the baseline from which improvement opportunities were identified. The classification revealed that several tasks were being performed internally by default, despite being capable of execution whilst the machine was still running, and that the task sequence was not optimised to minimise the critical path.

Stage 2 – Converting Internal to External

With internal and external activities clearly separated, the second stage focused on converting internal tasks to external ones wherever possible, directly reducing the machine stop time.

The first conversion concerned the lead operator's setup sequence. An analysis of the changeover revealed that the lead operator was waiting for all sheets to clear the press before beginning setup of the Flexo 1575 introducer. By reordering tasks so that the lead operator sets up the introducer while sheets are still passing through the buffer upstream of the press, this preparatory work is completed before the machine stops, saving 3 minutes from the lead operator's critical path.

The second conversion addressed the blanking plate preparation. In the current state, preparation of the blanking plate for the next order was performed internally, requiring the machine to be stopped. By acquiring a second metal bar, the blanking plate for the incoming order can now be prepared whilst the machine is still running, converting this task from internal to external. As

shown in Figure 13, the second bar is already prepared for the next order whilst the other is being used.



Figure 13: Second metal bar enabling external preparation of the blanking plate for the next order.

Stage 3 – Streamlining Remaining Activities

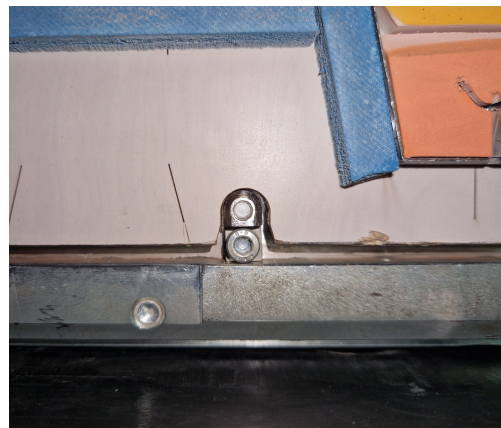
The third stage focused on streamlining the internal activities that remained after conversion, by reallocating tasks between operators, eliminating unnecessary adjustments, improving tooling, and standardising operator knowledge.

The EasyBreak configuration, which in the current state was performed by the lead operator during the machine start phase, was reallocated to the auxiliary operator. Although this task remains internal, its reallocation removes it from the lead operator's critical path, freeing the lead operator to focus on print registration and quality sampling during the startup phase. Auxiliary operators were trained to perform this task independently to support this reallocation.

The flat die table was equipped with new easy-fit positioning pins to speed up mould placement during changeover. The original pins had become so worn as to be unusable, meaning the auxiliary operator was positioning the mould by eye, introducing variability and consuming unnecessary time. The new pins restore precise and repeatable die positioning, as illustrated in Figure 14.



(a) Before: worn positioning pins



(b) After: new easy-fit positioning pins

Figure 14: Replacement of worn positioning pins on the flat die table.

Two tool-related improvements were implemented to reduce the time required for mechanical fastening and unfastening during changeover. First, the small Allen key previously used to fasten

and unfasten bolts on the press was replaced with a larger T-shaped key, providing greater leverage and significantly reducing the effort and time required for each operation, as shown in Figure 15.

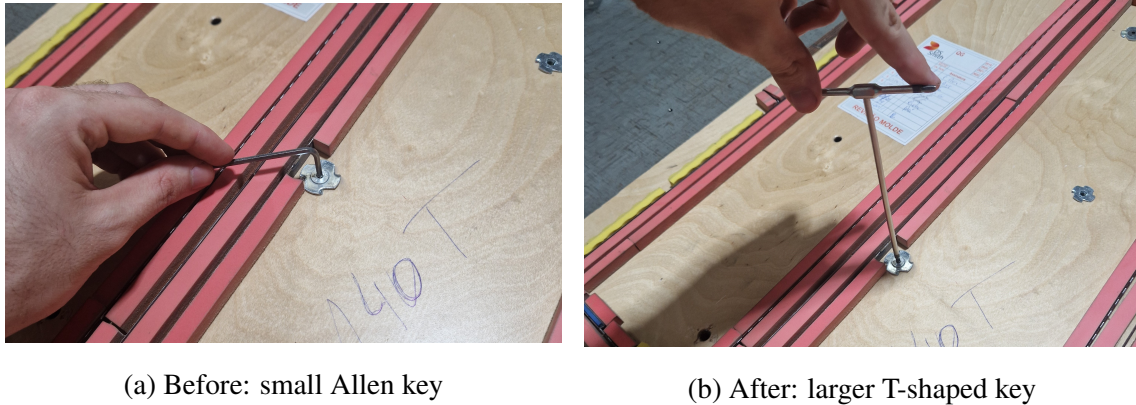


Figure 15: Replacement of the allen key with a T-shaped key for bolt fastening operations.

Second, a bolt inside the Flexo 1575 printer was replaced with an easy-open bolt, eliminating the need for a tool entirely for that operation, as illustrated in Figure 16.

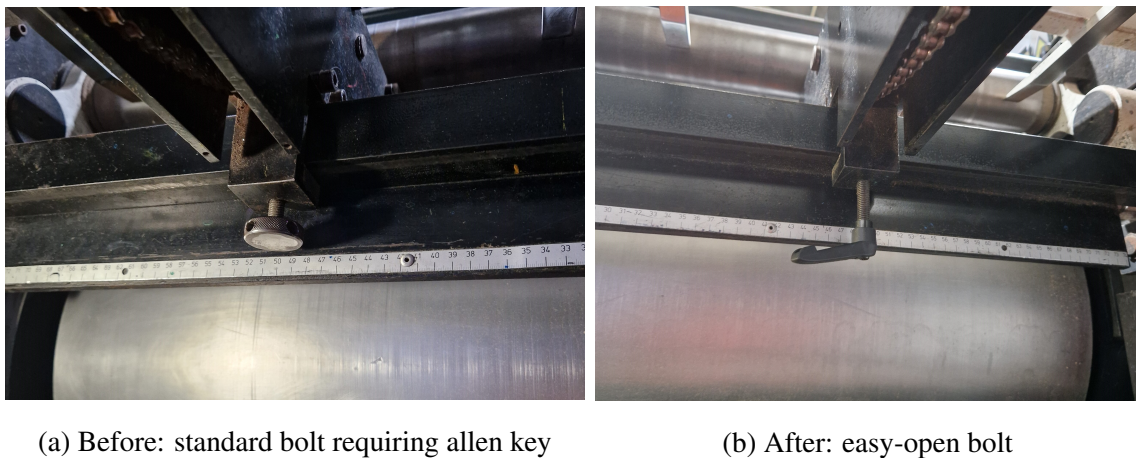
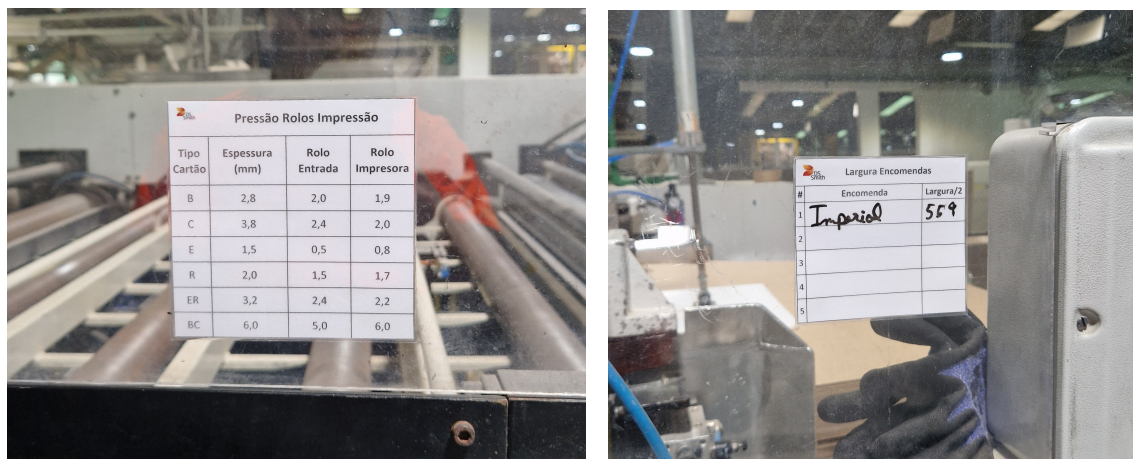


Figure 16: Replacement of a standard bolt with an easy-open bolt inside the Flexo 1575 printer.

Finally, two visual work instruction tables were developed and installed at the machine to standardise operator knowledge and reduce variability during setup. The first specifies the correct printing pressure for each board type (B, C, ER, BC, and others) eliminating the reliance on individual operator experience and reducing the trial-and-error adjustments that previously contributed to the misclassified Quality Control and Printing Adjustments downtime.

The second provides a pre-registration sheet for operators to record the sheet widths of upcoming orders at the start of each shift, avoiding repeated interruptions to consult the production system during changeovers. Both tables are shown installed at the machine in Figure 17.



(a) Printing pressure reference by board type

(b) Sheet width pre-registration table

Figure 17: Visual work instruction tables installed at the Bobst SPO 1600 line.

4.2.2 Breakdowns – Downtime Analysis and Reduction

As established in Section 3.5, the Pareto analysis of downtime categories recorded during the baseline period identified eight priority categories accounting for 82.45% of all recorded stoppage time. Quality Control and Printing Adjustments, which together account for 11.20% of stoppage time, are addressed through the SMED implementation described in Section 4.2.1, as they largely reflect misclassified changeover time. The remaining six categories are addressed in this section. Jam – Exit Zone (24.24%) corresponds to stoppages in the EasyBreak separator or palletising area, including situations where the auxiliary operator cannot keep pace with the output or boxes require revision. Warped Board (20.79%) reflects stoppages caused by deformed corrugated sheets arriving at the machine from upstream processes. Jam – Die-cutting (11.44%) corresponds to sheets or boxes becoming stuck within the cutting and blanking section of the press. Flatbed Die Adjustments (7.96%) represent time lost to mechanical adjustments of the cutting and creasing tools during or between production runs. Finally, Jam – Introductor (3.69%) captures stoppages caused by sheets failing to feed correctly into either the Flexo 1575 or the Bobst press and Introductor Failure (3.13%) reflects mechanical problems in the same area.

A root cause analysis of each category was conducted through direct observation on the shop floor and structured interviews with machine operators, following the *gemba* principle of going to the actual place to understand the actual situation. This analysis revealed that the underlying causes of the priority stoppage categories converged on five critical areas along the machine line: the Flexo 1575 introductor, the Bobst press introductor, the blanking and separator area, the flat die mould adjustments, and the EasyBreak and palletising area. Targeted improvement actions were developed and implemented for each area, as described in the following subsections.

Flexo 1575 Introductor

The root cause analysis of stoppages originating at the Flexo 1575 introductor identified two mechanical faults. The first concerned the pneumatic press responsible for holding sheets down on the introductor table whilst the operator loads a new stack. Observation revealed that the press was occasionally failing to retract when the operator pressed the pedal, preventing sheet loading and causing interruptions. With the support of the maintenance team, it was determined that the pneumatic mechanism was exerting a slight lateral force, preventing the pneumatics from retracting correctly. The misalignment was corrected by maintenance, restoring reliable operation of the press.

The second fault concerned sheet feeding irregularities that were causing sheets to stall or fail to advance correctly into the printer. Observation revealed that the moving plate responsible for advancing sheets into the feed rollers was not level, with the left side sitting lower than the right. This misalignment meant that sheets were not being pushed forward evenly, contributing to inconsistent feeding and stoppages. The plate was levelled, restoring uniform sheet advancement. Figure 18 illustrates the Flexo 1575 introductor with the pneumatic press and moving plate identified.

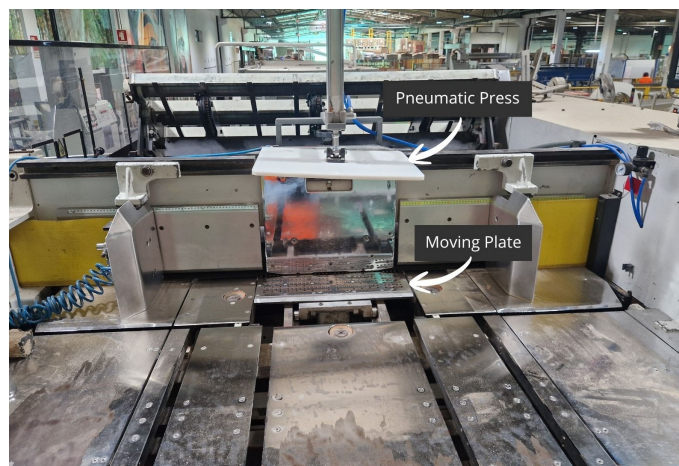


Figure 18: Flexo 1575 introductor showing the pneumatic press and moving plate.

Bobst Press Introductor

Two mechanical issues were identified at the Bobst press introductor through direct observation. The first involved sheets striking a component during feeding rather than passing smoothly through the feed path. Investigation revealed that a small plastic roller positioned immediately before one of the suction cups was sitting lower than the suction cup it preceded, causing incoming sheets to catch on the suction cup. The roller was raised to be level with the adjacent components, eliminating this interference.

The second issue was identified in sheets with a slight upward warp at the leading edge – a frequent occurrence given the warped board identified as a primary stoppage cause – which were consistently missing the machine's claws and jamming at the entry point of the press. The claws are responsible for catching each individual sheet and advancing it into the cutting section, and

any sheet whose leading edge curves upward sufficiently will pass above them rather than being caught. Observation revealed that the metal guide positioned at the claw entry point was too high, failing to deflect the leading edge of warped sheets downward into the claws. The guide was lowered so that it effectively directs incoming sheets into the claws regardless of minor upward warping, significantly reducing the frequency of introducer jams. Figure 19 shows the metal guide at the claw entry point of the press introducer.



Figure 19: Metal guide at the claw entry point of the Bobst press introducer.

Blanking and Separator Area

The root cause analysis of Jam – Die-cutting stoppages identified a longstanding and unresolved mechanical issue in the blanking area of the press. The blanking section consists of an upper blanking tool and a lower piece known as the *guillotine*, which together separate finished box units from the processed sheet. Observation and operator interviews revealed that almost every order required manual repositioning of the upper blanking tool by the operators – an intervention that should not be necessary under normal operating conditions, and one that had persisted unresolved for over a year despite multiple attempts to diagnose it.

The root cause was identified through systematic observation and consultation with the most experienced operator on the line: the *guillotine* had drifted approximately 2 cm out of its correct position. As a result, when a thicker board passed through the press, it displaced the upper blanking tool slightly upward; when a thinner board followed, the gap between the upper and lower pieces was too large to effect clean separation, causing sheets to jam and requiring operator intervention to reposition the tool. The *guillotine* was recalibrated to its correct position and the upper blanking tool was properly secured, eliminating the need for manual adjustment between orders and saving approximately 10 minutes per order across the majority of production runs. Figure 20 shows the blanking tool and *guillotine* area of the press.



Figure 20: Blanking tool and *guillotine* area of the Bobst SPO 1600 press.

A complementary improvement was implemented to reduce the time lost during counter plate adjustments. Operators had been cutting and preparing strips of hard plastic with double-sided tape on the spot whilst the machine was stopped, adding unnecessary time to each intervention. A dedicated drawer was organised with pre-prepared strips ready for immediate use, converting this preparation from an internal to an external activity. A note was placed in the drawer instructing the auxiliary operator to replenish the strips whenever the supply is running low, ensuring continuous availability. Figure 21 shows the organised drawer with the pre-prepared strips.



Figure 21: Drawer with pre-prepared plastic strips for counter plate adjustments.

Flatbed Die Adjustments

Flatbed Die adjustments are an inherent part of the die-cutting process, particularly for new moulds and new orders, as the cutting and creasing tools require fine-tuning to achieve clean cuts and stable box separation. The root cause analysis identified operator inexperience as the primary driver of excessive adjustment time: experienced operators are able to diagnose cutting problems quickly and resolve them at the first attempt, whilst inexperienced operators require significantly more time and multiple interventions to achieve the same result. To address this, a knowledge

transfer initiative was implemented in which a veteran operator from another machine on the shop floor provided hands-on mentoring to the Bobst SPO 1600 operators, transferring diagnostic knowledge and practical adjustment techniques that are difficult to codify but critical to efficient operation.

EasyBreak and Palletising Area

The root cause analysis of Jam – Exit Zone stoppages identified two issues in the EasyBreak and palletising area. The first concerns orders whose box separation dimensions fall below the EasyBreak's minimum capability of 19 mm between separations. For such orders, the EasyBreak cannot perform automatic separation, requiring the auxiliary operator to separate boxes manually, significantly slowing output and occasionally causing exit zone stoppages when the operator cannot keep pace with the volume of boxes. Whilst existing orders of this type could not be modified retrospectively, the issue was escalated to the design office so that new orders are reviewed against the EasyBreak's dimensional capabilities before being accepted, preventing the recurrence of this constraint in future production planning.

The second issue concerned the EasyBreak's separation timer, which was labelled in centimetres but displayed an incorrect scale, meaning operators were systematically programming incorrect separation distances without being aware of it. A corrected conversion scale was designed and installed around the timer dial, ensuring that operators can programme the EasyBreak accurately in centimetres, as shown in Figure 22.

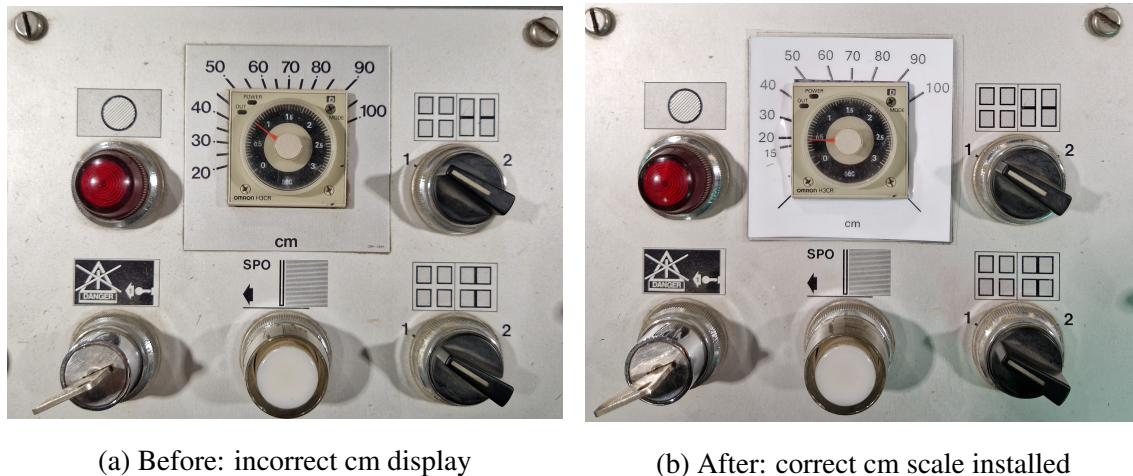


Figure 22: EasyBreak separation timer before and after installation of the centimetre conversion reference.

4.3 Performance Improvements

With the Availability improvements described in Section 4.2 in place, attention turns to the Performance component of OEE, which at 61.8% is also a significant driver of the machine's productivity deficit. As established in Section 3.4, Performance losses on the Bobst SPO 1600 are attributable

to two of the Six Big Losses: Idling & Minor Stops, reflecting brief interruptions of two minutes or less, and Reduced Speed, reflecting the gap between the machine's actual running speed and its theoretical maximum. The following subsections address each of these categories in turn.

4.3.1 Idling & Minor Stops

As described in Section 3.4, minor stoppages on the Bobst SPO 1600 typically manifest as brief jams resolved quickly by the operator, and are classified separately from formal downtime as events of two minutes or less. Rather than treating minor stoppages as a distinct improvement category with its own set of actions, the project adopted a structured approach organised around critical machine areas and their underlying root causes, addressing both major and minor stoppages simultaneously. This reflects the operational reality that minor stops and unplanned downtime frequently share the same root causes: when a fault occurs, the operator may resolve it within two minutes on some occasions, whilst on others the same underlying issue escalates into a longer stoppage as the operator diagnoses what is causing the repeated interruptions and intervenes more substantially.

Three of the mechanical fixes described in Section 4.2.2 have a particularly direct impact on minor stoppages. The levelling of the moving plate at the Flexo 1575 introducer reduces brief sheet feeding failures that require the operator to reset the printer – interventions that typically last between 10 seconds and 1 minute depending on the operator's proximity to the introducer at the time of the fault. The lowering of the metal guide at the Bobst press introducer reduces the frequency of introducer jams that are commonly resolved in under two minutes by removing the stuck sheet and restarting the press. Finally, the recalibration of the *guillotine* and securing of the upper blanking tool in the blanking and separator area addresses both the larger stoppages caused by systematic blanking tool misalignment and the minor stops that occur when a single sheet is not separated correctly and the operator quickly removes it and restarts the machine.

A further source of minor stoppages on the Bobst SPO 1600 concerns brief machine stops caused by throughput limitations along the line – for example, the machine being paused whilst the palletising area is cleared of finished boxes. These stoppages are a direct consequence of speed constraints rather than mechanical faults, and are therefore expected to reduce as a result of the speed constraint improvements described in Section 4.3.2.

4.3.2 Reduced Speed – Speed Constraints

As established in Section 3.4, the Bobst SPO 1600 operated at an average run speed of 1,506 sheet-s/hour during the baseline period (not considering minor stops) – the operational metric reported in PC-Topp and used by operators and management to monitor machine speed – against a target of 1,800 sheets/hour. As a preparatory step for the speed constraint study, a press speed conversion reference was produced and installed next to the speed dial. The machine's speed is set via a dial calibrated on a scale from 1 to 10, but no reference was available to operators indicating the sheets per hour corresponding to each setting. Operators were therefore coordinating press speed

by feel rather than by precise measurement, making it difficult to set and reproduce target speeds consistently. The conversion table, shown in Figure 23, displays the dial level on the left and the equivalent sheets per hour on the right, allowing operators to set and communicate target speeds precisely and providing the common reference needed to conduct the speed observation study in a meaningful and reproducible way.



Figure 23: Press speed conversion reference installed next to the speed dial.

To systematically identify the factors limiting run speed, a structured observation study was then conducted over the course of one week, in which multiple production orders were monitored to determine the maximum achievable speed for each order and the constraint preventing further increase. The observation was recorded using a structured template, the format of which is presented in Table 4.

Table 4: Speed constraint observation template.

Order	Units/Sheet	Maximum Speed	Speed Constraint	Comments

The study revealed that the palletising area was the binding speed constraint in approximately 90% of observed orders. A secondary finding concerned operator confidence: at the time of the study, operators had been habitually running the machine at reduced speeds – typically around 1,700 sheets/hour – partly as a response to the frequent stoppages that had characterised the machine’s performance prior to the downtime improvements described in Section 4.2.2. With those improvements already in place, the observation study provided an opportunity to systematically test higher speeds and observe what constraints actually emerged. In practice, many of the perceived speed limitations proved to be unfounded: increasing speed to 2,300 sheets/hour on appropriate orders did not produce the additional problems operators had anticipated, giving them the empirical evidence needed to operate with greater confidence at higher speeds. It is worth

noting that the target of 1,800 sheets/hour is an average that accounts for the natural variation in run speed across different order types – orders with thick board or a high number of boxes per sheet necessarily run slower, whilst simpler orders can reach the machine's maximum of 2,300 sheets/hour.

Palletising Constraint – EasyBreak Utilisation

The primary palletising constraint was identified in orders with multiple boxes per sheet – typically 7, 9, or in some cases up to 18 boxes – where the separation distance between boxes falls below the EasyBreak's minimum capability of 19 mm, requiring the auxiliary operator to separate boxes manually. In these cases, two distinct problems were observed: either the auxiliary operator alone could not keep pace with the machine's output even at minimum speed, or the lead operator stepped in to assist, requiring them to move repeatedly between the palletising area and the loading area whilst monitoring the order, which is not a safe or sustainable working practice.

To address this, a deep study of the EasyBreak's full capabilities was conducted, revealing that operators had significant gaps in their knowledge of the machine and were manually separating orders that the EasyBreak was in fact capable of handling automatically. Detailed operating instructions with worked examples were developed and made available to operators, enabling them to programme the EasyBreak correctly for a wider range of orders and eliminating unnecessary manual separation. Figure 24 shows the instructions installed at the machine.



Figure 24: EasyBreak operating instructions installed at the machine.

As a further measure, the use of two auxiliary operators simultaneously was evaluated for orders with high box counts. Whilst this arrangement proved effective for the specific orders where manual separation was unavoidable, it was not considered a viable permanent solution: the benefit is limited to a subset of orders, and the financial cost of assigning an additional operator full-time to the line was not justified by the overall performance gain. The trial was therefore discontinued, with EasyBreak utilisation identified as the more sustainable and broadly applicable solution.

Chapter 5

Results and Discussion

This chapter presents the results of the improvement actions implemented on the Bobst SPO 1600 line and described in Chapter 4. Results are evaluated against the baseline period of January–February 2026, which established the machine’s current state KPIs as documented in Chapter 3, and against the company-defined performance targets introduced in Section 3.3.

The evaluation period used to assess the impact of the implemented actions corresponds to weeks 21 to 23 of 2026, covering 18 May to 5 June. This period was selected because it represents the first window in which all improvement actions described in Chapter 4 were fully implemented and operational, making it the most reliable basis for comparison against the baseline. Where weekly trend data is presented, the full monitored period from week 6 to week 23 is shown to provide visibility of the evolution of each indicator throughout the project.

The chapter is structured in three complementary parts. Section 5.1 presents results from the perspective of the company-defined operational objectives, combining a weekly trend chart with a final before/after comparison. Section 5.2 then adopts the OEE framework used throughout this project to decompose the observed improvements into their Availability and Performance components, providing a structured account of which losses were reduced and by how much. Finally, Section 5.3 consolidates the findings from both perspectives into an overall results summary and translates the productivity gains achieved into an estimate of their economic impact for the company.

5.1 Results: Company Objectives Perspective

5.1.1 Weekly Evolution of Productivity

The weekly evolution of the headline productivity indicators from the company objective perspective on the Bobst SPO 1600 line is presented in Figure 25, covering the full monitored period from week 6 to week 23 of 2026.

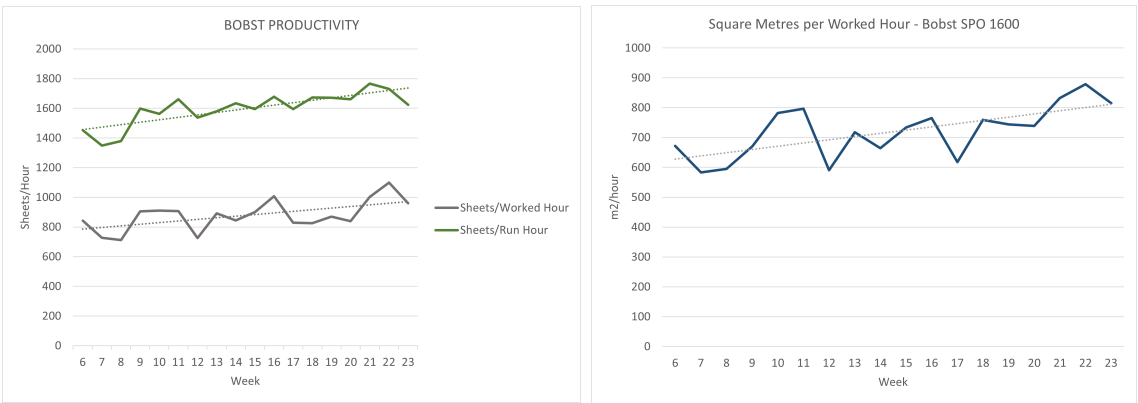


Figure 25: Weekly evolution of productivity indicators on the Bobst SPO 1600 line, weeks 6–23 (2026).

All three indicators display a clear upward trend across the monitored period, confirmed by their respective trendlines. Run speed increased progressively as a result of the speed constraint improvements described in Section 4.3.2, the mechanical fixes implemented along the machine line, and the growing operator confidence in running the machine at higher speeds following the reduction in stoppage frequency. Sheets per worked hour and square metres per worked hour followed a consistent upward trajectory reflecting both the run speed gains and the reduction in unplanned downtime. A period of stagnation is nonetheless visible between weeks 14 and 20, during which the improvement trend temporarily halts despite the actions already being in place.

This stagnation is largely explained by an operator transition that took place during this period. From week 14, a new lead operator began operating the machine, coinciding with the departure of the most experienced lead operator on holiday. Additionally, the experienced lead operator was subsequently required on another machine line for portions of weeks 17, 18, and 20, further limiting the consistency of machine operation during this window. These circumstances were compounded by a concurrent shortage of experienced auxiliary operators, which affected both setup execution and the management of stoppages during production runs. Together, these factors introduced a level of operational instability that constrained the machine’s performance independently of the technical improvements implemented. Stable operating conditions, with a consolidated operator team, were only achieved from week 21 onwards.

5.1.2 Final Results Against Company Targets

Table 5 presents the final results for the evaluation period of weeks 21 to 23, compared against the January–February 2026 baseline across the headline operational indicators.

Table 5: Operational KPI comparison: baseline versus results period.

Indicator	Baseline	Results (W21–23)	Improvement
m ² per worked hour	639	844	+205 (+32.1%)
Sheets per worked hour	821	1,030	+209 (+25.5%)
Run speed (sheets/hour)	1,506	1,732	+226 (+15.0%)
Total downtime (%)	30.4%	25.9%	−4.5pp
Setup time (min)	24.0	22.8	−1.2 (−5.0%)
QC + Print adjustments (% worked hours)	3.10%	2.00%	−1.10pp

The productivity results represent the most significant achievement of the project. Square metres per worked hour increased from 639 to 844, a gain of 205 m²/h corresponding to a 32.1% improvement over the baseline. Sheets per worked hour rose from 821 to 1,030 (+25.5%), whilst run speed increased from 1,506 to 1,732 sheets per hour (+15.0%), reflecting both the mechanical improvements implemented along the machine line and the growing operator confidence in sustaining higher speeds following the reduction in stoppage frequency. These gains are mutually reinforcing: a higher run speed directly increases output per worked hour, whilst the reduction in unplanned downtime ensures that a greater proportion of worked time is spent in active production. The combined effect of these two drivers accounts for the magnitude of the productivity improvement observed.

The company target of 900 m²/worked hour was not fully reached, with a remaining gap of 56 m²/h. This gap is attributable in part to the operator experience constraint described in Section 5.1.1, which limited the machine's performance during a significant portion of the monitored period and continued to exert an influence on the results period through the ongoing development of the auxiliary operator team. As operator experience consolidates and the improvement actions become further embedded in daily practice, continued progress towards the 900 m²/h target is expected. The actions and conditions required to close this remaining gap are discussed further in Chapter 6.

Total downtime decreased from 30.4% to 25.9% of worked hours, a reduction of 4.5 percentage points. This improvement reflects the cumulative effect of the breakdown and SMED actions implemented in Chapter 4, which targeted the priority stoppage categories identified in the baseline Pareto analysis. A detailed decomposition of the downtime reduction by category is presented in Section 5.2, where the new downtime categories are discussed within the OEE framework.

The setup-related indicators provide particularly strong evidence of the effectiveness of the SMED implementation. Setup time as recorded in PC-Topp decreased from 24.0 to 22.8 minutes, meeting and surpassing the company target of 24 minutes. Crucially, the combined weight of Quality Control and Printing Adjustment stops (the two downtime categories identified in Section 3.6 as containing misclassified setup time) decreased from 3.10% to 2.00% of worked hours, a reduction of 1.10 percentage points. This corroborates the argument made in Chapter 4 that a portion of these stops reflected changeover activity recorded under the wrong category, and con-

firmly that the SMED actions reduced not only the formal setup time but also the in-production adjustment stops that had previously inflated these categories. As with the productivity indicators, further consolidation of operator experience is expected to support continued improvement in setup performance, particularly for auxiliary operators whose proficiency in executing the revised changeover sequence continues to develop.

5.2 Results: OEE Perspective

5.2.1 Weekly OEE Evolution

The weekly evolution of the three OEE components monitored throughout the project is presented in Figure 26, covering the full monitored period from week 6 to week 23 of 2026.

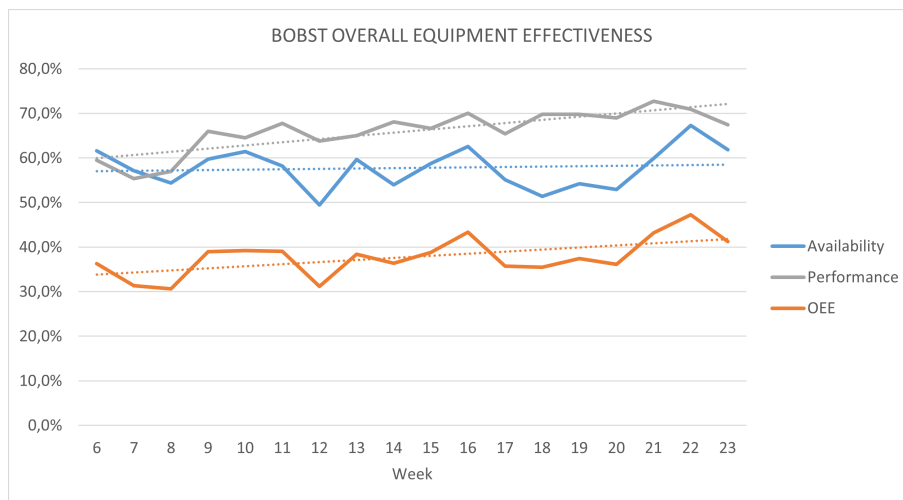


Figure 26: Weekly evolution of Overall Equipment Effectiveness and its components on the Bobst SPO 1600 line, weeks 6–23 (2026).

The two components display markedly different patterns of evolution throughout the monitored period. Performance improved progressively from the early weeks of the project, rising from approximately 61% in week 6 to consistently above 65% by week 10, and reaching values above 70% in the final weeks. This steady upward trajectory reflects the nature of the actions driving Performance gains: the mechanical fixes along the machine line, the speed constraint improvements, and the correction of the EasyBreak utilisation, which took effect relatively early and produced consistent gains throughout the project. Availability, by contrast, showed no meaningful upward trend throughout the majority of the monitored period, oscillating between 50% and 63% from week 6 to week 20 with a trendline that remains essentially flat. From week 21 onwards, Availability reached its highest values of the entire monitored period, reflecting the stabilisation of operating conditions described in Section 5.1.1. Overall OEE followed the combined trajectory of both components, oscillating between 30% and 43% for most of the period before reaching its strongest values in the final weeks.

The divergence between the two components reflects their different response profiles to the implemented actions. The actions targeting Performance produced improvements that are directly observable in the run speed and minor stop frequency from early in the project. The actions targeting Availability – breakdown resolution and SMED implementation – address stoppage categories whose full reduction depends not only on the technical fixes themselves but also on consistent execution in daily production. It is therefore in the final weeks of the project, once all actions were fully embedded and operating conditions had stabilised, that the Availability component reflects the true extent of the improvement achieved, and that the overall OEE reaches its highest recorded values.

5.2.2 Final OEE Results

Table 6 presents the final OEE results for the evaluation period of weeks 21 to 23, compared against the January–February 2026 baseline.

Table 6: OEE component comparison: baseline versus results period.

Component	Baseline	Results (W21–23)	Improvement
Availability	57.8%	62.3%	+4.5pp (+7.8%)
Performance	61.8%	71.9%	+10.1pp (+16.3%)
OEE	35.4%	44.3%	+8.9pp (+25.1%)

Overall OEE improved from 35.4% to 44.3%, a gain of 8.9 percentage points corresponding to a 25.1% relative increase. The following subsections decompose this result into its Availability and Performance components, analysing the specific drivers of improvement in each case.

Availability

Availability improved from 57.8% to 62.3%, a gain of 4.5 percentage points. To understand the drivers of this improvement, Table 7 presents a side-by-side comparison of the downtime categories recorded during the baseline and results periods, expressed as a percentage of worked hours.

Every downtime category directly targeted by the improvement actions described in Chapter 4 recorded a reduction between the baseline and results periods. The two largest absolute reductions were observed in Jam – Exit Zone (–2.10pp) and Warped Board (–2.70pp), which together accounted for 45.0% of baseline stoppage time. The reduction in Exit Zone jams reflects the combined effect of the guillotine recalibration and the securing of the upper blanking tool, which eliminated the systematic misalignment that had been causing sheets to jam at the blanking and separator area on almost every order. The reduction in Warped Board stoppages from 5.70% to 3.00% of worked hours is attributable to a combination of the mechanical adjustment implemented at the Bobst press introducer, which increased the machine’s tolerance to warped sheets by directing their leading edge reliably into the claws, and a possible contribution from improvements in board quality from the upstream corrugator process.

Table 7: Downtime category comparison: baseline versus results period (% of worked hours).

Downtime Category	Baseline	Results (W21–23)	Change
Jam – Exit Zone	6.60%	4.50%	–2.10pp
Warped Board	5.70%	3.00%	–2.70pp
Jam – Die-cutting	3.10%	2.80%	–0.30pp
Flatbed Die Adjustments	2.20%	1.40%	–0.80pp
Quality Control	1.90%	1.40%	–0.50pp
Print Adjustments	1.20%	0.60%	–0.60pp
Jam – Introductor	1.00%	0.60%	–0.40pp
Introductor Failure	0.90%	0.00%	–0.90pp
First Order	0.70%	1.30%	+0.60pp
Die Defect or Missing	<0.50%	1.40%	↑
Print Jam	<0.50%	0.00%	↓
Other Breakdowns	<0.50%	0.70%	↑
Printing Group 2	<0.50%	0.60%	↑
Quality Consultation	<0.50%	0.50%	↑
Subtotal of listed categories	25.10%	19.80%	–5.30pp
Cumulative coverage	82.44%	80.50%	–
Total downtime (all categories)	30.4%	25.9%	–4.50pp

A particularly significant result is the complete elimination of the Introductor Breakdown category, which recorded 0.00% of worked hours in the results period, directly validating the mechanical fixes implemented at both the Flexo 1575 and Bobst press introductors. Flatbed Die Adjustments recorded a reduction of 0.80pp, reflecting the combined effect of the knowledge transfer initiative and the mechanical improvements implemented along the machine line. Jam – Die-cutting recorded the most modest reduction of the targeted categories (–0.30pp), reflecting the fact that whilst the guillotine recalibration addressed one of its primary drivers, die-cutting jams arise from a broader set of causes that were not all within the scope of this project.

The Quality Control and Print Adjustments categories, which together decreased from 3.10% to 2.00% of worked hours (–1.10pp), warrant particular attention in the context of Availability. As established in Section 3.6, these two categories contained a proportion of misclassified changeover time that was systematically recorded as in-production downtime. Their reduction, combined with the decrease in setup time from 24.0 to 22.8 minutes, confirms that the SMED implementation reduced not only the formal changeover sequence but also the setup activity that had previously been absorbed into production time and recorded under these categories, contributing directly to the Availability improvement observed.

The lower section of Table 7 identifies categories that increased or became more visible in the results period. Die Defect or Missing rose to 1.40% of worked hours, reflecting a logistics constraint in the milk run supply process that falls outside the scope of this project. First Order stoppages increased from 0.70% to 1.30%, consistent with a higher proportion of first orders in the production mix during the results period rather than any deterioration in setup performance. Other Breakdowns, Printing Group 2, and Quality Consultation emerged as more visible categories in the

results Pareto, collectively accounting for 1.80% of worked hours. Their increased prominence is in part a consequence of the reduction in the dominant stoppage categories, which allows smaller issues to surface as the next tier of improvement opportunities, a pattern characteristic of progressive lean implementation. The net effect of the reductions in targeted categories and the increases in external categories is a total reduction of 5.30pp across the listed categories, translating into the observed 4.50pp Availability improvement when accounting for all stoppage categories.

Performance

Performance improved from 61.8% to 71.9%, a gain of 10.1 percentage points and the dominant driver of the overall OEE improvement. This gain is reflected in the run speed increase from 1,506 to 1,732 sheets per hour (+15.0%), driven primarily by the resolution of the EasyBreak utilisation constraint identified in Section 4.3.2. As established in Chapter 4, operators had been manually separating orders that the EasyBreak was capable of handling automatically, imposing an unnecessary speed ceiling on a significant proportion of production runs. The deployment of detailed EasyBreak operating instructions enabled operators to programme the machine correctly for a wider range of orders, eliminating unnecessary manual separation and allowing the press to sustain higher speeds across a greater proportion of production time.

The mechanical improvements implemented along the machine line also contributed to the Performance gain through their effect on minor stoppages: brief interruptions of two minutes or less that suppress running time without being classified as formal downtime. Minor stops decreased from 3.1% to 2.7% of worked hours, a modest but positive reduction consistent with the stabilisation of feeding and separation behaviour achieved through the introducer and blanking area fixes. Whilst individually short, the cumulative effect of minor stops on run speed and output is meaningful, and their reduction contributed to the machine's ability to sustain higher speeds more consistently throughout each production run.

A further contributor to the Performance improvement was the shift in operator behaviour with respect to machine speed. As described in Section 4.3.2, operators had been habitually running the press below its capability, partly as a response to the frequent stoppages that had characterised the machine's performance prior to the improvement actions. As mechanical reliability improved and stoppage frequency decreased, operators gained the empirical confidence to run the machine at higher speeds, with the structured observation study providing the evidence base needed to support this behavioural change.

Despite the significant Performance improvement achieved, a residual gap of 3.4 percentage points remains relative to the 75.3% target. This gap is partly structural: orders with a high number of boxes per sheet or with separation distances below the EasyBreak's minimum capability of 19 mm impose a physical limit on the speed at which the auxiliary operator can manage the palletising area, constraining the press speed regardless of mechanical condition. For such orders, the palletising area remains the binding speed constraint, and its full resolution would require either a redesign of the affected orders or additional investment in automated separation capability.

These represent the next logical opportunities for Performance improvement and are discussed further in Chapter 6.

5.3 Results Overview

Having presented the results from both the company objectives and OEE perspectives, this section provides a final synthesis of the findings against each of the defined performance targets. Table 8 summarises the baseline, results period average, company target, and remaining gap for each indicator.

Table 8: Performance indicator comparison: baseline, results period, and company targets.

Indicator	Baseline (Jan–Feb 2026)	Results (W21–23)	Target
m ² /worked hour	639	844	900
Sheets/worked hour	821	1,030	1,140
Run speed (sheets/hour)	1,506	1,732	1,800
Downtime %	30.4%	25.9%	21%
Average setup time (min)	24.0	22.8	24
OEE	35.4%	44.3%	–
OEE Availability	57.8%	62.3%	65.8%
OEE Performance	61.8%	71.9%	75.3%

The results period achieved substantial improvements across every indicator relative to the baseline. Setup time is the only target that was fully met and surpassed, decreasing from 24.0 to 22.8 minutes against a company objective of 24 minutes. Productivity improved markedly, with m²/worked hour increasing by 32.1% and sheets per worked hour by 25.5%, whilst run speed rose from 1,506 to 1,732 sheets per hour, approaching the 1,800 target. OEE improved by 8.9 percentage points, driven principally by the 10.1pp gain in Performance, which at 71.9% is within 3.4 percentage points of its target and represents the strongest relative achievement of the OEE components. Availability improved by 4.5 percentage points, reflecting the cumulative effect of the breakdown and SMED actions implemented throughout the project.

The company targets for m²/worked hour, downtime, and Availability were not fully reached within the project period. The remaining gap in m²/worked hour of 56 m²/h and the 4.9 percentage point gap in downtime are attributable to two principal factors. First, warped board persists as the largest single remaining stoppage category at 3.00% of worked hours, and its full resolution would require intervention in the upstream corrugator process, which falls outside the scope of this project. Second, the auxiliary operator team continues to develop its proficiency in executing the revised changeover sequence and managing stoppages, and further consolidation of operator experience is expected to translate into continued Availability improvement. The actions required to address these remaining gaps are discussed in Chapter 6.

The improvement trend established across the monitored period, combined with the stabilisation of operating conditions from week 21 onwards, provides a solid foundation upon which the remaining targets can be pursued in subsequent improvement cycles. The following subsection translates this productivity gain into an estimate of its economic impact for the company.

5.3.1 Economic Impact

To express the productivity improvement in financial terms, the company's reported open-hour cost rate of 37.37 €/hour is used. This rate represents the fully loaded cost of operating the Bobst SPO 1600 line during its open hours.

The relevant metric for this analysis is productivity expressed in square metres per open hour, calculated by dividing total output by total open hours for each period. During the baseline period, the line produced 525,518 sheets at an average of 0.78 m² per sheet, corresponding to a productivity of 554.7 m²/open hour. During the results period, the line produced 208,227 sheets at an average of 0.82 m² per sheet, corresponding to a productivity of 726.6 m²/open hour. This represents an improvement of 31.0% in output per open hour, consistent with the 32.1% improvement already reported for m²/worked hour in Table 8.

To translate this rate improvement into a monthly economic estimate, the baseline period's average monthly output of 204,952 m²/month is used as a fixed reference volume. At the baseline productivity rate of 554.7 m²/open hour, producing this volume requires approximately 381.3 open hours/month. At the results-period productivity rate of 726.6 m²/open hour, the same volume requires only approximately 291.1 open hours/month, a reduction of 90.2 open hours/month. At the company's open-hour cost rate, this corresponds to an estimated saving of approximately 3,371 €/month, or approximately 40,450 €/year.

This figure should be interpreted as an estimate rather than a precisely quantified saving, as the actual economic gain is also influenced by factors such as month-to-month variation in the average m²/sheet, the number of shifts worked, and the use of overtime hours. It nonetheless provides a concrete indication of the financial significance of the productivity gains achieved, and confirms that the improvement actions implemented on the Bobst SPO 1600 line translate into a meaningful economic benefit for the company.

Chapter 6

Conclusion

This project set out to improve the productivity of the *Bobst SPO 1600* flatbed die-cutting press at Nova DS Smith Packaging Guilhabreu through the structured application of lean manufacturing methodologies, targeting a company-defined objective of 900 m²/worked hour against a baseline of 639 m²/worked hour. The improvement programme was structured around the Six Big Losses framework, with interventions addressing Setup & Adjustment losses through SMED, unplanned downtime through root cause analysis and targeted mechanical corrections, and Performance losses through the resolution of speed constraints and the elimination of unnecessary manual separation activity. Prior to these targeted interventions, a 5S implementation established an organised and standardised working environment, directly fulfilling the sub-objective of workplace organisation and providing the foundation upon which the subsequent improvement actions were built.

The results achieved over the evaluation period of weeks 21 to 23 confirm that the diagnostic and implementation approach was well-founded. OEE improved from 35.4% to 44.3%, driven by a 4.5 percentage point gain in Availability and a 10.1 percentage point gain in Performance. Productivity increased by 32.1%, from 639 to 844 m²/worked hour, and average setup time decreased from 24.0 to 22.8 minutes. Every downtime category directly targeted by the improvement actions recorded a reduction, and the Introductor Failure category was fully eliminated. Expressed in economic terms, the productivity gain corresponds to an estimated saving of approximately €40,450 per year at the company's reported open-hour cost rate, confirming the financial materiality of the improvements achieved.

The company target of 900 m²/worked hour was not reached within the project period; however, the improvement trajectory established, combined with the stabilisation of operating conditions from week 21 onwards, demonstrates that the foundation for continued progress is in place. The residual gap is attributable to two factors: warped board arriving from the upstream corrugator process, which at 3.00% of worked hours remains the single largest stoppage category and lies outside the scope of this project, and the operator team's stability and continued development of proficiency in the revised working methods.

6.1 Future Work

Three recommendations are proposed in order of priority. The most immediate opportunity lies in the continued development of the machine's operator team. For lead operators, the priority is consolidation of machine knowledge and problem-solving capability, specifically the ability to diagnose cutting, feeding, and registration issues quickly and resolve them at the first attempt. Ensuring this knowledge reaches the least experienced operators represents the most direct path to reducing Flatbed Die Adjustment time and unplanned stoppage duration. For auxiliary operators, the priority is the accumulation of experience through repetition: as operators build familiarity with the revised changeover sequence, the EasyBreak procedures, and the rhythm of the machine line, setup times will decrease further and their ability to support the lead operator will increase. Building a stable, experienced team across both roles, reducing rotation and ensuring continuity, is the single most important lever for closing the remaining gap to the 900 m²/worked hour target.

The second recommendation concerns the warped board issue. A structured investigation into the upstream corrugator process to identify and address the root causes of board deformation would directly target the largest remaining stoppage category and represents the natural continuation of this improvement programme.

The third recommendation addresses the residual Performance constraint in the EasyBreak palletising area. For orders with a high number of boxes per sheet or with separation distances below the EasyBreak's minimum capability of 19 mm, the palletising area remains a binding speed constraint that cannot be resolved through process improvement alone. Addressing it would require either a review of the affected order designs or investment in greater separation capability, and represents the next frontier for Performance improvement on the *Bobst SPO 1600* line.

Bibliography

- Alvarado-Vasquez, R., Espinoza-Gonzales, D., Maradiegue-Tuesta, F., and Pinzón-Hoyos, F. (2025). OEE improvement in the peruvian flexible packaging industry through predictive maintenance and SMED. In *2025 IEEE Ninth Ecuador Technical Chapters Meeting (ETCM)*.
- Dal, B., Tugwell, P., and Greatbanks, R. (2000). Overall equipment effectiveness as a measure of operational improvement. *International Journal of Operations & Production Management*, 20(12):1488–1502.
- DS Smith (2017). Box-to-box in 14 days. <https://www.dssmith.com/sustainability/circular-economy/our-business-old/box-to-box-in-14-days>. Accessed: May 2026.
- DS Smith (2025). International paper completes acquisition of ds smith. <https://www.dssmith.com/uk/about-the-international-paper--ds-smith-combination>. Accessed: May 2026.
- FEFCO (2024). About the industry. <https://www.fefco.org/about-fefco/about-the-industry>. Accessed: May 2026.
- Hadisaputra, N. S. and Hasibuan, S. (2022). Analysis of OEE improvements in blow molding machines in the plastic packaging manufacturing industry using six big losses and FMEA methods. In *Proceedings of the International Conference on Industrial Engineering and Operations Management*, pages 1421–1431, Nsukka, Nigeria. IEOM Society International.
- Hansen, R. C. (2002). *Overall Equipment Effectiveness: A Powerful Production/Maintenance Tool for Increased Profits*. Industrial Press.
- Imai, M. (1986). *Kaizen: The Key to Japan's Competitive Success*. McGraw-Hill.
- Krafcik, J. F. (1988). Triumph of the lean production system. *Sloan Management Review*, 30(1):41–52.
- Liker, J. K. (2004). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*. McGraw-Hill.
- Market Data Forecast (2025). Europe corrugated boxes market size, share and forecast. <https://www.marketdataforecast.com/market-reports/europe-corrugated-boxes-market>. Accessed: May 2026.
- Muchiri, P. and Pintelon, L. (2008). Performance measurement using overall equipment effectiveness (OEE): literature review and practical application discussion. *International Journal of Production Research*, 46(13):3517–3535.

- Nakajima, S. (1988). *Introduction to TPM: Total Productive Maintenance*. Productivity Press.
- Ohno, T. (1988). *Toyota Production System: Beyond Large-Scale Production*. Productivity Press.
- Shingo, S. (1985). *A Revolution in Manufacturing: The SMED System*. Productivity Press.
- Toyoda, E. (1987). *Toyota: Fifty Years in Motion*. Kodansha International.
- United Nations (2015). The 17 goals. <https://sdgs.un.org/goals>. Accessed: June 2026.
- Womack, J. P. and Jones, D. T. (1996). *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. Simon & Schuster.
- Womack, J. P., Jones, D. T., and Roos, D. (1990). *The Machine That Changed the World*. Rawson Associates.

Sustainable Development Goals

The United Nations Sustainable Development Goals (SDGs) provide a global framework for evaluating the broader societal and environmental impact of engineering work (United Nations, 2015). Although this project was conducted within the operational context of a single manufacturing facility, the methodologies applied and the results achieved have implications that extend beyond the immediate production setting. Table 9 presents an analysis of the SDGs addressed by this project, identifying the specific targets to which it contributes, the nature of those contributions, and the performance indicators that can be used to measure them.

Whilst the contributions identified are grounded in the specific operational context of Nova DS Smith Packaging Guilhabreu, the methodologies applied in this project (OEE analysis, SMED, and 5S) are broadly transferable across the manufacturing sector. The results achieved on the Bobst SPO 1600 illustrate how lean manufacturing practice, rigorously applied, can simultaneously advance industrial productivity, improve working conditions, and promote more efficient use of resources, demonstrating the alignment between operational excellence and sustainable development.

Table 9: Sustainable Development Goals addressed by this project.

SDG	Goal	Contribution	Performance indicators and metrics
8	8.2 – Achieve higher levels of productivity through technological upgrading and innovation	The application of OEE analysis, SMED, and 5S resulted in a 32.1% increase in machine productivity (from 639 to 844 m ² /worked hour), demonstrating that structured lean practice can deliver significant productivity gains on existing equipment without capital investment.	m ² per worked hour; OEE score; run speed (sheets/hour)
	8.8 – Protect labour rights and promote safe, secure, and decent working environments	The 5S implementation reduced the physical effort and cognitive burden on operators through the replacement of improvised tools with purpose-built equipment, reorganisation of tool storage to minimise unnecessary motion, and reallocation of ergonomically demanding tasks, contributing to a safer and less physically draining working environment.	Number of ergonomic improvements implemented; reduction in unnecessary operator motion; operator feedback on working conditions
9	9.2 – Promote inclusive and sustainable industrialisation and raise industry's share of employment and GDP	Improving the performance of a 40-year-old machine through process improvement rather than asset replacement demonstrates that industrial competitiveness can be sustained without new capital investment, supporting the long-term viability of the operation and the employment it sustains.	m ² per worked hour; OEE score; total downtime (%)
	9.4 – Upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency	The application of TPM, SMED, and OEE improvements to a die-cutting press improves resource-use efficiency of existing equipment. Reducing unplanned downtime by 4.5 percentage points and increasing machine utilisation extends the productive life of the asset, deferring the environmental and financial cost of replacement.	OEE Availability (%); total downtime (%); average setup time (min); reduction in breakdown frequency
12	12.2 – Achieve sustainable management and efficient use of natural resources	By producing more output per unit of machine time, the improvements achieved reduce the energy, raw materials, and labour consumed per square metre of board produced. The productivity gain from 639 to 844 m ² /worked hour means the same production volume is achieved with fewer worked hours and lower resource consumption per unit of output.	m ² per worked hour; energy consumption per m ² produced (kWh/m ²); reduction in worked hours required to meet production targets
	12.5 – Substantially reduce waste generation through prevention, reduction, and reuse	Reducing unplanned stoppages and mechanical misalignments decreases waste from defective board, trial sheets during changeovers, and idle machine time. The SMED implementation reduces trial sheet production during startup, whilst the blanking area corrections eliminate sheet jams and separation failures that previously generated scrap output.	Reduction in Quality Control downtime (% worked hours); reduction in Print Adjustments downtime (% worked hours); setup time (min)