



# Evaluating Lean and Agile Manufacturing Systems in Textile Printing Production

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**Abstract.** The rapid evolution and intensifying competition within the textile industry necessitates production systems that are not only efficient but highly adaptive. This study introduces a novel approach by integrating Lean Manufacturing and Agile Manufacturing principles specifically within the textile printing process, an area that has been less explored. Lean strategies, centered on Overall Equipment Effectiveness (OEE) and the Six Big Losses model, were utilized to systematically eliminate inefficiencies. Simultaneously, an Agile Manufacturing framework, structured around Agility Drivers, Capabilities, and Providers, was deployed to boost responsiveness to dynamic market demands, particularly from the fast fashion sector. Addressing the major bottleneck of extended machine setup times and suboptimal equipment performance in conventional operations, the research applied Single Minute Exchange of Dies (SMED) techniques and agile constructs directly on the production floor through a constructive research methodology. The outcomes reveal significant gains in both setup speed and operational flexibility, marking a pioneering step toward transforming traditional textile production into a more agile and competitive model. This work provides a fresh strategic roadmap for adapting legacy systems to the realities of today's volatile markets.

**Keywords:** Lean Manufacturing, Agile Manufacturing, Textile Printing.

## 1 Introduction

The textile industry remains one of the most vital sectors contributing to national economic growth and employment, especially in developing countries. However, in recent years, this sector has faced increasing pressure due to globalization, shifting consumer preferences, and the rise of fast fashion, which demands rapid design changes, shorter product life cycles, and more frequent production adjustments. Within this context, the printing process in textile manufacturing stands out as a critical area, characterized by high product variation, frequent changeovers, and complex coordination across functions. These conditions create significant challenges in maintaining efficiency, consistent quality, and timely delivery, particularly when relying on conventional production systems.

To overcome such challenges, Lean Manufacturing has been widely adopted for improving operational efficiency through waste reduction and structured process

improvement techniques such as Overall Equipment Effectiveness (OEE), Value Stream Mapping, and Single Minute Exchange of Dies (SMED). Meanwhile, Agile Manufacturing has emerged as a complementary approach that enhances an organization's flexibility and responsiveness to market changes by focusing on capabilities such as speed, adaptability, and cross-functional integration. While both approaches have been proven effective independently, the integration of Lean and Agile in a unified framework remains limited in current literature, particularly within the context of printing processes.

Several research gaps have been identified through a review of existing studies. First, most prior research treats Lean and Agile Manufacturing as separate paradigms, resulting in a lack of comprehensive frameworks that evaluate their synergistic application. Second, few empirical studies have applied Lean–Agile integration specifically to textile printing, despite its unique production characteristics such as design variability, short lead times, and dependency on skilled labor. Third, while SMED is commonly used as a Lean tool to reduce setup time, its potential role in enhancing agility within production systems has received little attention. Finally, existing evaluations often focus solely on technical metrics, overlooking organizational readiness, cultural factors, and workforce involvement, which are critical enablers of sustainable manufacturing transformation. This research employs a mixed-methods approach combining real-time operational data and organizational assessments to produce a holistic evaluation model. The findings are expected to provide both theoretical contributions and practical guidance for transforming conventional textile production into a leaner, more responsive, and competitive system aligned with the demands of the modern fashion industry.

## 2 Literature Review

This chapter presents several relevant theories related to Lean Manufacturing, Agile Manufacturing, Single Minute Exchange of Dies (SMED), Overall Equipment Effectiveness (OEE), and the Agile Manufacturing framework. Additionally, this chapter reviews previous studies that are closely aligned with the topic of integrating Lean and Agile approaches within the textile printing production process.

Previous studies have shown that Lean implementation can improve productivity through systematic waste elimination and process standardization [1], [2]. In particular, SMED has been widely applied to reduce setup and changeover time in various manufacturing contexts [3]–[5]. More recent applications confirm that SMED can be combined with other lean tools to strengthen flow and reduce downtime on production floors [6]–[12]. Case-based evidence also highlights practical enablers and barriers when implementing lean in specific industries [13]. In addition, agile and lean concepts have been discussed as complementary managerial approaches for improving responsiveness and learning in organizations [14].

## 2.1 Lean Manufacturing

Lean manufacturing is a systematic approach aimed at identifying and eliminating waste (non-value-added activities) through continuous process improvement, ultimately delivering perfect products to customers. It encompasses the reduction of all forms of waste, including material and time inefficiencies, both of which are regarded as waste within the lean framework. Lean manufacturing primarily emphasizes enhancing lead times, improving quality, and reducing operating costs, with active employee participation being essential for its success. Fundamentally, lean manufacturing seeks to minimize the time between customer order and product delivery by systematically removing sources of waste.

**Single Minute Exchange of Dies (SMED).** Single Minute Exchange of Dies (SMED) is a lean manufacturing technique used to reduce the time required for equipment changeover. It focuses on separating internal setup activities (those that can only be performed when the machine is stopped) from external ones (those that can be done while the machine is running) and simplifying both. By applying SMED, companies can significantly decrease machine downtime, increase flexibility, and enable faster transitions between different product designs or orders. In this study, SMED is crucial for reducing setup times during printing motif changes, which directly improves production responsiveness.

**Overall Equipment Effectiveness (OEE).** Overall Equipment Effectiveness (OEE) is a standard for measuring the productivity of manufacturing equipment. It combines three essential factors: Availability (machine uptime), Performance (production speed), and Quality (good output versus defects). A high OEE score indicates that equipment is being used efficiently, producing high-quality products quickly with minimal downtime. In this research, OEE is used to assess the current performance of the textile printing machines and evaluate improvements after Lean and Agile strategies are applied.

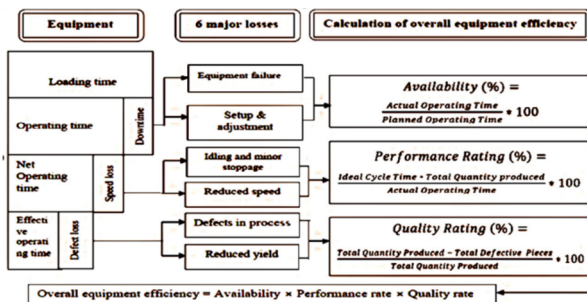


Fig. 1. Calculation of OEE from three factors

Fig. 1 presents the losses during the production process (man/machine/material) and thereafter eliminate them, losses are divided into 16 different categories, and they are accordingly grouped. Among these 16 losses, Nakajima [15] classified six big losses in order if they had to be eliminated and did not consider all the factors reducing capacity utilization such as planned downtime, lack of material, labor, etc.

This research focuses on the production process within the printing division of a textile manufacturing company, specifically covering the stages from pretreatment and preparing to final evaluation in the finishing process.

**Pareto Diagram.** The Pareto Diagram is a quality tool used to identify the most significant factors contributing to a problem. It is based on the 80/20 rule, which suggests that roughly 80% of problems are often caused by 20% of the causes. In this study, the Pareto Diagram helps prioritize the main sources of downtime and defects in the printing process, guiding which problems should be addressed first to achieve maximum improvement with the least effort.

## 2.2 Agile Manufacturing

Agile Manufacturing focuses on building a production system that is highly flexible, responsive, and capable of adapting to rapid market changes. To support this agility, several key tools and frameworks are applied, particularly those that emphasize organizational capabilities and quick responsiveness. In this study, the Agile Manufacturing framework is utilized by assessing three main components—Agility Drivers, Agility Capabilities, and Agility Providers—as summarized in Table 1. Together, these elements create a foundation for a production system that can adapt quickly to variations in customer demand and frequent design changes.

**Table 1.** Agile Manufacturing Components

Component	Description	Examples
<b>Agility Drivers</b>	Factors that trigger the need for change and agility	Fast-changing customer demands, market competition, technology shifts, economic volatility.
<b>Agility Capabilities</b>	Internal strengths that enable rapid and effective response to changes	Fast setup changes, flexible production lines, quick decision-making, cross-functional teamwork.
<b>Agility Providers</b>	Resources and systems that support the development of agility	Skilled operators, flexible printing technology, integrated production planning systems, agile organizational structures.

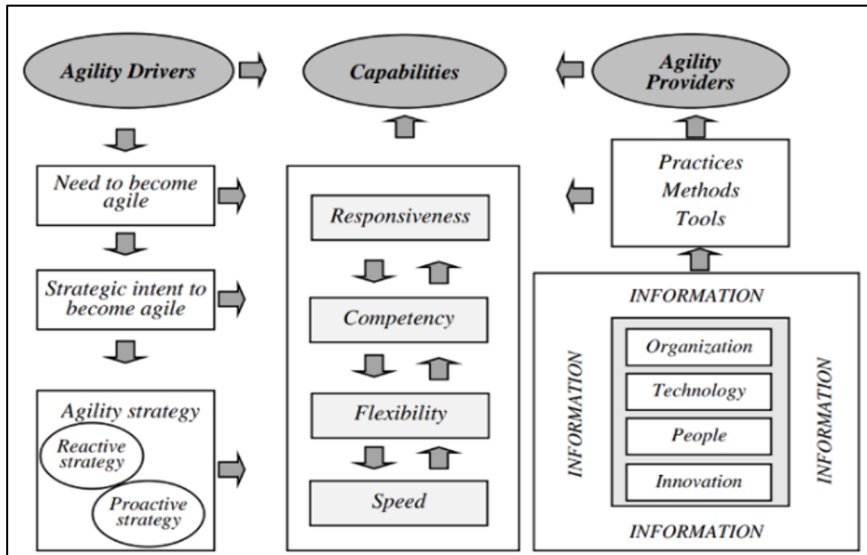


Fig. 2. Agility Conceptual Model

Fig. 2 describes the conceptual model of agility by Zhang and Sharifi [16] and illustrates the essential elements required to build an agile manufacturing organization. It consists of three main components: Agility Drivers, which are the internal and external factors (such as technology shifts) that create the need for agility; Agility Capabilities, which refer to the organization's ability to respond through responsiveness, competency, flexibility, and speed; and Agility Providers, which are the supporting elements tools, methods, practices, and resources that enable agility. These providers span across four key dimensions: organization, technology, people, and innovation. Information flows continuously between these elements, enabling coordination, learning, and rapid adaptation to change.

### 2.3 Methodology

**Data Collection.** Data collection was carried out to obtain detailed information regarding the causes of inefficiency and performance losses. In this study, data was collected over the period of 2024 to identify major factors contributing to the low Overall Equipment Effectiveness (OEE) of the Zimme printing machine, calculation of OEE is detailed below. The production operation runs on three shifts per day, each shift lasting 8 hours, resulting in 24 hours per day (implementation in machine fig 3).



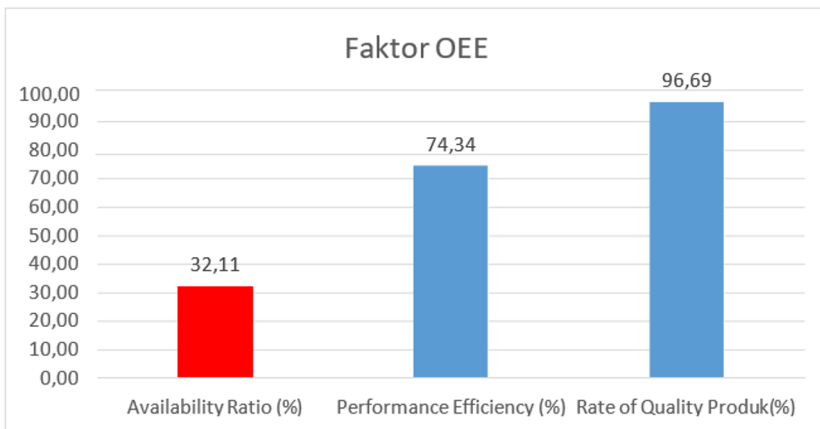
**Fig. 3.** Zimmer Printing Machine

**Identification of Loss in Productivity.** Using the standard OEE equations (Table 2):

**Table 2.** OEE Factors Equations

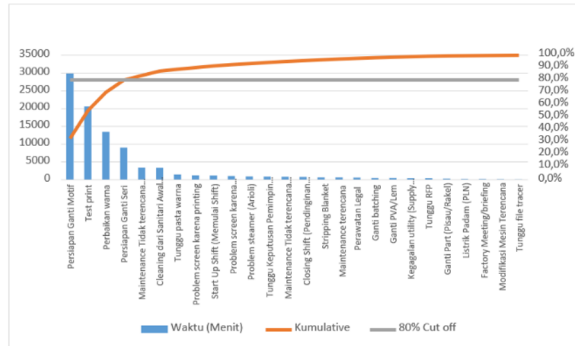
No.	Standard Range	Equations
1.	Availability Rate (AR)	$\bullet = \text{Operating Time} / \text{Loading Time} = 32.11\%$
2.	Performance Rate (PR)	$\bullet = (\text{Ideal Cycle Time} \times \text{Output}) / \text{Operate Time} = 74.34\%$
3.	Quality Rate (QR)	$\bullet = \text{Good Output} / \text{Total Output} = 96.69\%$
4.	OEE	$\bullet = \text{AR} \times \text{PR} \times \text{QR} = 34.90\% \times 74.34\% \times 93.39\% = 24.2\%$

This OEE value is significantly below the ideal standard of 85% recommended by the Japan Institute of Plant Maintenance (JIPM) [17], highlighting the urgent need for improvement actions.



**Fig. 4.** Breakdown of OEE Factors: Availability, Performance, and Quality

**Identification of Major Losses by Pareto Analysis.** Based on the Pareto principle (80/20), which suggests that 20% of causes often contribute to 80% of the impact, the analysis identified four critical sub-activities that represent the highest contributors to production time losses in the printing process. These are: Motif changeover preparation (29.785 minutes), test printing (20.522 minutes), color correction (13.365 minutes), and series changeover preparation (8.967 minutes). The cumulative time lost in these four activities represents the dominant portion of total downtime, as shown in the Pareto chart, and indicates clear priorities for improvement.

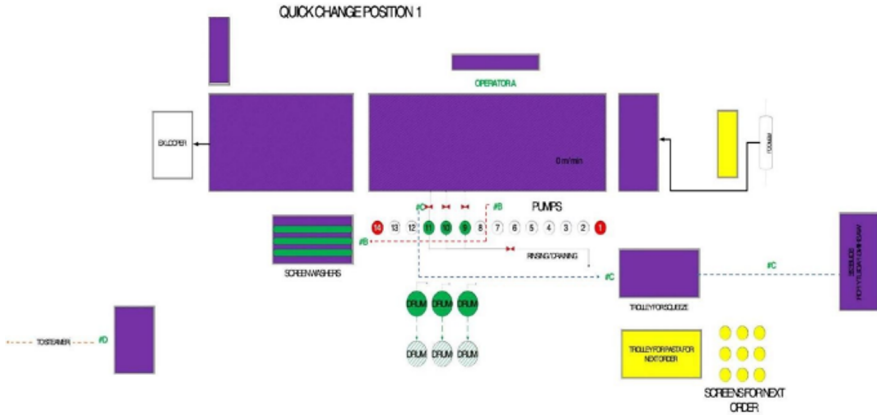


**Fig. 5.** Pareto of Sub-Activities and Major Time Losses

Fig. 5 describes significantly three out of these four major contributors fall under the "Setup and Adjustment" category, which includes preparatory tasks required before production can begin. These findings emphasize the importance of optimizing setup processes as a strategic target for reducing downtime.

## 2.4 Results and Discussion

**Lean Manufacturing Implementation - SMED (Single-Minute Exchange of Dies).** SMED is one of several lean manufacturing techniques aimed at minimizing waste within production processes, and it has a significant influence on various industries, including motif changeover preparation.



**Fig. 6.** SMED Conceptual Stages Practical Techniques in Zimmer Printing

The concept from Fig. 6 describes, SMED implementation procedure is classified into four separate stages:

- Stage 1: Identifying and separating internal and external setups.

The initial observation results and the classification of each changeover activity as internal or external are summarized in Table 3.

**Table 3.** Classification of Activities Before SMED

No	Description	Before Type of Process
1	Open pump valve and prepare paste priming	Internal
2	Return empty trolley	External
3	Transport printed fabric to steamer	External
4	Take squeegee to wash trolley and clean it	External
5	Take screen and insert into format	External
6	Prepare next screen	External
7	Prepare next paste	External
8	Clean the screen	Internal
9	Sew priming/production fabric	Internal
10	Install/mount screen (with another operator)	Internal
11	Arrange squeegee onto trolley	External
12	Arrange screen onto screen rack	External
13	Place remaining paste drum onto trolley	External
14	Install/mount squeegee	Internal
15	Install drum and hose for paste	External
16	Return empty paste drum to paste kitchen	External
17	Return screen to engraving area	External
18	Ready at southern position	External
19	Ready at northern position	External
20	Ready at plaiter position	External
21	Monitor production	Internal
22	Check test print results via steaming and washing dry	Internal

- Stage 2 : Transforming Internal Activities into External Activities.

As shown in Table 4, during the motif changeover process on the Zimmer printing machine, several tasks initially performed while the machine is stopped can be shifted to external activities. Although both internal and external tasks consume time, transferring certain internal activities—such as screen preparation, paste material setup, and equipment cleaning—to external preparation significantly increases machine availability between orders. Many external activities, including material handling, tool organization, and preliminary cleaning, are typically not visible during internal setup but play a critical role in reducing overall changeover time and enhancing production efficiency.

**Table 4.** Classification of Activities Before and After SMED

No	Description	Before Type of Process	After Type of Process	Improvement
1	Open pump valve and prepare paste priming	Internal	External	Prepare paste priming externally before changeover
2	Return empty trolley	External	External	Standardize trolley return process and optimize material flow
3	Transport printed fabric to steamer	External	External	Organize better fabric flow to steamer to avoid delays
4	Take squeegee to wash trolley and clean it	External	External	Use quick-wash equipment or automate cleaning process
5	Take screen and insert into filmat	External	External	Prepare screens beforehand and store near filmat
6	Prepare next screen	External	External	Pre-stage next screen during running production
7	Prepare next paste	External	External	Pre-stage paste material before the next order
8	Clean the screen	Internal	External	Use pre-washed screens to reduce in-process cleaning time
9	Sew priming/production fabric	Internal	External	Train operator on quick sewing techniques
10	Install/mount screen (with another operator)	Internal	External	Provide ergonomic tools for faster screen installation
11	Arrange squeegee onto trolley	External	External	Arrange squeegee storage area closer to working point
12	Arrange screen onto screen rack	External	External	Organize screen racks by order sequence
13	Place remaining paste drum onto trolley	External	External	Optimize leftover paste handling with standardized carts
14	Install/mount squeegee	Internal	External	Use assistive tools to speed up squeegee installation
15	Install drum and hose for paste	External	External	Standardize drum and hose setup templates
16	Return empty paste drum to paste kitchen	External	External	Introduce quick-release systems for paste drums
17	Return screen to engraving area	External	External	Create fast return lanes for screens
18	Ready at southern position	External	External	Mark ready positions clearly for efficient handoff
19	Ready at northern position	External	External	Mark ready positions clearly for efficient handoff
20	Ready at plaiter position	External	External	Mark ready positions clearly for efficient handoff
21	Monitor production	Internal	External	Standardize production monitoring checklist
22	Check test print results via steaming and washing dry	Internal	External	Develop quick visual inspection and feedback loop

- Stage 3: Reorganizing Setup Activities.

It is essential to organize the working environment by positioning tools, screens, and paste materials as close as possible to their point of use. Ensuring that all machines, fixtures, and setup aids are fully operational is critical. Simplifying setup adjustments—such as implementing quick-lock mechanisms, alignment jigs, and pre-calibrated fixtures—can significantly reduce internal setup time and avoid unnecessary rework, ultimately improving overall changeover efficiency.

- Stage 4: Performing Setup Activities in Parallel.

Enhancing the setup process also involves enabling parallel activities where multiple operators prepare different components simultaneously. Standardization of screens, paste containers, and support equipment allows setup tasks to be performed faster and more efficiently. Documenting standard setup procedures provides a reference for operators and maintenance teams, facilitating continuous improvement and ensuring that best practices are consistently applied during motif changeovers on the Zimmer machine.

## 2.5 Agile Manufacturing Implementation

**Agility Drivers.** Agility Drivers are the internal and external forces that trigger the need for agility in manufacturing operations. These drivers may include operational inefficiencies, technological advancements, customer quality demands, and environmental variability.

The instability of dryer temperature during the textile printing process acts as a significant internal driver, as it leads to fabric defects (stains) and increased production costs due to rework. Externally, technological advancements in real-time monitoring systems (IoT-based sensors) and higher customer expectations for product quality further drive the need for agile and responsive operations. The implementation of a Digital Temperature Monitoring System (see fig.7) on the Zimmer dryer directly responds to these agility drivers by:



**Fig. 7.** Sensor Temperatur Dryer Machine Zimmer

### 1. Real-Time Monitoring

The production team can monitor the dryer temperature remotely and instantly, allowing immediate action whenever deviations occur. This enhances operational responsiveness.

### 2. Stored Temperature Data

The system records temperature data for each production batch, making it easier to trace quality issues to specific conditions. This supports traceability and decision-making agility.

### 3. Visual Display at the Machine

Operators can see real-time temperature readings directly at the machine. Any sudden rise or drop in temperature can be detected and corrected quickly, increasing on-site operational flexibility.

### 4. Agility Capabilities

The implementation of SMED in the Zimmer printing machine directly supports the development of Agility Capabilities.

**Table 5.** Contribution of SMED to Strengthening Agility Capabilities in Production Printing

Agility Capability	SMED Contribution
Responsiveness	Reduces setup time, enabling quick adaptation to order changes and production demands.
Competency	Standardizes and optimizes setup procedures, improving operator skills and process reliability.
Flexibility	Modularizes setup tasks, allowing easier switching between different product types or motifs.
Speed	Minimizes changeover duration, increases machine utilization, and shortens production lead time

As shown in Table 5, SMED strengthens key agility capabilities in the Zimmer printing process. First, SMED enhances responsiveness by significantly reducing setup times, allowing the production team to quickly adapt to changes in product orders or design variations with minimal disruption. This ensures a faster reaction to customer demands and market shifts.

Second, SMED builds competency by standardizing setup procedures, optimizing the preparation of screens and paste materials, and training operators in best practices. As a result, the workforce becomes more skilled and consistent in executing changeovers, improving operational reliability.

Third, SMED increases flexibility by enabling easier and smoother transitions between different motifs and products. Setup activities, such as mounting screens and handling paste drums, are modularized and streamlined, allowing the system to handle product diversity without significant downtime.

Lastly, SMED directly improves speed by minimizing the time needed for machine adjustments, which increases machine availability and throughput. This acceleration of changeover processes shortens lead times and strengthens the overall agility of the textile production system. Thus, SMED serves as a crucial enabler for enhancing responsiveness, competency, flexibility, and speed, aligning the production system with the core principles of agile manufacturing.

**Agility Providers.** Agility Providers are the enabling elements tools, methods, practices, and resources—that build and sustain organizational agility. They are categorized into four critical dimensions : organization, technology, people, and innovation. These elements facilitate continuous information flow, rapid decision-making, effective coordination, and adaptive learning across the manufacturing system.

To operationalize these providers, this study proposes several improvement projects across organization, technology, people, and innovation dimensions, as summarized in Table 6.

**Table 6.** Projects to Strengthen Agility Providers in Production Printing

Dimension	Proposed Project	Expected Impact
Organization	Standardization of Quick Changeover Procedures	Reduces variability and ensures consistent, efficient setups
Technology	Digitalization of Dryer Temperature Monitoring	Real-time control, faster detection of process deviations
People	Continuous Skill Development and QCO Training	Builds agility competencies and enhances operator responsiveness
Innovation	Development of Digital Knowledge Base	Accelerates learning, troubleshooting, and continuous

- Organization

Standardization of Quick Changeover (QCO) Procedures: Create comprehensive, standardized work instructions and SOPs for each step of motif changeover, screen handling, paste preparation, and machine setup activities. Impact: Ensures all operators perform changeovers consistently and efficiently, reducing variability and facilitating faster training of new personnel.

- Technology

Digitalization of Dryer Temperature Monitoring: Implement real-time monitoring sensors and centralized data logging systems for the Zimmer dryer (already initiated in your research). Impact: Enhances real-time visibility, quick detection of deviations, and data-driven corrective actions, enabling greater responsiveness and proactive control.

- People

Continuous Skill Development and QCO Training Programs: Regular training sessions focused on SMED techniques, agile mindsets, rapid troubleshooting, and proactive maintenance practices. Impact: Builds operator competency, enhances cross-functional teamwork and empowers staff to make fast, informed decisions during production fluctuations.

- Innovation

Project: Development of a Digital Knowledge Base for Setup Best Practice: Build an internal digital repository that captures best practices, lessons learned, standard setup sequences, and troubleshooting guides accessible via tablets or operator screens at the workstation. Impact: Promotes organizational learning, facilitates faster problem-solving, and drives continuous improvement in setup activities and production flexibility.

### 3 Conclusion

The increasing competitiveness and dynamic nature of the textile industry require manufacturing systems that are both highly efficient and adaptable. This study evaluated the integration of Lean Manufacturing and Agile Manufacturing approaches within the

textile printing process, focusing on improving operational performance through SMED (Single-Minute Exchange of Dies) and enhancing system flexibility using the Agility Framework.

Before the implementation of Lean tools, the printing division of the textile company exhibited low Overall Equipment Effectiveness (OEE), recorded at 24.2%. By applying the SMED methodology, setup activities were analyzed, separated into internal and external tasks, reorganized, and parallelized where possible. After implementing SMED improvements:

- Average setup time was significantly reduced, as reflected by decreased preparation time for motif changeover processes.
- Setup-related losses were reduced by approximately 65.06%, resulting in major efficiency gains.
- OEE improved by approximately 9.67%, indicating a substantial enhancement in equipment utilization and process stability.

Additionally, to strengthen organizational agility, this study introduced supporting projects aligned with Agility Provider's dimensions:

- Standardization of quick changeover procedures (Organization)
- Digitalization of dryer temperature monitoring (Technology)
- Continuous skill development and QCO training programs (People)
- Development of a digital knowledge base (Innovation).

Through these initiatives, Agility Capabilities were significantly improved: the system's responsiveness, competency, flexibility, and speed were enhanced, enabling quicker adaptation to order changes and minimizing the risk of production disruptions.

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