APPLICATION OF LEAN MANUFACTURING TO IMPROVE PROCESSES AND INCREASE PRODUCTIVITY IN THE TEXTILE INDUSTRY OF PERU: CASE STUDY

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ARTICLE INFO

Article details
Submitted by authors 28 Aug 2023
Accepted for publication 20 Jul 2024
Available online 30 Aug 2024

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DOI
http://dx.doi.org//10.7166/35-2-2932

ABSTRACT

This study aims to improve the fabric-cutting process of cotton garment-exporting micro and small businesses by identifying and eliminating waste, defined as the processes that do not add value in cutting area of a textile company. In addition, the lean manufacturing approach is applied by employing tools such as value stream mapping (VSM), single-minute exchange of dies (SMED), and work standardisation. The proposed philosophy is based on data analysis, economic validation, and simulation using the historical data from the company under study. Consequently, a decline in default rework and delayed processes along with an increase in the productivity index is expected.

OPSOMMING

Hierdie studie het ten doel om die materiaal snyproses van katoen-klere-uitvoer mikro en klein besighede te verbeter deur die vermyding en verwydering van afval, gedefinieer as die prosesse wat geen waarde toevoeg nie, binne die sny-area van 'n tekstielmaatskappy te identifiseer. Daarbenewens sal die skraal vervaardiging-benadering toegepas word deur die gebruik van gereedskap, soos waarde-stroomkaarte (VSM), enkele-minuut-die-uitruiling (SMED), en werkstandaardisering. Die voorgestelde filosofie is gebaseer op data-analise, ekonomiese validasie, en simulasie met behulp van die historiese data van die maatskappy onder studie. Gevolglik word 'n afname in standaard herskrywings en vertraagde prosesse, tesame met 'n toename in die produktiwiteitsindeks, verwag.

1. INTRODUCTION

In Peru, small and micro-enterprise companies (SMEs) are key drivers of economic growth, representing 40% of the gross national product (GNP) [1]. Consequently, equipping these companies with the right tools to address their potential difficulties is essential for improving their competitiveness and concurrently enhancing their productivity.

This study aims to improve the fabric-cutting process of cotton-garment-exporting MSEs by identifying and eliminating waste, defined as the processes that do not add value in the cutting area of a textile company.

For the selected case study, issues were identified in the production process, specifically in the cutting phase that hamper its efficient development and continuous use of its resources. Enhancing the manufacturing process of cotton garments and minimising their operation times can address these issues. The present approach started with a literature review on implementing the lean manufacturing philosophy, which aims to eradicate waste that is, activities that do not generate added value to the company under examination.

Presently the textile industry faces significant limitations owing to the COVID-19 pandemic, stalling its growth, as reported by the Peruvian Ministry of Production [2]. This manuscript complements and provides an extended version of a prior conference paper [3]. It is organised into four sections: the literature review, the proposed solution, the project validation, and a discussion of the results. The conclusions are framed in alignment with the primary and specific objectives.

2. LITERATURE REVIEW

Today, global competition persuades many companies to be more efficient and to generate value-added products to transcend sectors and remain competitive. Therefore, minimising or eradicating waste is crucial to these companies. To this end, several philosophies could reduce or eliminate such inefficiencies.

This study conducted an extensive literature review of research papers and scholarly articles pertinent to the research topic across various countries. This exploration spanned numerous scientific databases, including ScienceDirect, Scopus, Emerald Insight, Web on Science, Proquest, and Alicia-Concytec. Consequently, the incorporated articles are indexed in specialised journals on the topic, encompassing both international and national languages, ensuring that the information remains current and is aligned with global realities. The case study has been divided into two segments: a review of the literature relevant to the problem and an examination of the technique slated for the development of the proposal.

2.1. Review of problem statement

Improving productivity always plays a crucial role in determining the success of an industry [4] or of specific SMEs. Typically, compared with large enterprises. SMEs encounter difficulties such as obstacles in achieving economies of scale via volume production or bulk purchasing of raw materials, because of their ignorance of successful theories that have been previously implemented [5]. Based on these observations, it is suggested that companies concentrate on three strategic questions reducing overall costs, improving quality via an appropriate assurance system, and improving productivity using appropriate tools and techniques. Thus, the application of value stream mapping (VSM) and 5s is recommended for efficient production by eliminating waste and implementing flow. In their article, Habib et al. [6], addressed the issue of delayed time in shoe manufacturing processes and the subsequent inefficiencies that were generated in the entire production. Their research indicated that the use of VSM improved productivity, as it enabled the identification and eradication of delay-prone activities, improving their processes, timelines, and defects.

In their research, Piñeiro et al. [7] highlighted the structural deficiencies that hinder the competitive evolution of SMEs in Bogota's textile sector, especially when juxtaposed against Chinese competition through a systemic approach. Essentially, firms should cultivate strategic planning that fosters enhancement and strengthens their competitive performance on domestic and international fronts. The study found that the key factors influencing Latin American enterprises include innovation, productivity, human capital development, and integrated processes. Herrera proposed continuous enhancement to increase competitiveness, aligning production processes with methodologies to improve efficiency and ensure a better work environment. Arrarte et al. [8] analysed the textile sector to identify the factors affecting the productivity of SMEs. They employed financial analysis techniques that determined the competitive aspects of this sector, namely imports, exports, balance of payments, contraband, and tariffs. Notably, five recent studies have shared sentiments about global trends, the search for lower costs, increased competition, re-shoring of production, product technology, technology in production processes and marketing in order to make organisations more competitive against others. These enterprises encounter problems, such as limited funds and a highly competitive market. The authors affirmed the need for a strategic change, emphasising that in a market fragmented by dominant multinational brands, the longevity and success of SMEs depend on adaptability, real-time information access, and the right change management skills [9] [10] [11] [12].

Khaliji et al. [13] descried in their study, the export scenario in Pakistan, which suffers from a diminished productivity metric in the textile domain. The authors aimed to invigorate exports via cotton utilisation and, through their statistical examination, found that cotton garment production surged, contributing to a 27% increment in total exports. Conversely, insights from five different articles emphasise the significance of integrating ICT into textile enterprises, not merely as a supplementary tool but as an intrinsic component of their developmental processes. This integration is deemed pivotal for fostering innovation and global competitive participation. The competitive edge is invariably connected to technological pioneering, which often facilitates optimised process and resource allocation, leading to the minimisation or removal of waste or non-value-adding activities [14] [15] [16] [17] [18].

2.2. Review of techniques

According to Industrial Vision [19], lean manufacturing stands out as one of the most successful philosophies in addressing these challenges. It is a philosophy that uses methods and systems to improve the work environment, processes, and business performance. Hernandez and Vizán [20] stated that “Lean culture is not something that begins and ends, it is something that should be treated as a cultural transformation if it is to be lasting and sustainable, it is a set of techniques focused on added value and the people”.

In their study, Millán et al. [21] focused on the implementation of lean manufacturing tools in SMEs in the textile sector. For this, they introduced a methodology focused on an SME in the municipality of Tulancingo, comprising eight phases. Initially, the needs of the company were identified through process mapping, SIPOC, and VSM followed by problem identification the process through which the generated bottlenecks are identified using Ishikawa and Pareto diagrams. The third phase involved planning and verifying the resources that were necessary using a schedule of activities, control panel, critical path, and others. The fourth phase involved recognising the activities that failed to add value with the aim of modifying or eliminating them. The fifth phase proposed enhancements based on the identification of potential avenues for improvement leveraging lean tools. In the sixth phase, a pilot test developed the proposal of the lean manufacturing and lean six sigma tools. The seventh stage ensured consistent monitoring and reinforcing of the improvements previously suggested.

Vinayagasundaram et al. [22] conducted a study that revealed that the industry was unable to meet customer demands because of increased cycle times for individual processes and excessive rework stemming from high rejection rates. Their research described several enhancement measures aimed at reducing the rejection rates that affected productivity. Post-implementation time studies were undertaken to gauge the process outcomes, which revealed an improvement in the foundry sectors productivity using lean tools.

Based on surveys conducted with 76 companies in Pakistan, Abbas et al. [23] stated that companies implemented the lean philosophy to reduce costs. The main tools employed in this area were 5S, Kaizen, VSM, and single-minute exchange of dies (SMED). The study determined that 22% of the larger enterprises showed an adequate implementation of this philosophy.

Another study of the implementation of lean manufacturing philosophy was carried out in India by Maruddhamuthu et al. [24]. Their findings indicated that the first step was to design and develop the value chain map (VSM), which would provide information on the duration of each manufacturing process. In this way, they could propose the tools required to eliminate the problems. Thus, in this study, the VSM and SMED were used to decrease the time for each day.

Marmolejo et al. [25], in their study, emphasised the importance of reducing production durations to give the company a competitive advantage. Their approach included assessment of the prevailing state using a tree diagram, facilitating the identification of problems and its root causes. A time analysis was subsequently conducted. Finally, the authors concluded that process flow redesigns educed lags and superfluous transportation, which then reduced the required activities from 21 to 9. Moreover, the integration of lean manufacturing principles, specifically 5S, influenced the cycle duration, leading to a drop in the percentage of non-value-adding activities and a subsequent cost reduction.

3. RESEARCH APPROACH

A previous study [3] investigated and comparatively analysed an issue related to cutting processes in a small-scale Peruvian apparel enterprise. Based on the literature, this study comprehensively understood the issue and suggested a general form and a general solution based on the implementation of lean manufacturing. This general solution was then simulated using Arena software, culminating in a comparative analysis of the problem indicators with those of the general solution and with other alternatives reported in the literature.

3.1. Framework to improve process through lean manufacturing

AlManei et al. [26], in their exploration, pinpointed the problem and its fundamental causes, supported by a literature review. Their research found that lean manufacturing philosophy was the optimal methodology for their case study. In the application of this philosophy, they introduced a design that organised the lean tools to be incorporated in the study, distributed across three pivotal stages. These stages and their constituent steps are summarised in Table 1.

Table 1: Methodological design

Improve lean manufacturing		
Stage 1	Stage 2	Stage 3
Preparation	Design	Implementation
1. Assessment of the current situation 2. Lean team organisational chart 3. Recognition of need for change	1. Value maps 2. Planning for change 3. Creating a feedback mechanism	Implementation will take place after approval of the first two stages is represented in a GANTT

Source: Own elaboration, based on Almanei et al. [26]

The deployment of the lean manufacturing methodology for this case study was structured in three distinct stages:

3.1.1. Preparation phase

In the initial stage, the company's prevailing state concerning the issue was mapped and assessed. A problem was pinpointed in the cutting area, with the suboptimal cutting process emerging as the primary problem. This manifested itself in the form of losses, reprocessing and bottlenecks, which caused financial consequences impacting 20.41% of total sales. Subsequently, four types of waste (i.e., defects, delay, reprocessing, waiting times) were identified and examined serving as focal points in the study. Following identification of the problem, it was vital to select and grasp the nature of these types of waste. Based on this understanding, both general and specific objectives were outlined (refer to Table 2).

Table 2: Goals

Overall goal	**Specific goals**
Proposal to improve the process in the cutting area for garment manufacturing	Standardisation of cutting process
	Standardisation of communication and training plan
	Standardisation of quality process

Source: Own elaboration

During the second phase, in alignment with the organisational chart of the company, change agents were identified. In this case, the manager and production chief assumed the roles of change agents, while the master cutter was designated as the experience agent. Their attention was concentrated on the cutting process to facilitate necessary modifications with minimal errors. Subsequently, the lean team, complete with its leader and sub-leader, was identified. They would strategically appoint participants who would transition to the training phase.

In the concluding stage, a comprehensive training, encompassing theoretical and practical aspects of lean manufacturing tools, was provided to the three chosen operators. At the same time, the team was tasked with identifying the established processes and subsequently optimizing them.

3.1.2. Design phase

Initially, a value map was constructed using the VSM tool to visualise and understand the garment-making process. This tool helped to pinpoint wasteful practices and non-value-adding activities. The case study revealed a time discrepancy in the cutting area relative to the takt time (3.40 days/t-shirt as opposed to 0.93 days/t-shirt). Thus, the lean teams focus was directed towards the cutting domain.

Further, to find opportunities for improvement, the Process Analysis Diagram (PAD) of the cutting area was scrutinised, leading to the creation of a VSM encompassing the cutting activities, such as raw material storage, cutting area transfer, cloth placement on the table, template positioning, taping, cutter transfer, and the cutting process, followed by the transfer to the tailoring area. The takt time was determined to be 0.03 days/t-Shirt for a batch of 845 t-shirts. Imbalances were identified across three operational zones and three transfers, which were regarded as wasteful waiting periods warranting attention because they generated an economic impact amounting to $17,173 from delays, $78,098 from defects, and losses adding up to $25,593.

Subsequently, upon the identification of improvement opportunities, the implementation of the tools (SMED, visual control, and standardisation) was planned to reduce the frequency of the identified root causes, namely improper processes, lack of process knowledge, and lack of requirement revision. Using the SMED tool, it became evident that all the activities were internal, with five of them being non-value-adding (NVA). A proposal was that the master cutter be aided by an assistant to trim the cycle times and to transform these NVA activities into external value-added activities. For instance, the fabric rolls would be oriented horizontally in sets of four; the laying process would employ an extension machine and cutting would occur on the same extension table, eliminating the need for cutter transfer.

By leveraging this tool, cycle times that eliminated the initial bottlenecks were reduced, decreasing the total time of cutting activities from 3.40 days to 1.12 days for a batch of 845, which in turn translated into reducing delay-induced costs to $2,244. Under the visual control tool, reminders were instituted for the master cutter and assistants consistently to use the fabric extension machine, ensuring appropriate fabric tension, especially given its proximity to the cutting table. This implementation reduced defect frequencies from 403 to 126. Last, the work standardisation tool suggested a sequence of activities, emphasising the review of the fabric direction and pertinent measurements (refer to Figure 1).

Description	Op	T (days) average	T(days) Target	Symbol				
				○	⇨	D	□	▽
Injunction-to-cut income	1			x				
Master cutter reviews requirement	1						x	
Check fabric address	1	0.02	0.02				x	
Check on template parts measurement	1						x	
Cut	1			x				
Total	5	0.02	0.02	02	0	0	03	0

Source: Own elaboration

Figure 1: Activity

Under the proposed framework there was a notable reduction in yearly defects. Concerning incorrect fabric orientation, defects were reduced from 353 to 110. Similarly, errors in template measurements experienced a reduction from 334 to 104.

In the third phase, following the implementation of enhancements in the cutting area, a conclusive VSM for the production area was prepared. This representation revealed the absence of bottlenecks, with the total production duration for 845 units being completed in 46.99 days, closely aligning with the target of 49.26 days. Thus, it could be affirmed that the initial project objectives had been duly realised.

In conclusion, the feedback mechanism allowed the master cutter and the team members to articulate their ideas and project proposals that were aimed at refining the processes, making them more efficient so that they had a positive impact on the productivity indicator of the cutting area. As delineated by BCR (2015), productivity serves as an index of growth and development in enterprises.

3.1.3. Implementation phase

The implementation stage took 39 weeks and should have been carried out after the approval of the two previous stages. However, given the prevailing national circumstances, a simulation via the Arena software was selected. A financial validation was undertaken concurrently to assess the net present value (NPV), internal rate of return (IRR), and Benefit /Cost - B/C of the case in question.

In alignment with the details, the measurement indicators were assessed, focusing on the objectives of the enterprise under examination, as shown n Figure 2.

Measurement of indicators

In alignment with the aforementioned details, the indicators were to be assessed (refer to Figure 2), focusing on the objectives of the studied enterprise.

Indicators	*Current situation*	*Units*	*Target action*	*Target action*	*Theory*	*Change variation required*	*Situation improvement*	*Condition*
On-time service level	81.51%	Percentage	Increase	95%	Confidence level	⬆ 13.49%	90.39%	Acceptable
Takes	18.49%	Percentage	Decrease	5%	Margin of error	⬇ 13.49%	9.61%	Acceptable
Cutting area process time for a batch of 845 T-shirts/requirement	3.4	Days	Decrease	1.29	Company goal	⬇ 2.11	1.12	Excelllent
Percentage of rework for defects	13.12%	Percentage	Decrease	5%	Company goal	⬇ 8.12%	4.23%	Excelllent
Productivity cut	0.38	Index	Increase	1.298	Company goal	⬆ 0.92	1.16	Acceptable
General productivity	1.008	Index	Increase	1.587	Company goal	⬆ 0.58	1.18	Acceptable

Source: Own elaboration

Figure 2: Measurement of indicators

3.2. Findings

It was observed that the on-time delivery rate stood at 81.51%. According to the company's aspirations, this should ideally escalate to 95%. Conversely, delayed deliveries accounted for 18.49%, with plans to reduce this to a mere 5%. The production duration for crafting 845 t-shirts was found to be 2.4 days, whereas the objective of the enterprise required it to be streamlined to 1.29 days. In respect of defect percentages, the current rate was 13.12%, with the aim of reducing it to no more than 5%. Such refinements were likely to amplify the productivity of the cutting domain.

4. VALIDATION

In this section, they are identified using the simulation validation of the current cutting process when compared with the simulation of the improved cutting process. Similarly, a financial validation is carried out, evaluating the VAN, TIR, and B/C to ascertain the feasibility of the project.

4.1. Simulation validation

The simulation process was conducted using the intrinsic framework of the cotton garment manufacturing cutting process as input.

4.1.1. Description of the actual process

For the current process of the cutting area, historical data from the company under study was sourced. This covered a yearly demand of 26,200 t-shirts, with an average lot consisting of 845 units across 31 processes annually.The procedure began with the master procuring the requirement, and then progressing to the Raw Material - RM storage. The transfer to the cutting region occurred next, where fabric positioning took place, followed by template placement and its securing using tape. This setup was then relayed to the cutter, who carried out the actual cutting, after which the garment was taken to the manufacturing zone.

This system is shown below (Figure 3), accompanied by a categorisation of its controllable and uncontrollable inputs (refer to Tables 3 and 4).

Controllable and uncontrollable inputs

The system included an entity in transit, which was the batch order of the customer (requirement). This entity had attributes, such as the interarrival time between batches, while the workstations showed service time as a characteristic attribute.

Table 3: Controllable and non-controllable inputs

CONTROLLABLE	Number of workers	Because there is only one production area, there is currently one worker for all stations.
	Number of stations	These are the activities for manufacturing the final product.
	Employee salary	This accounts for the remuneration of the employee.
	Hours of work	The operator works 8 hours a day.
NOT CONTROLLABLE	Time between arrivals of batches of requirements	
	Service times	

Source: Own elaboration

The controllable variables found are given in Table 4.

Table 4: Controllable variables

Stations	Operations	Machinery	Operators
MP WAREHOUSE	Store	0	1
	Move	1	1
LAYING TABLE	Put screen on table	0	1
	Place templates	0	1
	Fix templates	0	1
	Transfers to cutter	0	1
CUTTING TABLE	Make cuts	1	1
	Move clothing area	0	1

Source: Own elaboration

Table 5 depicts the detail of the variables in the process.

Table 5: Detail of the variables

Non-controllable	**Time between arrival of request lots – TLL**	
	Service time at each station	
Station 1	Station 2	Station 3
Store – TSA	Place fabric – TSColT	Make cut – TSCorT
	Place template – TSColP	
Transfer MP – TSTMP	Fix squad – TSFP	Transfer to seam – TSTTC
	Transfer to cutter – TSTC	

Source: Own elaboration

In Table 5 the detail of the variables is shown; in Table 6 the entities, attributes, and activities; and Table 7 presents the distribution of the activity.

Representation of the system

The systemic examination covered the period from selecting the requisite raw material to the fabric cutting required to meet the demand of the internal client from a given department.

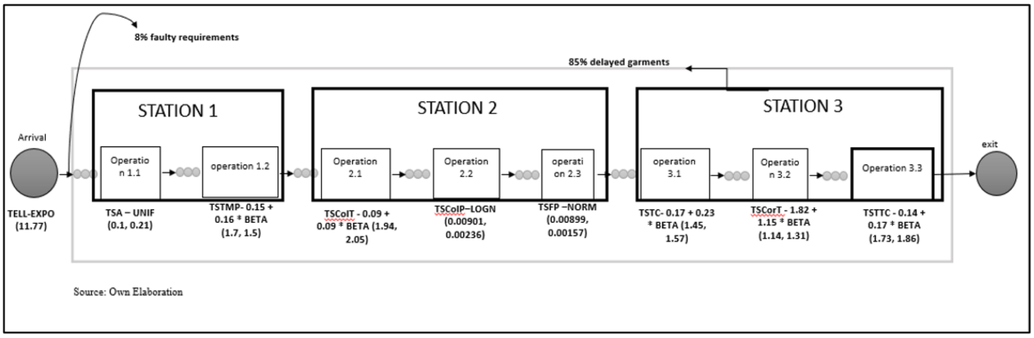

Figure 3: Representation of the system

Table 6: Entities and attributes

<table>
<tr><th>Entities</th><th>Attributes</th><th>Activities</th></tr>
<tr><td rowspan="4">Requirement</td><td rowspan="4">TLL
Probability of abandonment because of damage</td><td>Reaching the system</td></tr>
<tr><td>Abandonment by failure</td></tr>
<tr><td>Queuing at Station 1</td></tr>
<tr><td>Occupy trainer</td></tr>
<tr><td rowspan="4">STATION 1</td><td rowspan="4">TSA
TSTMP</td><td>Wait for a requirement</td></tr>
<tr><td>Review requirement</td></tr>
<tr><td>Select MP</td></tr>
<tr><td>Move MP</td></tr>
<tr><td rowspan="6">STATION 2</td><td rowspan="6">TSCoIT
TSCoIP
TSFP
TSTC</td><td>Wait screen</td></tr>
<tr><td>Stack fabrics</td></tr>
<tr><td>Place templates on fabrics</td></tr>
<tr><td>Cutting ribbons</td></tr>
<tr><td>Fix templates on fabrics</td></tr>
<tr><td>Move stacked fabrics with insoles</td></tr>
<tr><td rowspan="4">STATION 3</td><td rowspan="4">TSCorT
TSTTC</td><td>Wait for fabrics with insoles</td></tr>
<tr><td>Cutting fabrics</td></tr>
<tr><td>Move cut fabrics to the clothing area</td></tr>
<tr><td>Exiting the system</td></tr>
</table>

Source: Own elaboration

4.1.2. Model construction

The logical model was constructed by applying software tailored for discrete event simulation. The company's system was simulated using the Arena tool. In addition, the distributions for each of the system's activities were obtained; this data is consolidated in Table 7.

In contrast, the projections obtained from the methodology enabled the simulation of the enhanced cutting process (refer to Figure 5). This revealed the elimination of the transfer-to-cut activity, given its lack of added value.

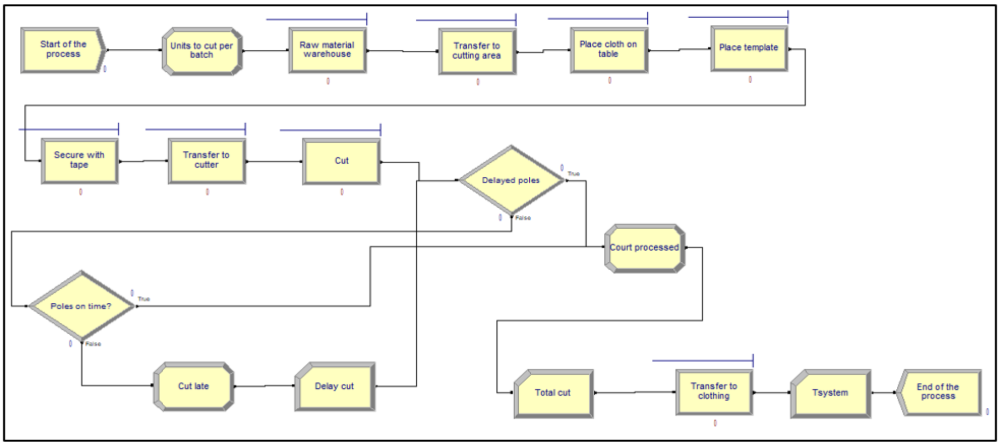

Figure 4: Model of cutting process system - Current situation

Source: Own elaboration

Table 7 shows the cutting process in the current situation and in the improved situation, showing the differences between the performances.

Table 7: Distribution of activity

Cutting process - current situation			
N°	Activities	Operators	Current
1	MP store	1	UNIF (0.1, 0.21)
2	Transfer to cutting area	1	0.15 + 0.16 × BETA (1.7, 1.5)
3	Put screen on table	1	0.09 + 0.09 × BETA (1.04, 2.05)
4	Place template	1	LOGN (0.00901, 0.00236)
5	Fix with tape	1	NORM (0.00899, 0.00157)
6	Transfer to cutter	1	0.17 + 0.23 × BETA (1.45, 1.57)
7	Cut	1	1.82 + 1.15 × BETA (1.14, 1.31)
8	Transfer to clothing area	1	0.14 + 0.17 × BETA (1.73, 1.86)

Source: Own elaboration

Cutting process - improved situation			
N°	Activities	Operators	Current
1	MP store	2	0.02 + WEIB (0.0198, 11.2)
2	Transfer to cutting area	2	0.04+ 0.04 × BETA (2.61, 2.77)
3	Put screen on table	2	0.03 + WEIB (0.0226, 2.65)
4	Place template	1	WEIB (0.00968, 6.05)
5	Fix with tape	1	ERLA (0.00036, 25)
6	Cut	2	0.57 + 0.68 × BETA (1.42, 1.52)
7	Transfer to clothing area	2	TRIA (0.03, 0.045, 0.08)

Source: Own elaboration

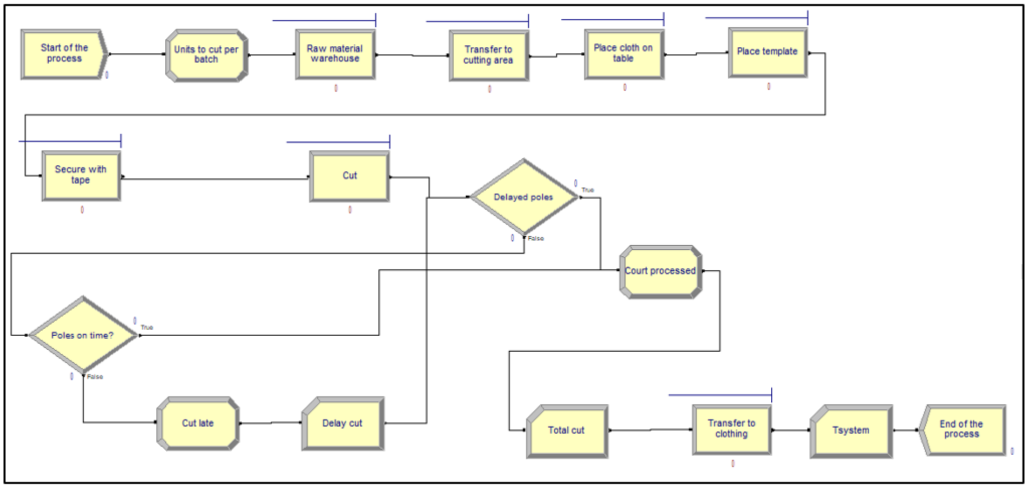

Figure 5: Cutting process system model - Improved situation

Source: Own elaboration

Two results were generated from the two simulations, which were then compared. They are summarised in Table 8.

Table 8: Comparison of current conditions with post-implementation results

	Current		Improvement	
	Calculation	Simulation	Calculation	Simulation
Results	Days	Days	Days	Days
Process time	2.91	3.94	0.84	1.18
Process time with delay	3.40	3.99	1.12	1.11
	3.40	3.99	1.12	1.18
Replicas				
Variation		0.59		0.06
% variation		17.23%		5.78%
Total processes	31.00	31.00	31.00	31.00
Processes with delay	5.00	5.88	2.00	2.83
On-time processes	26.00	25.13	29.00	28.17

Source: Own elaboration

Table 8 indicates that for the current cutting process, the minimal process duration was 2.91 days for an average batch of 845 units. When accounting for delays, the duration was 3.40 days. The simulation indicated 3.94 days for the former and 3.99 days for the latter. By selecting the maximal values, a variation of 0.59 days between them was obtained, translating into a percentage variation of 17.23%. Thus, the improvement process should have remained within or below this value (17.23%). As for the process times, the calculated and simulated values were 26 and 25.13, respectively, while the delayed processes were 5 for the current model and 5.88 for the simulated one.

Furthermore, Table 8 reveals that for the improved cutting process, the minimal process duration was 0.84 days for an average batch of 845 units. With delays, the typically computed duration extended to 1.12 days. The simulation yielded 1.18 days for the initial value and 1.11 days for the latter. By selecting the maximum values, there was a marginal variation of 0.06 days, which corresponded to a percentage variation of 5.78%. It is notable that this was less than the 17.23% variation observed in the current simulation. In respect of process times, the calculated and simulated figures stood at 29 and 28.17, respectively, while the obtained delayed processes were 2 for the calculation and 2.83 for the simulation.

Therefore, the proposed enhancement was validated and deemed feasible.

4.2. Economic validation

For the financial validation, determining the opportunity cost (COK) was necessary. This was ascertained via the capital asset pricing model (CAPM), yielding a COK of 12.98%. The next section discusses the project validation flow.

It was shown that the annual savings amounted to about $21,089, which was less than the total investment. With a NPV of $11,934, greater than zero, and an IRR at 23.46% - surpassing the COK of 12.98% - the project's feasibility was confirmed. The benefit-to-cost ratio (B/C) was found to be 1.31, signifying that for every $1.31 of revenue, the expenditure was $1.

5. DISCUSSION

According to the problem analysis and proposed methodological design, the simulation validation revealed that the objective of reducing the cutting process time from 3.40 to 1.12 days for a batch of 845 t-shirts

set at a benchmark of 2.11 days realised. Furthermore, the reduction in reprocessing because of defects shifted from 13.12% to 4.23%, close to achieving the company's target of 5%. Moreover, the service level increased from 81.51% to 90.39% against the company's goal of 95%. Delayed processes were reduced from 18.49% to 9.61%, against the company's benchmark of 5%. Last, the productivity of the cutting area increased from 0.38 to 1.155, nearing the company's target of 1.3. While certain indicators did not meet the company's aspirations, they remained industry acceptable. Future projections or data for the year following the stabilisation process were anticipated to align with the company's targets.

Based on the literature survey outlined in section 3, which discussed the problems and methodological designs related to the current project, it became evident that the primary factors warranting attention were innovation, productivity, human capital development, and integrated processes. In the case study, two important approaches were employed to address the prevailing issue: (i) low productivity of the area owing to inadequate and non-integrated activities and (ii) workforce imbalances. The lean manufacturing methodology was adopted, given its proven efficacy in time reduction and process enhancement in various studies. The purpose of this implementation was not to be something that began and ended; rather, the aim was to have a sustainable cultural transformation, as suggested by the authors. Specifically, for the case study, tools such as VSM, SMED, and visual control were used. These tools, as affirmed by the authors in section 3, are predominantly used to identify the current situation and production times to pinpoint non-value-adding activities. This facilitated the elimination of bottlenecks and reduced reprocessing and losses in the designated area. To conclude, based on the articles that served as the basis of the project, a 57% reduction in non-value-adding activities was reported across the entire production area, which substantially decreased costs. In this study, a reduction of 16.67% was documented and validated for such non-value-adding activities. The discrepancy between these percentages could be attributed to the production area's size in each study. The current project focused solely on the cutting area; but if the entire production area were considered, the percentage would likely align more closely with the other reports in the literature.

Thus, the objective of enhancing the cutting process through the lean manufacturing methodology and its associated tools was successfully realised.

6. CONCLUSIONS

Based on the analysis that was conducted and the identification of the core problem, a design rooted in the lean manufacturing philosophy was developed, targeting a reduction in defects and waste to eliminate non-value-adding activities. The application of lean tools improved the cutting process, resulting in a reduction in its operational time from 3.40 days to 1.12 days for a batch of 845 t-shirts, surpassing the company's target of 2.11 days.

The productivity index of the cutting area increased from 0.38 to 1.16, positively influencing the overall productivity index. Currently the company is nearing the national productivity benchmark of 1.009, and this upward trend suggests potential improvements in the coming years. With the project's implementation, a projected growth of 1.18 over the national index is anticipated, positioning the company for international competitiveness.

The implementation of these tools resulted in savings of $105,448, accounting for 17.81% of total sales. Consequently, the economic impact diminished from $120,865 to $35,692.

For economic validation, the COK was first determined using the CAPM method, yielding a COK of 12.98%. The cash flow of the project revealed a positive NPV of $9,313 and an IRR of 20.54%, surpassing the COK. This indicated the viability of the project.

It is important that personnel receive the necessary training on the tools and methodologies in a simpler way both for the application and for future solution alternatives when changing and/or transforming the processes. This training would ensure that the communication process within the area was more integrated and fluid, since workers would be able to speak and understand the same language.

To ensure the successful implementation of the lean manufacturing philosophy and the proposed improvements, operators should be open to move on from their traditional practices and to embrace a cultural shift and empowerment through training. They need to recognise that change can usher in efficiency and better results.

DATA AVAILABILITY STATEMENT

All results of the simulation that was included in the paper can be found here: https://drive.google.com/drive/folders/19nRLDGQHdygJmL9WmuOP4TyNHoDaw0bS

ACKNOWLEDGEMENTS

This research work is funded by Dirección de Investigación - Universidad Peruana de Ciencias Aplicadas through UPC-EXPOST-2023-1, with the knowledge contribution of Instituto Politécnico da Bahia - Brazil.

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