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Production Management Model to Reduce the Percentage of Defectives by Applying Lean Manufacturing Tools in a Textile Sector: A case study

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Abstract **-** This research project focused on addressing the high percentage of defectives in a Small and Medium-Sized Enterprise (SME) in Peru's textile sector. Production defects had impacted the overall profitability. To mitigate these issues, three key Lean Manufacturing tools were implemented: 5S, SMED (Single-Minute Exchange of Dies), and Standardized Work. The main goal of this project was to decrease the rate of defective products, improving production efficiency while upholding high-quality standards. The outcomes achieved following the implementation of the three tools were extremely positive. The 5S methodology showed significant improvements, as evidenced by the final evaluation score of 72,06%, surpassing the initial score of 32,35%. The SMED tool achieved a notable reduction in production process time, decreasing it to 148,26 minutes. Lastly, the application of Standardized Work increased efficiency from 96,69% to 97,69% and contributed to reducing the percentage of defective products from 2,65% to 1,64%. Additionally, an economic flow analysis with improvements was conducted, requiring an investment of $8 705,97. The economic results included a Net Present Value (NPV) of $11 924,87, an Internal Rate of Return (IRR) of 48,36%, and a Benefit-Cost Ratio (B/C) of 2,37. It was also concluded that the invested amount was recovered in 3,74 months.

Keywords**:** 5S methodology, Single-Minute Exchange of Die, Standardized Work, textile, defectives.

1. Introduction

Defective production refers to the proportion of products that fail to meet established quality standards during the manufacturing process due to factors such as machinery performance, operator proficiency, raw material quality, and environmental conditions [1]. In the textile industry, the rate of defective products varies based on the type of fabric produced and the complexity of the associated production processes. According to industry standards [2], acceptable defect rates in textiles typically range from 0% for critical defects to 2,5% for minor ones. However, actual defect rates often exceed these thresholds due to inefficiencies within production systems.

A recent assessment of textile production in Peru highlights that local small and medium-sized enterprises (SMEs) experience elevated defect rates, which adversely affect their productivity and profitability. In a specific SME analysed, the defect rate for fabric production stands at 2,38%, mainly attributed to inefficiencies in the weaving process and insufficient quality control measures [3]. This company specializes in the production of knitted fabrics, including jersey and ribbed textiles, operating 12 circular machines, and employing over 20 staff members.

This study aims to implement Lean Manufacturing tools—specifically SMED, standardized work, and 5S—to reduce the defect rate in this SME. The objectives include identifying critical inefficiencies within the production process, implementing targeted improvements, and evaluating their effects on defect reduction, productivity enhancement, and profitability improvement. It is anticipated that these measures will significantly decrease waste, optimize resource utilization, and reinforce the company's competitive position in the textile industry.

2. State of art

A systematic review of relevant studies was conducted, identifying 400 articles, with 40 selected for detailed analysis. Of these, 34 were deemed highly relevant for the project. Several studies demonstrated the impact of Lean Manufacturing tools on operational efficiency. Amiel-Reategui et al. [4] found that SMED reduced machine downtime by 23%, cut set-up times by 35%, and improved OEE (Overall Equipment Effectiveness) from 46,90% to 60,18%, leading to a reduction in defects. Sharma and Lata [5] showed that implementing 5S increased efficiency from 67% to 88,8%. Makwana and Patange [6] reported a 64% increase in productivity and a 35% boost in operational efficiency with 5S. Aucasime-Gonzales et al. [7] demonstrated a 13% improvement in production efficiency and a 22,5% reduction in setup times using Lean Manufacturing and Lean Maintenance.

Jiménez et al. [8] applied TPM, SMED, and Work Standardization, increasing machine availability from 80% to 93%, reducing set-up time from 56,25 minutes to 22,30 minutes, and cutting annual breakdowns from 190 to 135. Lastly, Alcazar-Zamora et al. [9] found that SMED, Standardized Work, and TPM reduced waste by 25% (from 5,77% to 4,33%) and increased OEE from 42,29% to 61,53%. These studies emphasize the substantial influence of Lean tools in enhancing efficiency and minimizing waste across different industries.

3. Methodology

This research adopts an explanatory and correlational approach, as it seeks to identify the primary causes underlying the problem identified in the company. Additionally, the study is quantitative in nature, utilizing numerical data to measure variables and indicators. Independent variables, such as delays in fault detection and fabric production times, have been determined, while the dependent variable is the high percentage of defectives in the production process. Figure 1 provides an overview of the records, the implementation process, and the projected outcomes.

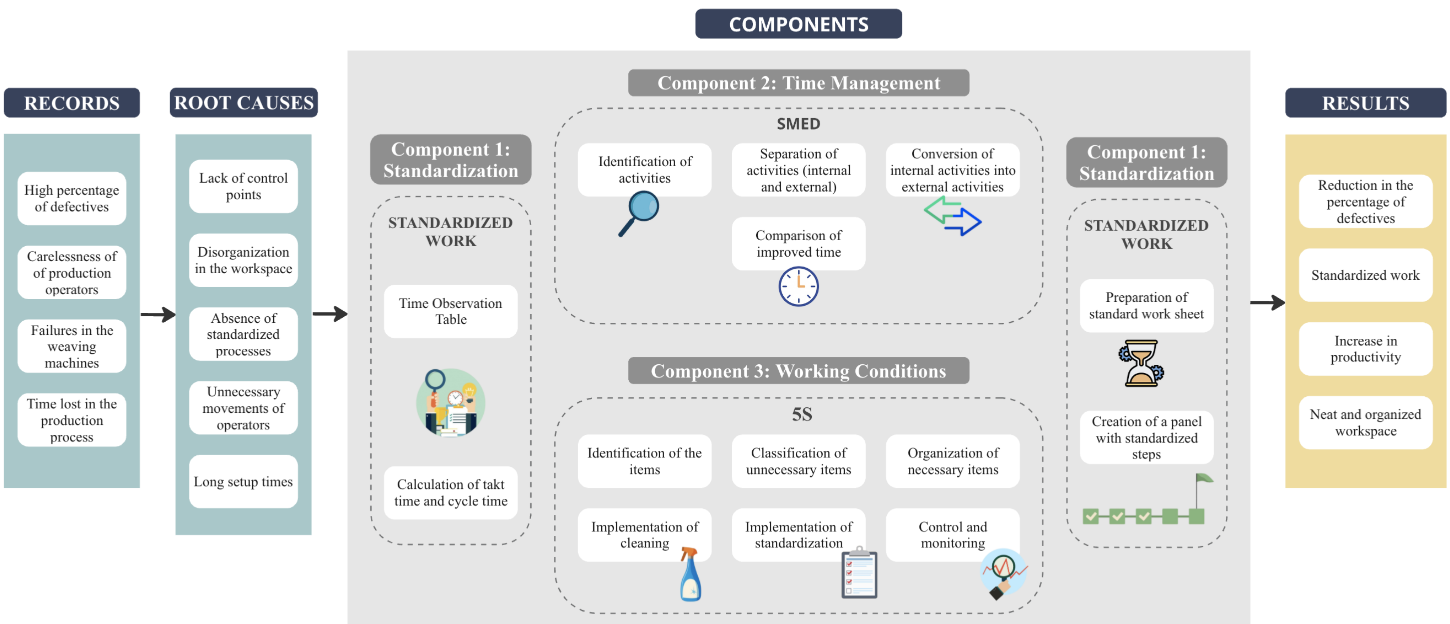

Fig. 1: Proposal Model

The graph shows the various records of the company and their root causes, which led to the decision to implement the solution tools Standardized Work, SMED, and 5S, with the aim of reducing the problems, especially the high percentage of defectives.

3.1. Component 1: Standardized Work

Standardized work is a Lean Manufacturing tool that focuses on establishing a structured and repeatable sequence of operations to ensure consistency and efficiency in production processes. It helps minimize variability, reduce waste, and improve workplace organization. According to Fin et al. [10], standardized work optimizes task execution and enhances productivity by promoting uniformity in operational processes. As the first step in implementing standardized work, the takt time was calculated as shown in the formula (1) using the following data:

- Daily available time: 4,185 minutes
- Daily demand: 1,275 kg = 51 rolls

$$\text{Takt time} = \frac{\text{Daily available time}}{\text{Daily demand}} \tag{1}$$

$$\text{Takt time} = 82{,}06 \text{ minutes / roll}$$

Since the calculated takt time is 82,06 minutes/roll and the cycle time before the improvement was 101,97 minutes/roll, changes to the production line are required. Consequently, the SMED and 5S tools were implemented to reduce time and improve activity organization. As the last step, after implementing these tools, the standardized work sheet was created.

3.2. Component 2: SMED

SMED is a tool that helps reduce machine setup and changeover times, improving production flexibility and minimizing downtime, which leads to enhanced productivity. According to Vieira et al. [11], SMED methodology focuses on categorizing setup activities into internal tasks, which require machine stoppage, and external tasks, which can be performed while the machine is still operating. The goal is to convert as many internal tasks as possible into external ones, thereby significantly reducing the time needed for equipment changeovers and improving overall production efficiency. As illustrated in Figure 2, the process of implementing this tool starts with identifying the activities within the production process. Then, the factors contributing to inefficiencies are examined, and simulations of both the initial and optimized scenarios are conducted using the Arena software.

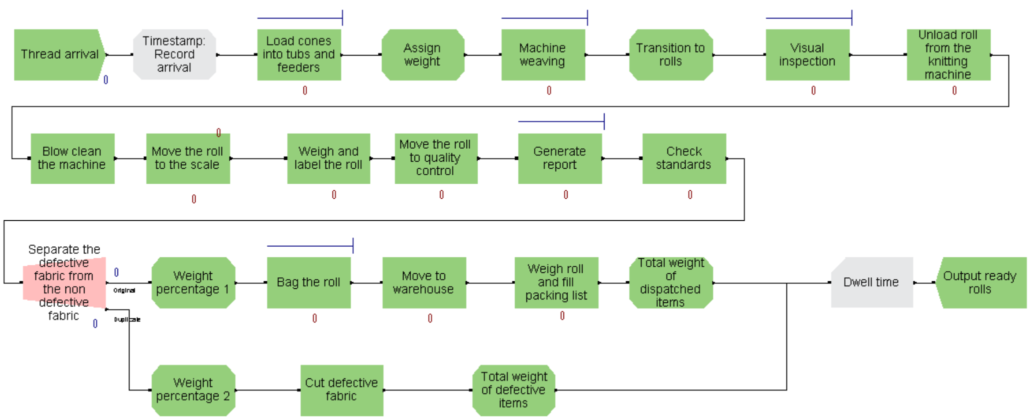

Fig. 2: Simulation Model

The population (N) was determined based on the approximate annual fabric production of 52 425 rolls for 2023, the year prior to the start of the improvement implementation. A maximum allowable margin of error of 0,05 and a confidence level of 95% (Z = 1,96) were used. Additionally, data heterogeneity of 50% was assumed, and the sample size was determined using the following formula (2).

$$n = \frac{N \times Z_{\alpha}^{2} \times p \times q}{e^{2} \times (N-1) + Z_{\alpha}^{2} \times p \times q} \tag{2}$$

$$n = 381{,}37 \approx 382 \text{ rolls}$$

A sample of 382 rolls was taken, with each roll weighing 25 kg, totaling 9550 kg of material entering the system.

3.3. Component 3: 5S

5S is a Lean Manufacturing tool that enhances workplace organization, cleanliness, and productivity by establishing an efficient and structured environment. It helps reduce waste, improve safety, and boost employee morale. The implementation of 5S leads to better resource utilization, reduced downtime, and increased productivity, while fostering a culture of continuous improvement. According to Kuchekar et al. [12], 5S consists of five steps:

- Seiri (Separate): Items in the workplace are categorized, and unnecessary items are removed to create more space and improve efficiency.
- Seiton (Order): Items and equipment are organized and placed in specific locations to ensure they are easy to find and use.
- Seiso (Cleaning): Regular cleaning of the workplace and equipment is performed to maintain a safe and tidy environment.
- Seiketsu (Standardize): Standard procedures and rules are developed and maintained to ensure the workplace remains organized and clean.
- Shitsuke (Discipline): Employees adhere to the established practices, ensuring the consistent application of the 5S principles. This methodology includes an improvement plan consisting of an initial audit, implementation of the 5S steps, and a final audit.

Additionally, as part of the tool's implementation, an audit format in the form of a questionnaire was developed. This was applied at the beginning and end of the process to evaluate the improvements achieved and is also conducted monthly to ensure continuous improvement. The questionnaire has a maximum score of 68 points, with each question assessed on a scale from 0 to 4, where 0 represents poor performance and 4 represents excellent performance. This format includes specific questions for each "S," allowing verification of compliance and calculation of a total score that reflects the level of tool implementation.

4. Results

For the improvement process and the implementation of the tools, training was first provided to the workforce on the tools, which allowed for a better understanding of them and thus enabled satisfactory results.

Upon the implementation of the SMED tool, the results obtained from the base model and the improved model are presented to facilitate a comparison and determine whether an improvement has been achieved. The results table is provided below.

Table 1: Comparison of results (Base-Improved)

Indicator	Base	Improved	Units
Indicator 1 (Total weight of defective items)	313,24	162,35	Kg
Indicator 2 (Total weight of dispatched items)	9236,70	9387,60	Kg
Dwell time	157,42	148,26	Min
Roll time in the process	79,05	74,47	min

As seen in the table, the results of the improved model reflect positive progress in all indicators compared to the base model, confirming that the application of the tool achieves its objective.

The application of the 5S tool consisted of carrying out each of the predefined "S" steps. As depicted in Figure 3, photographs were taken to document the implementation process and highlight the improvements made, comparing the initial state with the enhanced condition.

Fig. 3: Before and after applying 5S.

After completing the final audit, remarkable results were achieved, as detailed in the table. Table 1 shows a total score of 49 and a percentage of 72,06%. This progress represents a 50,10% percentage increase, reflecting a significant improvement compared to the initial audit results, demonstrating the correct use of the tool and the continuous efforts of the production operators.

Table 2: Initial audit - Final Audit.

		Initial Audit		Final Audit		Percentage Increment
Order	**5S**	**Score**	**Percentage**	**Score**	**Percentage**	
1°S	**Seiri**	8	36,36%	10	45,45%	20,00%
2°S	**Seiton**	5	22,73%	15	68,18%	66,67%
3°S	**Seiso**	7	31,82%	9	40,91%	22,22%
4°S	**Seiketsu**	2	9,09%	9	40,91%	77,78%
5°S	**Shitsuke**	0	0,00%	6	27,27%	100,00%
	Total	**22**	**32,35%**	**49**	**72,06%**	**55,10%**

Finally, the standardized work sheet was completed, as shown in Figure 4.

Standardized work sheet

#	Work Elements	Working time (min)	Walk (min)
1	Move the 12 boxes of thread and 2 boxes of lycra from the warehouse to the machines.		3,00
2	Load the spools of thread into the machine's vats.	30,00	
3	Mount the lycra spools onto the feeders.	20,00	
4	Machine weaving the thread 100%.	80,00	
5	Visual control of the fabric.	3,00	
6	Unload the fabric from the weaving machine.	0,80	
7	Blow clean the machine (once the roll is finished).	4,00	
8	Transfer the fabric to the scale (for 4 rolls).		1,20
9	Weigh the roll and mark the roll number, weaving machine number, batch number, weaver's name, and date on the fabric.	0,70	
10	Weaver delivers the rolls to the quality screen (for 4 rolls).		0,16
11	Generate report: Record weight and roll number and machine number.	0,30	
12	100% appearance control.	3,00	
13	If there are defects, cut the fabric, weigh the cut portion, and include the weaver's name and date in the report.	1,20	
14	Quality person stamps the fabric.	0,60	
15	Transfer the roll to the warehouse (for 4 rolls).		0,24
16	Weigh the roll, fill out the packing list, and load it onto the truck.	0,30	
17	Stop for malfunction.	2,00	

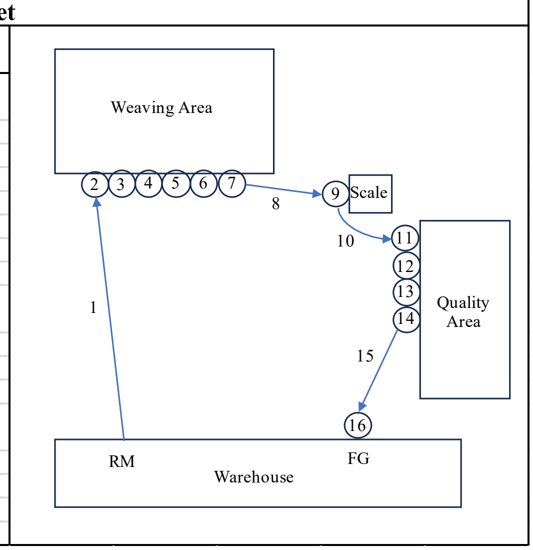

Fig. 4: Standardized work sheet

Finally, a final comparison was made with the indicators that were previously established as evaluation points. This comparison helps identify and confirm that the application of the proposed tools improves the established indicators. The following table shows the indicators obtained before implementing the tools, contrasting them with the new values obtained from the simulation.

Table 3: Indicator traffic lights

Tool	**Indicator**	**Unit**	**Traffic Light Classification**			**As is**	**To be**	**Achieved**
			Red	Yellow	Green			
Lean Philosophy	Total productivity	-	<0,95	0,95-0,97	>0,98	0,97	0,98	0,98
SMED	Total production time	Min	>170	170-150	<150	157,42	150	148,26
Standardized Work	% Efficiency	%	<90%	90%-97%	>97%	96,69%	98,00%	97,69%
	% Defective products	%	>3%	3%-2%	<2%	2,46%	1,50%	1,64%
5S Method	5S Compliance	%	<50%	45%-80%	>80%	32,35%	86,76%	72,06%

Some of the results obtained exceed the forecasted values, such as total productivity or total production time, while one is close to the target value. Nevertheless, it is confirmed that they have a positive impact on the goal, which is the improvement of these indicators through the application of the proposed tools.

Finally, after conducting the economic flow of the company, the results presented in Table 4 were obtained.

Table 4: Economic evaluation indicators

Indicators	**Results**
NPV	$ 11 924,87
IRR	48,36%
Cost-benefit	2,37
Payback	3,74 months

On the other hand, the implementation of Lean tools generated significant environmental benefits. By reducing production times and decreasing the percentage of defects, the use of energy and materials was optimized, thereby reducing indirect carbon emissions associated with energy consumption. This impact is particularly relevant in a context where environmental sustainability is a priority.

Additionally, the reorganization of the workspace through the 5S methodology fostered a cleaner and more organized environment, reducing the generation of solid waste and promoting recycling practices such as recycling thread cones and boxes. This not only reduced the direct environmental impact but also promoted a culture of sustainability among the workers, who actively participated. The decrease in waste and the optimized use of resources produced an immediate positive effect, while also establishing a stronger foundation for a more robust production system. These improvements reduced the environmental footprint of the production process, paving the way for a more sustainable and competitive model over time.

5. Discussion

The implementation of Lean Manufacturing tools has shown significant improvements in key performance indicators. These results align with previous studies, such as that of Aucasime-Gonzales et al. [6], which demonstrated that the adoption of Lean Manufacturing and Lean Maintenance (including SMED and 5S) in the manufacturing industry led to a considerable increase in efficiency, achieving an 18% improvement in productivity. In this study, a 1,03% increase in operational efficiency was achieved, validating the effectiveness of these tools in improving productivity and reducing defects. Similarly, the results of Makwana et al. [5], who applied 5S in a plastic machinery manufacturing company, reported a 64% increase in productivity. In the analyzed company, an increase in productivity was observed after implementing SMED and standardized work, along with a 33,35% reduction in defects.

On the other hand, when comparing our results with those of Amiel-Reategui et al. [4], who reported a 23% reduction in machine downtime and an improvement in Overall Equipment Efficiency (OEE) from 46,90% to 60,18%, our findings show a similar trend in terms of improving operational efficiency and reducing non-productive times. This pattern is also reflected in the results of Jiménez et al. [8], where machine availability increased from 80% to 93% and setup time decreased from 56,25 to 22,30 minutes. These results highlight the positive impact of tools like SMED and standardized work on improving equipment availability and setup times.

Finally, Alcazar-Zamora et al. [9] reported a 25% reduction in waste and an increase in OEE from 42,29% to 61,53%. Our results confirm that the implementation of Lean tools, such as SMED, 5S, and standardized work, also significantly contributes to waste reduction and overall improvement. It is important to note that the specific improvement percentages may vary due to the particular characteristics of the process and production environment studied. In summary, the integration of 5S, SMED, and standardized work has proven to be an effective strategy for continuous improvement, not only in reducing defects but also in achieving positive economic and environmental outcomes.

6. Conclusion

It is concluded that the development of the state of the art allowed the identification of the main challenges before the improvement, especially in the reduction of defects in the fabric production process. This provided a solid foundation to design a management model that addressed these challenges by integrating tools such as SMED, standardized work, and 5S.

The 5S tool was necessary to address disorganization in the workspace. This led to significant improvements in sorting, organizing, and cleaning, as reflected in the audit results, with an overall score increase of 55,10%. Additionally, the SMED and standardized work tools allowed for the identification and classification of activities, reducing unnecessary movements, and minimizing setup times to establish time for pre-controls and standardized steps, reducing the main issue of the defect percentage from 2,65% to 1,64%.

The impact of the improvements was clear. The implementation of these tools resulted in an increase in total production and, therefore, an average increase in net profit amounting to $1692,55 per month, demonstrating that the improvement was not only operationally effective but also economically beneficial for the company.

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