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Use Of Lean Manufacturing Tools To Identify The Factors Generating Environmental Impacts Associated With Productivity Waste In The Manufacturing Of Uniforms - A Case Study In A Uniform Manufacturing Industry Based In The Industrial Pole Of Manaus.

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Abstract
This article presents a study that demonstrates the applicability of Lean Manufacturing tools in identifying environmental impact factors in a clothing industry located in the municipality of Manaus, Amazonas. The focus of the study was on the production cells of the company, specifically Cell 1, in the manufacturing of pants and PPEs. The results of the first part of the study revealed that a detailed analysis of the production flow through Value Stream Mapping (VSM) allowed for the identification of non-value-added processes that contributed to waste and environmental impacts, such as improper use of plotting papers, fabric waste in the cutting sector, and electricity usage in the sewing sector. The second part of the study highlighted the challenges encountered in the company's production process, including unplanned downtime, unbalanced operations, and interruptions for the insertion of different products on the same production line. The application of Lean tools such as Takt Time, TRF, Continuous Flow, Heijunka, and Standardized Work was identified as crucial in improving operational efficiency and reducing waste, thereby contributing to the minimization of environmental impacts. The overall results of the study showed that the application of Lean Manufacturing tools allowed for the identification of processes associated with invisible environmental impact factors, resulting in a significant reduction in waste indicators, especially in delivery, intermediate stocks, and rework rates. Additionally, there was a noticeable decrease in energy usage and textile waste disposal, generating a positive environmental impact. The study also presented a framework of conditional indicators and goals, revealing significant progress towards more efficient and sustainable production, with an overall reduction of 45% in waste indicators and established goals of at least 20% reduction in each indicator related to environmental impacts. This study demonstrates the effectiveness of Lean Manufacturing approaches in promoting more sustainable practices in the clothing industry.

Key words: *Lean manufacturing; Clothing industry; environmental impacts.*

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I. Introduction

Over the past few decades, there has been a noticeable growth in demand for products within the fashion industry. However, the expansion of this industry faces a paradoxical challenge that outlines crucial issues related to economic and technological development, juxtaposed with fundamental issues related to environmental sustainability. As a result, the interest of the academic community in this paradoxical context has become increasingly frequent. Therefore, the aim of this study is to research these aspects that guide sustainable practices in the clothing industry.

Alves and Fernandes (2020), point out that sustainability questions concepts such as the materials used, how they are produced, and their ecological viability. (ALVES; FERNANDES, 2020).

In this sense, the industrial production of clothing should be observed, with a focus on production models, as well as on the observance of practices that diverge or contribute to more sustainable actions.

Toniol and Alberi (2020) raise another complementary aspect for the relevance of delving into academic studies with a focus on practices and production models adopted in the fashion industry. According to the authors, the question raised in these studies goes beyond economic relevance and industrial technological development, which lead to waste generation and consumption of raw materials, as the demand for clothing products is a matter of human necessity in aspects such as anthropology, culture, and society. (TONIOL; ALBERI, 2020).

According to the authors, clothing is one of the cultural manifestations that drives an economic structure, especially when treating clothing creation as a cultural practice that, by promoting consumption, moves this industry and generates economic interest. (TONIOL; ALBERI, 2020). However, it is known that mass production, inefficient resource management, and lack of environmental awareness have contributed to waste generation with negative impacts on the environment.

Pinheiro and De Francisco (2013) state that due to the expansion of activities in the textile manufacturing industry, there is an increase in inputs, energy, water, and materials, and consequently, an increase in waste throughout the production chain. (PINHEIRO; DE FRANCISCO, 2013). In this context, there is a need to identify and address waste factors that generate these impacts, with the aim of seeking sustainable solutions for the sector, as pointed out by Linke and Zaniarato (2022).

Waste production and management is a problem in today's society, and one of the productive sectors that deserves attention regarding waste is the fashion industry. The clothing manufacturing industry is part of this sector, and waste generation is significant, especially fabric scraps. (LINKE; ZANIARATO, 2022).

According to Buzzi, Ribeiro, and Carlesso (2013), concerning the challenges faced by the clothing industry regarding sustainability and waste identification, a relevant segment that deserves attention is the production of uniforms. According to the authors, the manufacturing of uniforms is an essential activity in various sectors of society. However, large-scale production of uniforms and a lack of management in this process can result in significant resource waste, as well as economic and environmental impacts for the company. (BUZZI; RIBEIRO; CARLESSO, 2013).

Therefore, it is believed that an effective alternative would be to explore the functionalities of Lean Manufacturing tools in order to identify and mitigate these waste factors that generate environmental impacts in the uniform manufacturing processes, while also presenting itself as a valuable perspective to align the growing demand for these products with the imperative of environmental Sustainability

According to Linke and Zaniarato (2022), Lean Manufacturing methodology can be an effective alternative in reducing waste and increasing production efficiency. It has been widely applied in various industrial sectors with a multidisciplinary approach and, in this sense, can contribute to identifying environmental impact factors arising from unconventional production practices and models. (LINKE; ZANIARATO, 2022)

According to the authors, in relation to the clothing industry, when we consider the high volume of production and consumption of resources used in this productive activity, it is configured as one of the industries that generates the greatest negative impacts on the environment, mainly in the disposal of textile waste during and during the dyeing process, and which is partly due to the high consumption of water and energy resources and waste generation, making it a medium-level polluter. (LINKE; ZANIARATO, 2022)

Ghobakhloo and Azar (2017), state that lean manufacturing is considered the most important tool for improving performance in an industry, as its main focus is to achieve success through continuous waste reduction. (GHOBAKHLOO E AZAR, 2017).

In this sense, it is estimated that through a systematic and continuous improvement-focused approach, Lean tools allow for the identification and elimination of inefficiencies in processes, reducing the demand for raw materials and minimizing environmental impact.

Link and Zanirato (2022) believe that the application of Lean manufacturing tools can also be a promising strategy for the clothing industry in the search for more sustainable and environmentally balanced production. (LINKE; ZANIARATO, 2022).

Considering the above, it is relevant to inform that this article started from the investigative premise regarding the use of lean manufacturing tools to identify environmental impact factors related to the sources of waste in raw materials, energy, and waste management in a professional uniforms and PPE industry located in the PIM - Polo Industrial de Manaus. Therefore, the study aimed to map the production flow and thus identify operational practices that resulted in significant losses of energy, inputs, materials, time, and other factors that cause environmental damage. In addition, sustainable solutions were proposed that can be implemented by companies in the sector to reduce the environmental impact of their activities.

II. Materials and Methods

Research Site Characterization

The research field for this study was an industry specialized in the production of professional uniforms, caps, and PPE, located in the Industrial Pole of Manaus (PIM). With over 30 years of experience in the market, the company currently employs 45 employees, with 32 positions solely dedicated to pre-production and production sectors. The production infrastructure consists of modern and highly technological machinery and equipment, including industrial machines with electronic panels and direct drive motors, as well as semi-automated equipment such as computerized modeling systems (CAD) and a grafting table equipped with an infestation system (CAM).

The physical layout in the sewing department, consists of 3 distinct cells: Flat Fabric, Knitwear, and Caps and PPEs, along with a unified subsector where finishing, inspection, pressing, and product packaging activities take place. For the purpose of analyzing the production process, we have selected the production line for flat fabric and professional denim uniforms, which will be referred to as "Cell 1" here. The line was chosen because it represents the highest production volume. According to data provided by the company, only the flat fabric line (Cell 1) produces the equivalent of 45% of customer order demand, with the remaining 35% represented by knitwear products and 20% by caps, respectively.

Although the layout encompasses the three cells mentioned above, during the on-site reconnaissance visit, it was observed that the layout is not suitable for continuous flow production. As shown in figure 1a, there is empty space in the arrangement of machines in Cell 1, leading to the accumulation of workpieces (intermediate stock) that are in production, as demonstrated in Figure 1b.

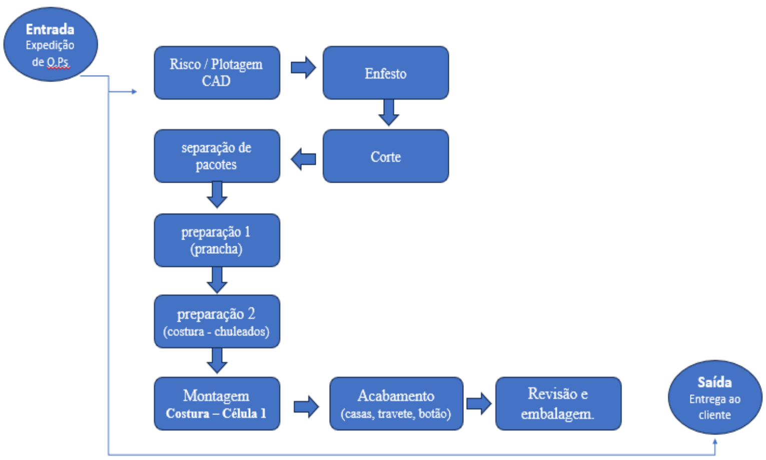
Figura 1: a) Current state layout; b) Intermediate stock on the production line

Source: Authors (2023).

After the visual verification of the aspects mentioned earlier, it became evident that there was a need to create a flowchart of this process to provide a simplified visualization of the production flow for pants and other similar products produced in the cell under study. As demonstrated in figure 2, the process follows the following production stages: CAD - pattern/plotting, spreading, cutting, package separation, preparation 1 (pressing), preparation 2 (sewing and edge stitching), assembly, finishing, and finally, inspection and packaging.

The flowchart in figure 2 succinctly presents the sequence of operations related to the production of pants and similar products based on on-site observations. It excludes all stages preceding the actual manufacturing processes to generate a more objective and focused analysis.

Figure 2: Flowchart of pants and similar products production



Source: Authors (2023).

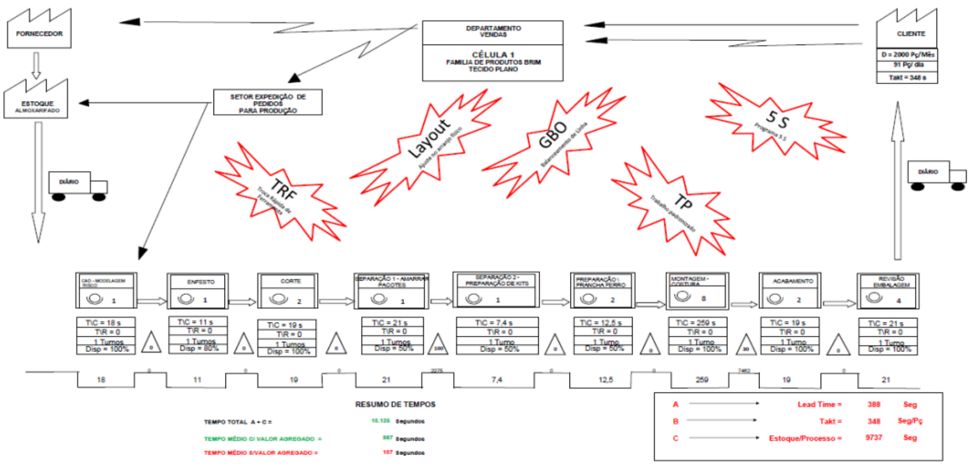
Methodological Procedures

In the mapping process, we considered the significance of the items produced in Cell 1, as identified in the company's documentation for a 90-day period before the start of this study. To compile data and achieve results, we chose to monitor the process through sampling, tracking the production flow of a batch of 91 pants from its entry into production to its completion. After visually identifying aspects related to the layout and production flow, we proceeded with more technically detailed data collection by using the VSM - Value Stream Map tool (Figure 3). This allowed us to identify processes and subprocesses with indications of greater waste potential, which might remain hidden without the application of this mapping tool. The mapping process, through the observation of non-value-added processes in the production flow, initially took place in the sewing departments: professional line and PPEs, as well as the adjacent departments: plotting and cutting, as these two mentioned earlier represent the beginning of the production flow.

In this context, after applying the VSM tool, combined with the analysis of documents and a previous interview conducted, it was possible to identify that the predominant production method in the company is pull-based. This type of production method relies on customer orders, which in a way ensures that the company does not generate finished product inventory.

During this data collection process, it was also necessary to perform, in addition to visual tracking, cycle time measurements to establish lead times, identify empty or unused spaces, intermediate stocks, rejects, paper and textile waste disposal, rework rates, and any signs of overproduction.

Figure 3: Current State VSM – Value Stream Map



Source: Authors (2023)

The Figure 3 shows the mapping of the production line flow in order to establish the situational diagnosis of the analyzed cell.

During the data collection process, as highlighted in the VSM, several key factors were taken into account for subsequent data analysis. These factors included timing and recording cycle time values for each step, the number of operators and their availability per shift, machine setup, and the arrangement of machines and operators in the physical layout (Figure 2). Additionally, the collected data was recorded and organized in Table 1 to facilitate both qualitative (root cause) and quantitative (volume and dimension) analysis.

In the plotting department of the industry, the waste factor tracking process involved identifying the accumulation of discarded paper due to errors in the cutting process. In the cutting department, the focus was on tracing the origin of high levels of textile waste resulting from batch processing in denim pants cutting. Based on the data collected using the VSM and visual monitoring of the production flow in sectors such as sewing, cutting, and storage, the information was tabulated. This data served as a basis for qualitative analysis of waste rates and the identification of performance indicators for tracking results.

Finally, to implement an environmentally impactful production model in the industry, a meeting was held with the leadership team from the analyzed sectors to develop an action plan based on the 5W2H tool. Through the presentation of the collected and analyzed data, specific Lean tools were proposed for use and application. These tools aimed to reduce environmental impact by a minimum of 20% in waste generation.

III. Results and Discussion

The results were generated within the scope of the shop floor, specifically in the sewing sector: Cell 1, and adjacent departments: plotting and cutting, where the production flow was observed. The production line chosen for this study, according to data provided by the company, was the one with the highest production volume, which consequently represented the greatest potential for environmental impact generation.

To validate the proposed environmentally mitigating production model, we also sought to assess the contribution of Lean tools in the development of the production model/management, based on the records made and the systematic monitoring of evidence, whether positive or negative, observed during the manufacturing process. Lean tools were used in this process for both identifying and applying new processes that had been analyzed and for creating a framework for compiling waste-generating factors and their relationship with the environmental impacts caused by the company.

To achieve the objectives outlined in this study, the following steps were taken: a situational diagnosis that prompted visits for visual process production monitoring. At this stage, initial data collection was conducted, including flow, movement, intermediate stocks, layout, and the generation of textile and paper waste, which were then tabulated.

Following visual identification, the application of VSM (Value Stream Map) (Figure 3) was initiated through data collection and monitoring of the production flow to support the creation of an analytical framework for waste factors and their relationship with environmental impact indices. Subsequently, an action plan was developed based on the evidence generated in the VSM to select and apply lean manufacturing tools and propose a prospective framework for the future state.

Through the application of Lean tools and analysis and documentation of the achieved results, it was possible to observe that the most significant aspects identified during the analysis of the production process were: the production pace that was not in line with the demand, an unfavorable layout for continuous flow production, as shown in Figure 1a, and the absence of technical guidance to the sewing team during task distribution. Although there was an effort to standardize sewing operations during the visual monitoring of the production flow, excessive movement between the product assembly stages was observed, leading to constant intermediate stocks, as depicted in Figure 1b.

Other equally relevant aspects that were identified relate to unplanned production stops for operator changes, operations with inadequate balancing, exacerbated by frequent interruptions in the process for the insertion of two or more concurrent products on the same production line, as demonstrated in Figure 4.

Figure 4: Multiple batches of production halted and insertion of different items in the same cell.

Source: Authors (2023).

Furthermore, constant out-of-time setups were identified, leading to unplanned stops for thread color changes and appliance/foot changes. During these moments, the machines remained powered on for approximately 12.5 minutes per day, resulting in unnecessary energy consumption amounting to 3.4 KW/hour per month. Additionally, there was material transportation and stalled pieces within the flow due to an unfavorable layout for continuous flow, resulting in 10.72 KW/hour per month, as demonstrated in Table 1, among other situations revealed in the VSM (Figure 3), representing non-value-added activities in the production process.

In this context, the resulting data indicated that problems stemming from an excessively long Lead Time, a high waiting time index, movement, evidence of intermediate stocks, waste, and rework provided the basis for the creation of a comparative table (Table 1). This table relates waste factors and environmental impact-generating indices observed in the analyzed company, in analogy to the criteria used in Sustainability Scorecard studies adopted by other companies in the same industry.

It was also possible to verify that among the indicators presented in Table 1, the following stand out: those that showed the worst level in terms of environmental impact were the textile waste generated during the cutting process, as these waste materials were disposed of in a common trash bin, which significantly harms the environment and was classified as severe. This was followed by the disposal of paper from the plotting department, which also ends up in a common trash bin but in smaller quantities generated monthly, so it was classified as moderate.

On another note, but of equal importance to this study, the indicators pointing to energy use impact factors classified as severe are: the waiting time for intermediate stocks of stalled pieces within the flow, as it leads to machines running without value-added operations in the production flow; and subsequently, the waste/rework rate, as it leads to excessive energy use due to machines being operated to fix defective pieces after the batch in the cell is completed.

It is also noted that although setup time results in machines running without value-added operations in the production flow, it was classified as moderate because the setup time can be programmed using the quick tool change methodology within the intersections of operations in the same batch and included in the production flow without a direct impact on excessive energy consumption.

Table 1: Waste Factors and Environmental Impact Generating Indices

Information gathered during the situational diagnosis of the company under study.						
INDICATORS	**UNIT OF MEASUREMENT**	**SOURCE GENERATOR**	**DESTINATION**	**ENERGY CONSUMPTION IMPACT FACTOR**	**VOLUME GENERATED IMPACT FACTOR**	**LEVEL - AGGRAVATION FACTOR**
Discarded paper	1,5 kg/day	Plotting	General waste	Unspecified	45 kg/month	medium,
Textile waste	29,5 kg/day	Cutting spreading	General waste	Unspecified	885 kg/month	heavy
Estimated wait time (Machine setup) - machines running without value-adding operations to the production flow.	5 stops of 2.5 minutes 12.5 minu/day	Sewing Department - Cell 1	Unspecified	3,4 kwh/month	Unspecified	medium
Intermediate inventory - parts halted within the flow - machines connected without adding value to the production flow.	161,6 min/day	Sewing Department - Cell 1	Unspecified	44,38 kwh/month	Unspecified	heavy
Scrap rate - machines connected to repair parts after production has concluded	14 pç/dia **39** min/day	Sewing Department - Cell 1	Unspecified	10,72 kwh/month	Unspecified	heavy

Source: Authors, (2023).

Based on the analysis of collected data (Table 1) and observation of the VSM (Figure 3), it was realized that there was a need to develop and propose a new framework (Table 2) that would highlight the previously mentioned indicators and indicate the relationship of the Lean tools that were applied in the implementation of a mitigating production model for the generated impacts and for achieving results. This framework also highlights some other established criteria of the methodology and objectives, such as a minimum goal of a 20% reduction in the indices observed in the current state.

Next, the waste indices in percentage terms are detailed, in relation to impact indicators and the application of Lean tools with a specific focus on the sewing sector, according to the methodological approach employed in this study.

Table 2: Relationship of impact indicators and application of Lean manufacturing tools.
Situation found in the current state of the sewing sector - data extracted during the mapping.

INDICATORS - SEWING SECTOR - CELL 1	**IDENTIFIED VALUES**	**GOALS FOR REDUCTION**	**IDEAL VALUE**	**LEAN TOOL APPLIED**	**WASTE INDEX**	**LEVEL - AGGRAVATION FACTOR**
Cycle time (lead time)	4,5 days	20%	3,6 days	Takt Time	12%	heavy
Wait time (Machine setup) - 5 stops 2.5 minutes/day	12,5 min/day	20%	2,5 min/day	SMED - Single-Minute Exchange of Die (Quick Tool Change)	8%	medium

Excessive movement	54,7 m/day	20%	10,9 m/day	Continuous flow - layout	5%	Light
Intermediate stock	150 pieces/day	20%	30 pieces/day	Heijunka	10%	heavy
Scrap/Rework rate	14 pieces/day	20%	2,8 pieces/day	STP - Standard Work	10%	heavy
Totals					45%	

Source: Authors (2023).

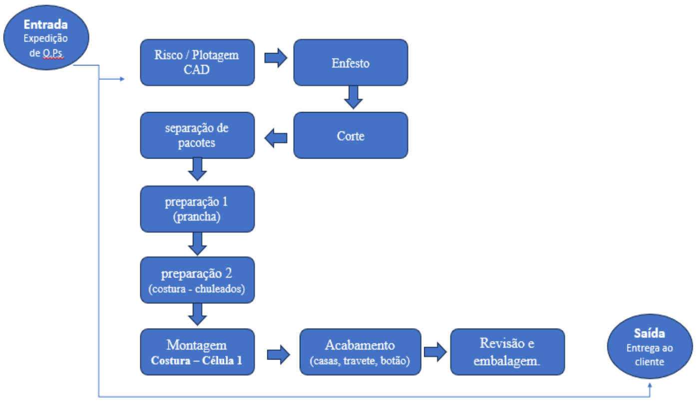
In (Table 2), waste indices in percentage values are demonstrated, up to a limit of 45%, specifically related to the sewing sector. According to lean methodology, a tool was applied for each indicator that allowed for a minimum reduction of 20%, as established by the target.

As a guiding model, (Table 2) indicates the severity levels concerning environmental impacts, those indicators that are equal to or exceed 10% of the total 45%, since for each indicator, desirable values are based on a minimum reduction target of 20%, in other words, double the value. Indicators with values below 10% in terms of severity are considered moderate, those below 5% , are considered mild or incipient.

As shown in the table (Table 2), it relates to the effort to minimize the analyzed indicators at the time of data collection VSM (Figure 3) and compiled in the table (Table 1). Thus, there is a noticeable gain in reducing movement, followed by productivity in production volume, and gains in quality by reducing rejects/rework, especially in reducing energy and textile waste disposal that has an impact on the environment.

Regarding the analysis of the productivity index, the gain was achieved through an average increase of 2.7 pieces per hour of work. This increase in the number of pieces produced reflects the result of an improvement in the flow, concentrating production through the First In First Out (FIFO) concept, meaning producing one batch of products at a time, without interrupting the flow for the entry of other products. To propose a continuous flow production model, the production flowchart of a batch of 91 pants was analyzed.

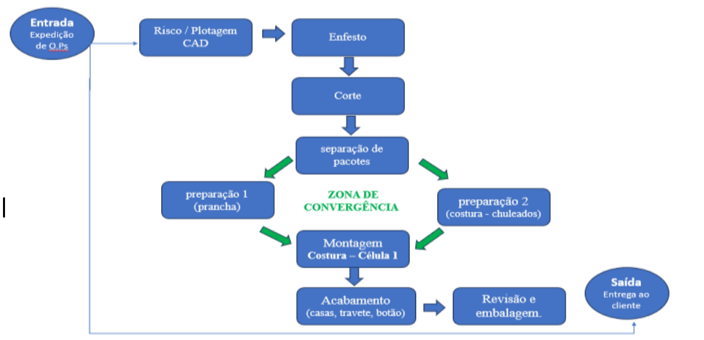
Figure 5: a) Initial State Flowchart



Source: Authors (2023).

Upon analysis, the flowchart (Figure 5a) appeared extensive without a convergence line between adjacent sectors, which led to the need to propose a new flowchart (Figure 5b).

Figure 5: b) Proposed Flowchart



Soure: Authors (2023).

Figure 5b presents a new flowchart that allowed for the creation of a convergence zone among adjacent sectors: Package Separation, Preparation 1, Preparation 2, and Assembly; thus significantly reducing the waiting time for standard parts in previously isolated sectors.

Another aspect considered in this study relates to the analysis of movement index and waiting time, focusing on the time machines and other equipment are idle, and operators are idle, in order to relate the impact factors generated by the unnecessary use of energy.

It was observed that one of the complicating factors in this aspect was related to the physical layout, and thus, this was the subject of study and optimization through the reconfiguration of the pre-existing layout for a new proposal of machine arrangement in the cell under study.

After analyzing the pre-existing layout, the need for alteration was observed, and a new arrangement was proposed, with machines and equipment strategically repositioned based on common characteristics, frequency of use, and/or sequential dependence of operations. In order to improve the reduction of movements in the production environment, a strategy of utmost importance for this purpose is the introduction of a fixed conveyor (referred to as a central board) between the machines, thus eliminating empty spaces and facilitating the effective transport of parts within the production cell, as illustrated in figures 6a and 6b.

Figure 6: a) Old Layout; b) New Layout with Central Conveyor.

Soure: Authors (2023).

Regarding the analysis of the quality index, considering that there was an average incidence of 14 rework pieces during each 528-minute shift per day, efforts were made to establish clearer criteria for standardizing methods for the production of professional pants.

Positive results in reducing the reject and rework rate were achieved through the application of Lean tool (Standardized Work - SW), as demonstrated in Figures 7a and 7b. It can be observed that the number of defective pieces at the end of each work shift reduced from 14 to an average of 6, with a reduction of over 50% in the rework rate.

Considering that this indicator was classified as severe in the impact indicators table and the application of Lean tools (Table 2), and that the severity index regarding environmental impacts exceeded 10% of the sewing sector's indicators, it was observed that after the application of Lean tools, the gain was a reduction to less than 5%, reclassifying it as mild or incipient within the applied model.

As demonstrated in the figures (Figure 7a and Figure 7b), standardization was achieved through the development and use of SOPs (Standard Operating Procedures), specifically in the assembly of product kits, from receipt and subsequently when inserting batches of products into the cell, thus eliminating errors arising from assembly doubts and lack of technical information.

The detailed analysis of the aforementioned aspects led to the creation of two tables: the first one (Table 1) related waste factors and environmental impact generating indices, highlighting issues such as textile and paper waste disposal, excessive energy usage due to machines running idle, and other critical problems. The second table, (Table 2), set reduction targets and linked them to the Lean approach for addressing each identified problem. Such analysis demonstrated the need for a minimum 20% reduction in waste indices to achieve desirable results.

The indicators were, therefore, classified based on the severity level concerning environmental impacts, with values exceeding 10% considered severe.

Based on the thorough analysis of the results obtained, it is possible to highlight substantial gains in various critical aspects within the company's production context. These gains encompass a noticeable reduction in movements, increased productivity, specific quality improvement through reduced rejects and rework, as well as a significant reduction in energy consumption and textile waste generation.

In this context, it can be concluded that this study outlined and precisely addressed crucial areas for improvement within the company's operation, implementing strategies based on the Lean philosophy to achieve waste reduction goals and identify factors generating environmental impacts. Furthermore, this study highlights substantial benefits in terms of operational efficiency, supported by Lean tools linked to the identification of environmental impact factors, thus contributing to the mitigation of environmental impacts and emphasizing the relevance of these findings in guiding corrective measures and strategies aimed at optimizing the overall performance of the company. Therefore, it is considered that the intervention model adopted in this study, if applied in other companies with similar characteristics, constitutes a useful and feasible tool in achieving these objectives.

IV. Conclusion

This study demonstrated the applicability of Lean Manufacturing tools for identifying environmental impact factors in a clothing industry located in the city of Manaus.

The study was divided into four phases: diagnosis (mapping), data analysis, model implementation, and result validation, based on the use of Lean Manufacturing tools, with a focus on production cells and adjacent sectors.

It was noted, therefore, that in the first phase, the mapping process conducted in this study enabled a detailed understanding of the production flow in the company's Cell 1.

Through a meticulous analysis of the collected data, it was possible to conclude that this study not only identified processes that do not add value but also highlighted processes and subprocesses that contributed to the generation of waste and environmental impacts associated with inadequate resource and material management. These impacts included the improper use of plotting papers, improper handling of fabrics in the cutting sector, and excessive electricity consumption in the sewing sector. These results were obtained through the application of the Value Stream Mapping (VSM) tool, which proved to be highly suitable for instantaneously analyzing the production flow, allowing for a significant situational diagnosis of the cell in question.

The study also revealed a series of challenges encountered in the company's production process, such as unplanned stops, unbalanced operations, and interruptions for the insertion of different products on the same production line. In this context, the importance of applying Lean tools, such as Takt Time, SMED (Single-Minute Exchange of Die), Continuous Flow, Heijunka, and Standardized Work, is emphasized to address these issues and improve operational efficiency. These methods contributed significantly to waste reduction and the minimization of environmental impacts.

The overall results pointed to the identification of processes that were initially imperceptible but linked to environmental impact factors. The application of Lean Manufacturing tools resulted in a significant reduction in waste indicators, with a focus on reducing energy consumption and textile waste disposal, thereby contributing to the mitigation of adverse environmental impacts.

The study also presented a framework of indicators and conditional goals reflecting progress toward more efficient and sustainable production, highlighting an overall 45% reduction in waste indicators and the achievement of at least a 20% reduction in each indicator related to environmental impact factors. Thus, the study demonstrated that Lean tools can be applied to various segments of the industry.

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