Implementation of Lean Manufacturing to Increase the Productivity of a Retreading Company

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Keywords: Retreading, Lean Manufacturing, Partial Labor Productivity

Abstract

The manufacturing sector is one of the pillars of the national GDP, so any inefficiency in its processes directly impacts the country's competitiveness. In this context, the company under study exhibits low partial labor productivity of 0.811 units/hour, along with a high circulation time within the tire retreading process. The application of Lean Manufacturing proved effective for waste reduction and continuous improvement. The problem analysis identified the application of 5S, which fostered an organized work environment by reducing material search times during cementing; Standard Work, which standardized scraping and banding activities, decreasing waste and rework; and SLP, which optimized the layout of areas to reduce internal travel and improve process flow. After implementing the Lean Manufacturing tools, which were validated through a pilot project and simulation in Arena, the company achieved an improvement in partial labor productivity to 1.117 units/hour. and circulation time was reduced due to the new layout.

1 Introduction

The automotive industry is one of the most important sectors in the market, as global car sales reached 74.6 million units in 2024, representing a 2.5% increase compared to 2023 [1]. Furthermore, in 2025, the country registered a 17.5% growth in light vehicle sales compared to the same month of the previous year [2], reflecting a larger potential market that will provide the company with an opportunity as a supplier in extending the lifespan of tires. According to a report by The Business Research Company, the tire retreading market reached $7.67 million in 2024 [3].

Retreading is not the only alternative for recycling or extending the life of used tires or their component materials. Other methods include re-threading, combustion, pyrolysis, and reuse [4], fuel production and energy recovery, and engineering applications. Electromagnetic separation of granulated components is used to extract metal inserts, and pulverization and separation are used to extract textile fibers. Milling is used to extract rubber powder [5]. Furthermore, research demonstrating improvements in the quality of materials used to extend tire life was also reviewed. For example, in treads, compounds reinforced with modified carbon black have shown better adhesion, less abrasion, and greater durability [6].

Despite the opportunities presented, the company still exhibits various variations and inefficiencies that disrupt the continuous flow and hinder optimal line performance, thus impacting labor productivity—a crucial aspect for strengthening the sector's competitiveness, especially considering its low recognition by the government and society. Currently, the company produces an average of 519 retreaded tires per month, with an average monthly labor productivity of 0.811 units/man-hour. With Lean Manufacturing tools, an increase of at least 23.2% is expected, a result achieved by Kumar et al., 2022 [7], where Lean Manufacturing tools were implemented in a company in the same sector.

The root causes, presented in Fig. 1, were identified using quality tools such as the 5 Whys. Based on this, the necessary research was developed to determine the precise tools that would significantly increase labor productivity. Based on the results obtained from authors mentioned later, it was decided to implement the 5S, SLP, and Standard Work methodologies. Previous studies have identified some reasons why labor productivity is affected, including education, age, training, and human capital [8], as well as travel times and defects found in the process. For the latter, it has been documented that the Endurica CL software was used to identify defects, contributing to a better understanding of rubber behavior under fatigue conditions [9]. Furthermore, recent research employs predictive modeling techniques using machine learning to anticipate tire performance and optimize resource allocation [10].

The main objective of the study was to increase labor productivity in the retreading process by applying Lean Manufacturing tools, demonstrating their effectiveness and leaving a clear and repeatable operating procedure that contributes to strengthening continuous improvement in the company.

Specific objectives:

- Improve the tire retreading production process flow to increase manual productivity by 24%.
- Decrease average monthly unproductive hours due to transport and search using SLP and 5S tools.
- Reduce the number of defective items resulting from scrap and rework using Standard Work tools.
- Validate the effectiveness of implementing Lean Manufacturing tools as a solution to low productivity, using Arena software.

The study will answer the research question: Can the implementation of Lean Manufacturing tools improve productivity in the retreading process?
The general hypothesis is that partial labor productivity will reach more than 1 unit/hour.
H0: u <= 1 unid/h-h
H1: u > 1 unid/h-h

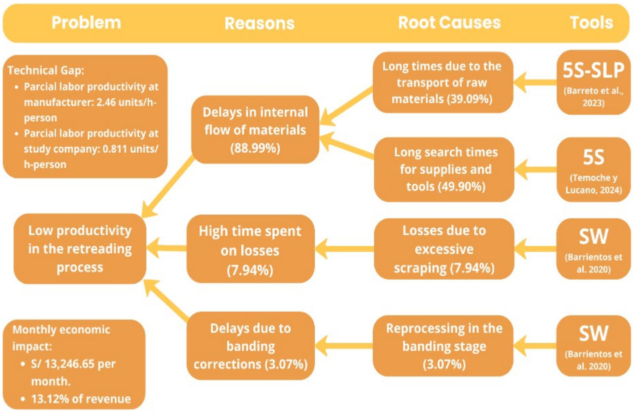


Figure 1. Problem tree diagram

The research will be divided into four parts. The first section will be the introduction, which focuses on the importance of the study, the company's context, and the problem to be analyzed, as well as a literature review of the tools mentioned in past studies related to the problem and the root causes of the research. The second section will present the methodology implemented, outlining the data collection methods and the procedures followed. The third section will present the results obtained after implementing the improvements and compare them with the current situation and success stories from external authors. Finally, the fourth section will present the conclusions of this research.

2 Methodology

This research is a quantitative study employing a mixed-methods approach. Initially, simulations were developed based on Systematic Layout Planning (SLP) and Standard Work, along with the application of the 5S methodology. These simulations drew upon previous studies by other authors. Subsequently, data was collected and calculations were performed to obtain real-world results for the indicators. Figure 2 illustrates the conceptual model, presenting current indicators related to root causes as input data and expected results based on literature reports as output data. These reports indicate that using 5S resulted in an approximately 20% reduction in worker travel time [11], that implementing SLP reduced operator travel time from 53 hours to 22.84 hours (a 56.91% decrease) [12], and that the application of Standard Work demonstrated an 8% reduction in the defect rate [13]. Evidence of this change is found in the dependent variable: labor productivity.

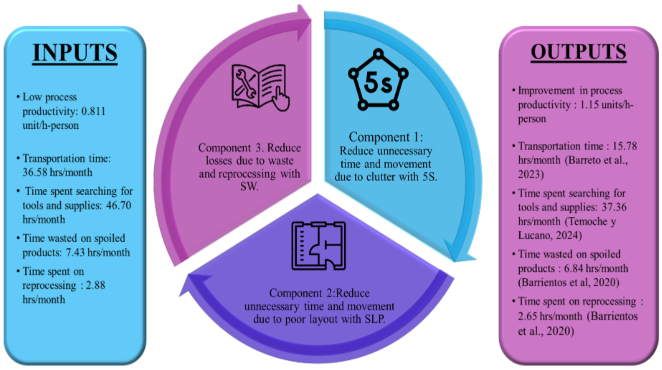


Figure 2. Conceptual Model.

In the simulation, two scenarios are developed: the AS IS scenario and the proposed TO BE scenario. Standard time data is used in the first-time study, while the most realistic data possible is used for the second scenario. [14] For the AS IS data collection, time study formats were used, applied through direct observation and by a trained operator. Critical activities were identified, cycle times were recorded, distances were measured, and incidents were documented. Subsequently, for the TO BE scenario, the same procedure was applied during the pilot, replicating the measurements under the proposed conditions.

The measurements considered included cycle times, downtime, distances travelled, defect frequency, and labour productivity. The measurements were carried out using basic tools such as digital stopwatches, measuring tapes, and inspection sheets.

To validate the AS IS model, a simulation was conducted using real process data, running for 20 eight-hour workdays. The resulting indicators were compared with the collected real data, revealing a variation of less than 5%. Consequently, the model was deemed statistically acceptable, viable, and reliable for accurately representing the system's actual state.

2.1 Data collection

Initial data includes records of unproductive time, defects, and rework generated over a one-year period (2024). This data was obtained through company information and data collection using stopwatches and recording templates.
For the implementation of the techniques, given a finite population, a sample size was determined, calculated using the following formula [15]:

$$n = \frac{N * Z^2 * p * q}{e^2 * (N-1) + Z^2 * p * q} \qquad (1)$$

N = Population

n = Sample size

Z = Statistical parameter according to the Confidence Level

e = Margin of error

p = Probability of the studied event occurring

q = (1-p) = Probability that the studied event will not occur

The value of "N" indicates that approximately 519 tires are retreaded per month. The confidence level of "Z" is 90%, "p" and "q" are both 0.5, and the margin of error "e" is 5%. This results in a sample size of 178.09 ≈ 178 retreaded tires.

To determine if the selected samples are appropriate for the research study and to obtain a more realistic result, the following inclusion and exclusion criteria were applied.

Inclusion criteria

- Acceptable condition for retreading: This refers to tires that passed the initial inspection and were suitable for retreading
- Tire type: Only canvas tires are considered for retreading.

Exclusion criteria:

- External interventions: This refers to tires whose processing was interrupted due to power outages.
- Administrative cases: This refers to tires that suffered delays due to permit or billing problems.
- Operator performance: Observations where operator performance was affected by extraordinary conditions (physical discomfort, severe fatigue) are not included.
- Tire manufacturing date: Tires manufactured more than 3 years prior will not be included in the retreading process.

2.2 Procedure Description

As shown in Figure 3, the research methodology begins with a diagnosis of the retreading process. This involves collecting data provided by the company and conducting interviews with the plant manager to determine the main problem and its root causes. Next, a literature review was performed to select appropriate solution tools. The following phase is the formulation of the conceptual model, which is related to the problem tree in Figure 1. This model must be validated by the research advisors. Once approved, an action plan is prepared and presented to the company manager for authorization to proceed to the next stage. The third phase involves implementing the selected tools, based on the pilot sample size. Once the correct implementation is approved, post-improvement data is collected. The research will be validated using Arena software. The retreading process, representing the TO BE model, was diagrammed in Arena, and the necessary formulas were modeled to obtain the respective indicators and compare them with the results prior to implementation.

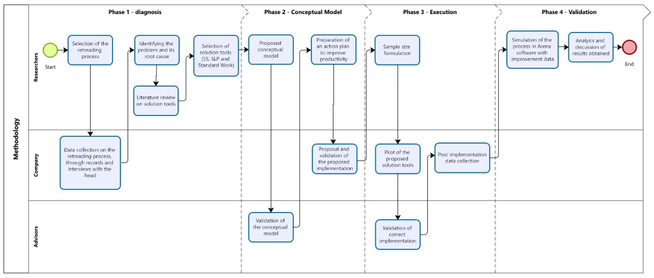
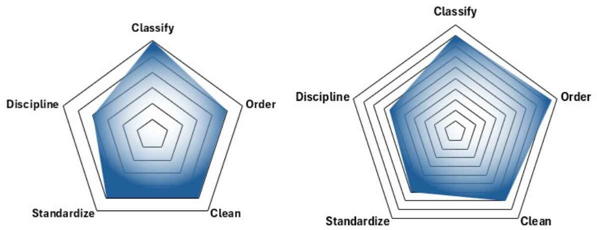


Figure 3. Research methodology

3 Results

This section presents the results obtained after the application of the 5S, SLP and Standard Work tools in the retreading company, which will be validated with a simulation in the Arena software, in which 12 replications will be made where each one simulates a period of 20 days of an 8-hour shift, complemented with the Input/Output Analyzer tools, for which a pilot test was carried out on a sample of 30 tires.

The 5S methodology provides a solid foundation for implementing other techniques. In the study by Vargas & Camero (2021), it was found that unnecessary time spent searching for materials and transporting personnel was reduced, and the organization and cleanliness of the production area were improved. [16] Figure 4 shows the results of the rating matrix before and after the implementation of 5S, evaluated using a checklist applied progressively at each stage. The compliance level increased from 25% initially to 80% after the intervention. Furthermore, unproductive time spent searching for supplies and tools located outside the designated area was reduced from 46.70 hours per month to 27.66 hours per month, representing a 40.76% reduction.



Category	Result
Classify	30%
Order	25%
Clean	25%
Standardize	25%
Discipline	20%
Average	25%

(a)

Category	Result
Classify	90%
Order	95%
Clean	80%
Standardize	70%
Discipline	65%
Average	80%

(b)

Figure 4. (a) Initial rating matrix result, (b) Final rating matrix result

Complementing the 5S methodology, the analysis of the relational diagram allowed for the identification of excessive travel distances and traffic congestion. With the new layout proposed using Systematic Layout Planning (SLP), the travel time to and from the warehouses was reduced from 36.58 to 24.41 hours per month, representing a 33.28% improvement.

Furthermore, the implementation of Standard Work resulted in a significant decrease in defects and rework. Following the standardization of critical activities in the pilot test, manual errors in the scraping stage that caused waste were reduced by 100%. On the other hand, regarding rework generated in the banding stage, a reduction in the duration of the activity was recorded; however, the number of reworks increased by 3.19%. Due to the small sample size and the fact that the operators are still learning and adapting to the new method and specifications, it is likely that the learning curve caused variations in performance, which diminish as the operators become accustomed to the standardized method.

To validate the proposed improvement, a simulation model was developed and designed entirely by the authors in Arena, represented in Fig. 5 as the TO BE model, with the purpose of obtaining the operational indicators and comparing them with the initial values, based on the distributions obtained from the pilot test.

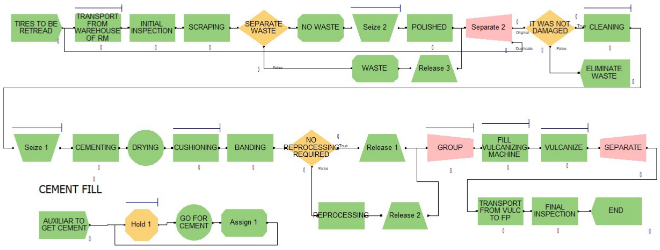


Figure 5. TO BE model of the process in Arena

As shown in Figure 6, the Output Analyzer allowed us to obtain the averages, confidence intervals, and variances of the main indicators. With a 95% confidence interval, it is observed that the averages of the comparisons are not overlapping, which indicates that the difference is not due to chance; therefore, it can be stated that there were changes with the implementation. Overall, the statistical analysis allows us to reject the null hypothesis (h0) that stated that there would be no differences between both scenarios and to accept that the implementation produced real changes in operational performance. Furthermore, reductions in the width of the intervals can be observed, implying a more controlled process.

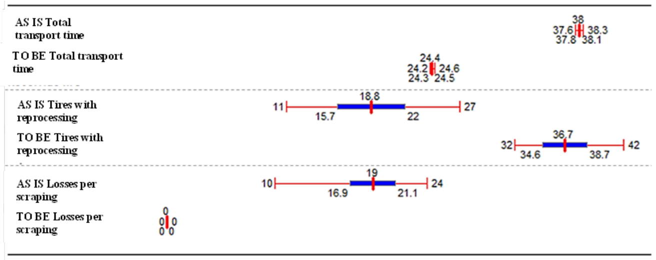


Figure 6. Comparison of indicators in Output Analyzer

Using the Input Analyzer, whose outputs are presented in Table 1, the initial statistical distributions for each activity were determined. This analysis made it possible to identify the actual behavior of the process times and subsequently to show a significant reduction in the duration of the activities, demonstrating once again the direct impact it had on the partial labor productivity obtained.

Table 1 Distribution of pre- and post- improvement activities

Activity	Distribution (initial)	Distribution (pilot)
Transfer from Warehouse	Triang (1, 2.27, 3)	Triang (0.65, 0.942, 1.23)
Initial Inspection	Unif (4, 6)	Triang (3, 4, 5)
Scraping	Unif (4, 8)	Unif (3.16, 4.96)
Polishing	Norm (4.96, 0.405)	Triang (3, 4.52, 4.68)
Cleaning	Norm (3.35, 0.233)	Unif (3, 3.51)
Cementing	Norm (6.43, 0.283)	Unif (4, 6)
Drying	Unif (19, 22)	Unif (19, 20.7)
Cushioning	Triang (5.62, 7.31, 8.98)	Unif (5.32, 7.59)
Banding	Unif (6, 10)	Unif (5.19, 7.99)
Reprocessing	Triang (3, 6.43, 8.94)	Triang (5.91, 5.92, 6)
Vulcanizing	Const (150)	Const (150)
Vulcanized Transfer to FG	Norm (2.31, 0.204)	Triang (0.64, 1.13, 1.48)
Final Inspection	Norm (8.25, 0.322)	Unif (6, 8)

Together, these improvements allowed for a partial increase in labor productivity, since, by reducing the time of non-value-added activities, there is a more efficient use of the effective time of operations, as shown in the indicators of Table 2, it was possible to retread an additional 196 tires per month compared to the current monthly average. This increase, then, confirms that the standardization of tasks and greater operational discipline contributed to stabilizing the pace of work, generating a more uniform process.

Table 2 Evaluation of indicators

Indicator	Month average	Pilot Test	Variance
Entry tires	632	854	35.13%
Retread tires	519	715	37.83%
% of retread tires	82%	84%	2.00%
Transport time to and from warehouse (hours)	36.58	24.41	33.28%
Time spent searching for supplies and tools (hours)	46.70	27.67	40.76%
% loss (defects)	3.05%	0.00%	100.00%
% of tires with reprocessing	3.66%	6.85%	87.11%
Productivity	0.811	1.117	37.83%

4 Discussion

The results obtained show that, after the implementation of Lean Manufacturing tools, it was possible to increase partial labor productivity from 0.811 units/h-h to 1.117 units/h-h, representing an improvement of 37.83%, thus proving its functionality, achieving better results than the study carried out by Kumar, in which it was possible to increase this same indicator by 23.2% [7], this can be attributed to the size of the company, since being an SME the changes can generate more noticeable impacts.

By implementing the 5S methodology, the rating matrix result increased by 55%, compared to the result obtained in a manufacturing company, whose value achieved an increase of 6.18% [16], reaching a maximum value of 66.18%, while the case study reached 80%.

Regarding the tools applied, the implementation of 5S in conjunction with SLP resulted in a significant decrease of 33.28% in travel times, which is consistent with the literature that states that implementing the respective system allowed them to reduce travel time by workers by up to 56.91% [12]. Likewise, the literature on Standard Work indicates that the application of the tool generates reductions in the defective rate of 8% [13], an effect that was also evidenced in this study by obtaining a total reduction in the amount of waste in the scraping activity.

Moreover, this behavior is aligned with findings from other Lean Manufacturing applications. For instance, one study that employed discrete-event simulation as its main tool modeled the production of a dual-exhaust system and reported a 10% increase in productivity and a 17% reduction in result dispersion. [17]

Similarly, research that implemented Value Stream Mapping (VSM) showed that analyzing and redesigning the production flow led to a reduction of non-value-added time from 7.56 to 2.69 days and a decrease in lead time of more than 60%. These results, validated through discrete-event simulation, reinforce the consistency between the improvements obtained in this study.[18]

With respect to the hypothesis put forward, since an increase in partial labor productivity to 1,117 units/man-hour was evident, the null hypothesis is rejected, therefore, it is concluded that there was an improvement after the implementation carried out.

Furthermore, as future work, the project proposes integrating AI, machine learning, and computer vision to automate processes such as early defect detection. Just as in the railway industry, where deep learning has enabled the highly accurate identification of faults, these technologies could be adapted to the production environment. This would allow for faster, more reliable controls with less manual intervention [19].

5 Conclusion

Following the implementation of the methodologies included in the improvement plan (5S, SLP and Standard Work), the results of the final indicators showed an increase in the performance of the process, demonstrating the value and usefulness of the intervention carried out in the company. As evidence of its effectiveness, a simulated increase of 37.76% in the monthly quantity of retreaded tires was obtained.

On the other hand, regarding the transfer time of raw materials and finished products, a significant reduction was simulated compared to the initial time. This result is attributed to the new layout obtained through the analysis of the SLP methodology. Furthermore, under the continuous improvement and productivity approach, the implementation of 5S allowed for better organization of materials, reducing the time spent searching for tools.

Finally, overall, an increase in the partial labor productivity of the process was determined, going from 0.811 to 1.117 units per man-hour, which shows a significant approach to the identified sectoral gap and fulfilling the general objective of the improvement project. This result demonstrates that implementing the improvement plan optimized resource utilization, reduced unproductive time, and strengthened best operational practices. Furthermore, the implemented tools establish a solid foundation for maintaining continuous improvement and ensuring the sustainability of the process over time.

6 References

[1] ACEA (2025) Economic and Market Report: Global and EU auto industry – Full year 2024
[2] Asociación Automotriz del Perú (2025) Informe del Sector Automotor, p.7.
[3] The Business Research Company, Tire Retreading Global Market Report (2025)
[4] M. H. Sitepu et al 2020 IOP Conf. Ser.: Mater. Sci. Eng. 801 012116
[5] Ziyad Tariq Abdullah, Remanufactured waste tire by-product valorization: Quantitative–qualitative sustainability-based assessment, Results in Engineering, Volume 22, 2024, 102229, ISSN 2590-1230
[6] S. Zhao, X. Wen, D. Tang, Y. Xu, C. Sun, H. Zhao, X Pei and L. Lin, Improved wear resistance of natural rubber-based tire materials via constructing carbon black/Ar plasma modified pyrolysis carbon black hybrid filler network, Tribology International, Volume 213 (2026)
[7] Kumar, G. Rakesh, M. Shivnath and G. Niraj, Productivity Improvement of HLLS Using Lean Technique in Assembly Line of an Automotive Industry (2022)
[8] Wicaksono, Padang, Yulial Hikmah, and Rayinda Nur Ilmiawani. 2023. "Productivity and Global Value Chains: A Tale from the Indonesian Automobile Sector" Economies 11, no. 10: 262.
[9] U. Gudsoorkar and R. Bindu Fatigue crack growth characterization of re-treaded tire rubber, Materials Today: Proceedings, pp. 2303-2310. (2021)https://doi.org/10.1016/j.matpr.2021.01.065
[10] J. Arun, N. Nedunchezhian, R. Murugesan and P. Pachaivannan, (2025). "Predictive Modeling for Sustainable

Tire Retreading and Resource Optimization in Public Transport System" Sustainability 17, no. 12: 5480.
[11] Temoche and Lucano, Proposal for improvement through the application of Lean Manufacturing to increase productivity in a manufacturing company. (2024)
[12] Barreto-Guillen, M. Gonzales-Sassarini, and J. C. Quiroz-Flores, Production Model under the Integrated Approach of Lean Manufacturing and SLP to Increase Efficiency in A Company of the Metal Mechanic Sector Marcelo Augusto, Volume 15(4), pp. 172-178, (2023)
[13] Barrientos et al., Lean Manufacturing Model of Waste Reduction Using Standardized Work to Reduce the Defect Rate in Textile MSEs. (2020)
[14] G. A. Linares, Prospective and trends in technology and skills for sustainable social development. Leveraging emerging technologies to construct the future: Proceedings of the 19th LACCEI International Multi-Conference for Engineering, Education and Technology (July, 2021)
[15] Alvarado Quito, K., Campodónico Durango, G. (2023). Análisis de las Fintech y su contribución al desarrollo de las Pymes en Guayaquil – Ecuador. Revista Universidad y Sociedad, 15(2), 475-483
[16] C. Salazar, H. Ore, B. Benavides, Y. Delgado and L. Pantoja, 5S Methodology, viable alternative in the improvement of food industry processes, (2020)
[17] Kampa, A. (2023). Modeling and Simulation of a Digital Twin of a Production System for Industry 4.0 with Work-in-Process Synchronization. Applied Sciences, 13(22), 12261.
[18] Velázquez-Serrrano, J., Rivera Gomez, H., Rámirez-Reyna, S. B., Granillo-Macias, R., & Montaño-Arango, O. (2025). Enhancing production efficiency through value stream mapping and simulation in the automotive industry. International Journal of Industrial Engineering and Management, 16(3), 239–252.
[19] Aparicio Pico, Lilia Edith, Amaya Marroquín, Oscar Julián, & Devia Lozano, Paola Andrea. (2023). Aplicación de Deep Learning para la identificación de defectos superficiales utilizados en control de calidad de manufactura y producción industrial: una revisión de la literatura. Ingeniería, 28(1), e18934. Epub March 04, 2023