

Improving Productivity in a Small Footwear Manufacturing Business Through Work Standardization and DDMRP

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Abstract

The footwear manufacturing sector is a key industry in the national economy, particularly among micro and small enterprises (MSEs), which face constant challenges related to low productivity, inefficient use of materials, rework, and long cycle times. This research proposes a continuous improvement model that integrates work standardization and the Demand-Driven MRP (DDMRP) methodology, complemented by sensor-based data collection technologies, in order to optimize the validation process. The study is conducted as a case study applied to an MSE in the footwear sector, using a hybrid approach that combines pilot implementation on the factory floor with simulation in Arena software. The main indicators analyzed were total productivity, cycle time, productivity per man-hour, rework, and material costs. The results obtained from the sample show a 26% improvement in productivity, an 88% reduction in rework, and a 7.5% optimization of cycle time, demonstrating the positive impact of the proposed model on operational performance. This research provides a replicable foundation for other micro and small enterprises in the sector, fostering a culture of continuous improvement geared toward competitiveness and sustainability.

Keywords

Productivity, footwear sector, DDMRP, Work standardization, Continuous improvement

1. Introduction

The footwear manufacturing industry represents a strategic sector for the Peruvian economy due to its impact on job creation, regional development, and its contribution to the Gross Domestic Product (GDP). In 2018, domestic production reached 57 million pairs; however, since 2019, growth has been affected by factors such as the COVID-19 pandemic and increased imports from countries like China and Brazil, which have diminished the competitiveness of the local industry (Mendoza et al., 2023). Nationally, the manufacturing sector has accounted for 13.43% of GDP over the past five years (BCRP, 2024) and employs 9.2% of the economically active population (EAP), with more than 1.7 million workers (INEI, 2022). Despite their importance, micro and small enterprises (MSEs) in this sector face significant challenges related to efficiency, planning, and productivity. This study focuses on a Peruvian MSE specializing in footwear manufacturing under a made-to-order production model. The company has approximately 30 employees and produces footwear for well-known domestic brands. Its production process consists of four stages: cutting, trimming, assembly, and finishing. Despite its ability to adapt to demand, the company faces technical limitations that directly affect its operational and economic performance. Among the main problems identified are high levels of rework and low productivity. According to data collected on the factory floor, initial total productivity is 0.21212 pairs/S/, representing a 52.86% gap compared to the industry average of 0.45 pairs/S/. Additionally, the average cycle time per pair is 178.83 minutes, and the maximum annual cost of materials amounts to S/ 683 532. These figures reflect performance below industry standards and highlight the urgent need for intervention. The root

cause analysis indicates that the deficiencies stem primarily from a lack of standardized procedures, inefficient management of operational knowledge, significant differences in efficiency among operators, and poor planning of material usage. These conditions result in opportunity losses totaling S/ 246 153 annually, in addition to economic impacts of 7.03% on revenue and 7.98% on total costs. The data reveal that 50.09% of the problems stem from low staff efficiency and 35.43% from rework, confirming the need to establish a continuous improvement model based on practical and adaptable tools for this type of company. In response to this analysis, this research proposes a continuous improvement model that integrates two fundamental pillars: work standardization, accompanied by the use of sensors for automated data capture—which allows for a comparison of the benefits of digital time tracking versus the traditional manual method—and, on the other hand, materials planning based on the Demand-Driven MRP (DDMRP) methodology. Unlike previous studies that address these tools separately, this model proposes a hybrid validation approach, combining real-world pilot tests on the factory floor with simulation using Arena Professional Simulator, which allows for observing the impact of the proposed improvements in a controlled and practical environment. This model not only seeks to address the current limitations of the analyzed company but also to offer a replicable approach for other micro and small enterprises (MYPEs) in the footwear sector or related industries. It is expected that the combined application of these tools will help bridge the existing technical gap, optimize resources, improve the quality of the final product, and strengthen the competitiveness of Peruvian companies in an increasingly demanding market.

1.1 Objectives

The overall objective of this study is to analyze the relationship between work standardization and increased worker productivity in a micro and small enterprise (MSE) in the footwear sector, as well as the impact of DDMRP on reducing raw material losses. To this end, the following research questions are formulated:

- What is the relationship between work standardization and improvements in labor productivity?
- How does the DDMRP contribute to reducing material losses in this type of company?

2. Literature Review

2.1. Work Standardization and Its Impact on Labor Productivity

Work standardization (STW) is a fundamental tool of the Lean Manufacturing system, aimed at establishing optimal operational sequences that improve efficiency and reduce variability. Its implementation has been shown to contribute to shorter cycle times, fewer human errors, and reduced wait times, in addition to increasing labor productivity (Mor et al., 2019; Ewnetu et al., 2023). Mendoza et al. (2023) reported a 49.79% increase in total productivity after applying STW at a footwear manufacturing plant. Similarly, Vásquez-Vargas (2020) demonstrated that integrating work standardization with time-and-motion analysis reduced unproductive time by 18.44%. These results demonstrate how the systematization of tasks can increase operator performance by eliminating unnecessary activities. Furthermore, Krysztof (2023) found that work standardization reduced execution times by 23% and increased efficiency by 11 percentage points.

2.2. Demand-Driven Material Requirements Planning (DDMRP) in Light Manufacturing

The Demand-Driven Material Requirements Planning (DDMRP) system allows for the accurate calculation of material requirements based on the master production schedule, optimizing inventory usage and reducing losses. This tool has been widely adopted by manufacturing companies due to its ability to synchronize demand with material availability (Malindzakova et al., 2022; Galvao et al., 2020).

In the context of lean manufacturing, particularly in micro and small enterprises (MSEs), demand-driven MRP represents a key strategy for optimizing resources and improving responsiveness to changing environments (Reyes et al., 2024). Carina et al. (2019) applied a hybrid model based on demand-driven material requirements planning in a small business, achieving optimal results in input planning. Meanwhile, Reis (2023) integrated this tool with Python programming, which allowed for the automation of calculations and increased accuracy in purchase orders. Ferreira et al. (2023) highlight that these integrations enable a more effective response to changes in demand, minimizing both overproduction and material shortages. Thus, demand-driven Material Requirements Planning stands as an adaptable and essential tool for improving operational efficiency in highly variable manufacturing environments.

2.3. Automated Data Capture to Support Standardization

The application of automated data capture technologies, such as RFID systems, has gained prominence in industrial settings where high precision in time measurement and process traceability is required. This technology enables the

recording of events in real time through the use of electronic tags that are read without physical contact (Finkenzeller, 2010). In light manufacturing, the use of RFID has proven effective in improving inventory control, product traceability, and the accurate measurement of cycle times in manual operations (Gubbi et al., 2013; Want, 2006). These applications are particularly useful in processes such as footwear assembly and preparation, where execution times must be validated to ensure productivity standards.

Womack and Jones (1996) note that traditional manual timing methods can be subject to inter-observer variability and recording errors, whereas digitization offers greater accuracy and scalability. In this regard, the incorporation of smart sensors improves data quality for time studies and strengthens decision-making based on operational evidence.

3. Methods

This study adopts an applied methodology with a hybrid approach, based on an experimental and simulated design, whose objective was to evaluate the impact of a continuous improvement model on a micro and small manufacturing enterprise (MYPE) in the footwear sector. The research was conducted at a company dedicated to the on-demand production of women's footwear for third parties, which faced operational challenges related to total productivity, cycle time, productivity per man-hour, rework, and material costs.

The methodology was structured into three main phases: diagnosis, implementation of solutions, and validation of results. During the first phase, field data was collected through direct observation, task timing, unstructured interviews, and document review. This stage allowed for the identification of operational inefficiencies, idle time, and variability in the execution of key processes. An analytical tool such as the Ishikawa diagram was also applied to identify the main root causes of production problems.

In the second phase, an improvement model consisting of two main components was designed and implemented: standard work (STW) and demand-driven material requirements planning (DDMRP). The STW component consisted of designing standard operating procedures, defining standard times, and developing visual routines for the cutting, trimming, assembly, and setup areas (Mor et al., 2019; Ewnetu et al., 2023). The DDMRP module was developed in Google Colab using libraries such as Pandas and Numpy, which enabled the automatic generation of net material requirements based on the bill of materials (BOM). This component involved evaluating different models, with linear regression incorporating seasonality and adjusted values yielding the optimal result.

3.1. Proposed Method

The proposed improvement model aims to address the main operational deficiencies identified in a micro and small manufacturing enterprise (MSE) in the footwear sector by integrating work standardization, Demand-Driven Material Requirements Planning (DDMRP), and automatic data capture technology. The methodological approach addresses the need to standardize production tasks, optimize material procurement, and digitize time tracking on the shop floor. This proposal is particularly relevant given that, in this sector, there is a notable lack of technologies such as RFID sensors, which prevents the generation of reliable process data, limits product traceability, and hinders continuous improvement. This shortcoming constitutes the main research gap addressed by this study.

The model is structured around three components:

3.1.1. Work Standardization (STW)

Standardized procedures were designed for the main process operations (cutting, trimming, assembly, and preparation). Each activity was defined using standard times obtained through timing, observed best practices, and operational validation. Visual sheets were developed showing the optimal sequence of tasks, quality requirements, and control points, with the goal of reducing variability, facilitating staff training, and eliminating rework. This approach is aligned with the findings of Mor et al. (2019) and Ewnetu et al. (2023), who assert that standardization constitutes an essential foundation for process control and continuous improvement.

3.1.2. Demand-Driven Material Requirements Planning (DDMRP)

A digital planning tool was developed in Google Colab that automatically calculates net material requirements. This tool uses sales history, input quantities per model, current inventory, and replenishment lead times as inputs. It integrates the evaluation of different models, yielding linear regression with seasonality and adjusted values as the optimal result. The system helps reduce stockouts and excess purchases, thereby optimizing the flow of materials.

According to Galvão et al. (2020) and Ferreira et al. (2023), automated, data-driven planning directly contributes to operational and financial efficiency.

3.1.3. Automatic Data Capture Using RFID Sensors

To bridge the gap in the footwear sector regarding the digital recording of processes, RFID sensors were installed at key production stations. These devices enable the continuous capture of process times without manual intervention. This not only improves the reliability of the records but also replaces the traditional method of timing with a stopwatch, providing a more robust database for performance measurement. The literature supports this application as an effective way to improve traceability, reduce errors, and obtain accurate operational information in real time (Want, 2006; Gubbi et al., 2013).

The model was implemented in six stages: (1) diagnosis of the current system; (2) design of the improvement model; (3) development of standardized tools and materials; (4) simulation using Arena and pilot testing.

This method not only seeks to optimize the processes of the analyzed company but also to provide practical evidence for a sector with limited digitalization, demonstrating that the use of affordable sensors and automated planning can generate significant benefits in terms of control, efficiency, and sustainability of operations.

3.2. Components of the Model

3.2.1. Problem Diagnosis

The diagnosis was conducted on-site during full production shifts. Time-sheets were used, direct interviews were conducted with operators and supervisors, and physical production records were reviewed. First, a Pareto analysis was created to prioritize the most frequent problems, followed by two Ishikawa diagrams to group their root causes. Likewise, a Value Stream Map (VSM) of the current state was developed, revealing waiting times, rework, and a lack of synchronization between areas. Furthermore, the 5W + 2H technique was applied to delve deeper into these causes, serving as the basis for designing the improvement model.

3.2.2. Implementation of Work Standardization (STW)

Standardization was implemented based on direct and repeated observation of operations. Multiple work cycles per task were recorded in each area. Based on these times and sequences, standard sheets were designed and validated by supervisors and lead operators. These sheets were printed and posted in visible locations. Brief training sessions were organized with each work team, and evaluation forms were distributed to verify compliance with the standard on the shop floor. During the first week of implementation, minor adjustments were made to the reference times, and visual control points were incorporated to reinforce correct execution.

3.2.3. Implementation of the DDMRP System

The DDMRP system was implemented using a Colab application. It was fed with historical production data, bills of materials (BOMs), average lead times for inputs, and current inventory levels. First, different models for demand forecasting were compared, and the one yielding the lowest MAPE was selected. Production and purchasing managers participated in a data collection session to validate the model's logic. The tool enabled the calculation of weekly net material requirements. Training was provided on how to use the interface, and the file was left accessible with automated instructions and protection for editable cells.

3.2.4. Pilot Project for Automatic Data Capture Using RFID Sensors

Radio Frequency Identification (RFID) is an automatic data capture technology that identifies objects using radio signals, without the need for physical contact or direct line of sight. An RFID system consists of a reader (or antenna) and data-transmitting devices, such as cards or tags, that contain unique information (Finkenzeller, 2010).

To overcome the limitations of manual timekeeping during the study, a custom prototype for automatic data capture based on this technology was designed and developed. The design of this hardware, as well as the identification cards assigned to operators for the automated recording of cycle times, are illustrated in Figure 1.

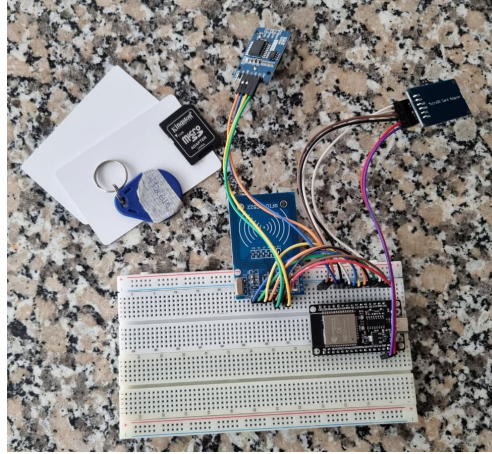


Figure 1. Prototype RFID sensor and ID cards developed for the time study

3.2.5. Model Validation

The proposed model was validated using a comprehensive approach that combined on-site measurements, data capture technologies, and computer simulation. The objective of this process was to evaluate the effects of Standardized Work (STW) and Demand-Driven Material Requirements Planning (DDMRP) on the production system, as well as to compare the accuracy and operational feasibility of two measurement methods: manual timing and RFID sensors.

As part of the pilot validation of the standardization tool, four key activities in the production process were selected. The first two were evaluated using the traditional method of stopwatch timing and direct observation, while the last two—preparation and assembly—were monitored using RFID sensors. At these stations, operators used personal cards that were scanned upon completion of each unit, generating timestamped records. This technique made it possible to accurately calculate the times between arrivals and the actual cycle time of the operations.

The times collected, both by stopwatch and by RFID, were subsequently entered into the simulation model developed in Arena Simulation Software. This model made it possible to replicate the production flow before and after the intervention, integrating not only the operational times obtained but also the improvements proposed based on the use of STW and the planning logic implemented through DDMRP. In this way, the model did not represent two independent systems but rather a single environment validated through various data sources.

Key indicators such as total productivity, productivity per man-hour, cycle times, rework, and material costs were configured within the Arena model, enabling the precise quantification of the impact of the implemented tools. Furthermore, the simulation allowed for the analysis of scenarios with different workloads and demand variability, thereby evaluating the robustness of the proposed model.

4. Data Collection

4.1. Description of the Scenario

This study was conducted at a Peruvian microenterprise engaged in footwear manufacturing under a made-to-order production model. The company has approximately 30 employees and produces for well-known national brands. The production process consists of four stages: cutting, trimming, assembly, and finishing. Despite its adaptability, the company faced operational deficiencies that significantly affected its productivity, material usage, and cost structure.

4.2. Initial Assessment

The initial analysis revealed performance well below industry standards. Total productivity stands at 0.212 pairs/S/. The average cycle time per pair was 178.83 minutes. Furthermore, the annual cost of materials amounted to S/ 683 532.00. These figures indicated low staff efficiency, a lack of standardized procedures, and poor materials planning. It should be noted that, for the establishment of the baseline and the subsequent cost analysis using DDMRP, the scope of the study was limited to the two inputs with the greatest criticality and economic impact on production: leather and

suede. The remaining minor inputs were included in fixed indirect costs, thereby ensuring a focus on the materials that generate the greatest operational and financial variability.

5. Results and Discussion

5.1 Numerical Results

To evaluate the quantitative impact of the model, the indicators for the initial situation were compared with those for the improved situation. As detailed in Table 1, significant improvements were achieved in the SME's critical operational variables, validating the effectiveness of the implemented tools.

It should be noted that the indicators entered into the simulator correspond exclusively to a representative sample of 500 to 800 pairs. Therefore, values such as the rework rate in the baseline scenario (3.00%) differ from the annual historical rate (35.43%), since the model isolates the direct operational variability of the batch under study to measure the exact impact of standardization, without including the macro-level fluctuations of an entire year.

Table 1. Results Obtained

Indicator	Initial Situation	Improved Situation
Productivity (pairs/S/)	0.21212	0.26667
Cost of materials (S/)	S/ 18 439	S/ 16 059
Labor productivity (pairs/H-H)	0.33246	0.35269
Rework rate (%)	3.00%	0.37%
Average cycle time (min/pair)	178.83	165.41
Total Production	800	800

Following the simulation of the proposed model, total productivity increased by 26.0%, and labor productivity improved by 6.0%. Likewise, the cost of critical materials (leather and hide) in the evaluated batch was reduced from S/ 18 439.00 to S/ 16 059.00, representing a 13.0% savings. Furthermore, the system's rework rate decreased dramatically by 88.0% (from 3.00% to 0.37%), and the average cycle time was reduced by 7.5% (from 178.83 to 165.41 minutes), consolidating the operational optimization of the process.

5.2 Graphical Results

This section presents the visual tools and flowcharts that support the diagnosis and redesign of the production process. Figure 2 illustrates the Value Stream Mapping (VSM) of the organization's current state, highlighting wait times and rework. Figure 3 shows the Process Operations Diagram (POD) adopted to standardize activities.

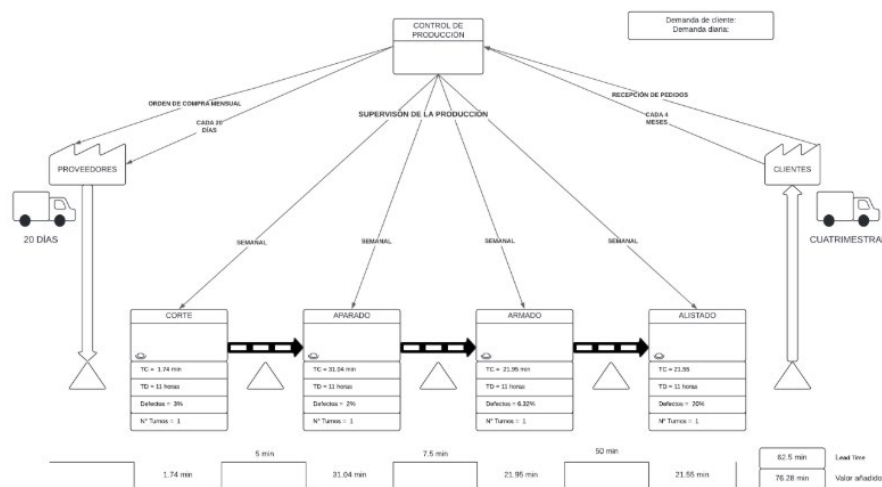


Figure 2. VSM of the company

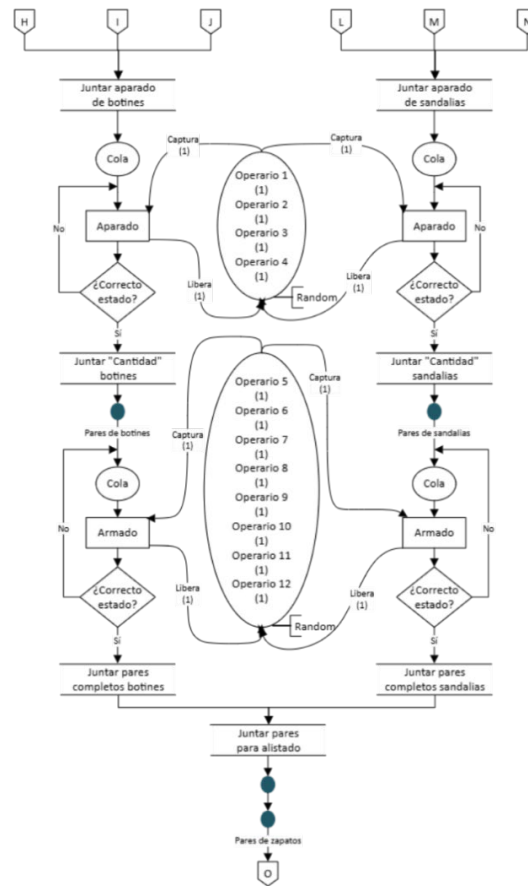


Figure 3. Example of a POD

The root causes of the inefficiencies, grouped during the data collection phase, were structured using the problem tree shown in Figure 4. Furthermore, the macro architecture of the improvement model and the representation of the comparative simulation environments in Arena (As-Is and To-Be) are shown in Figures 5 and 6, respectively.

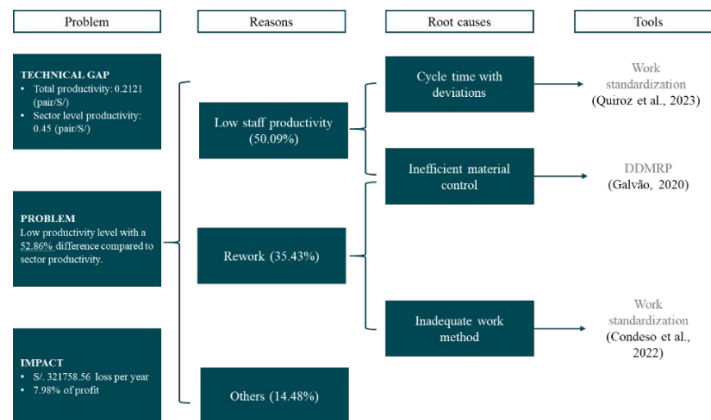


Figure 4. Problem tree

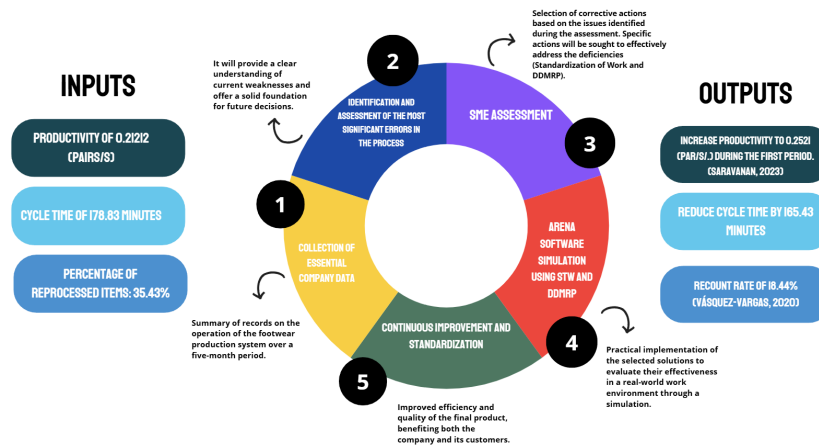


Figure 5. Macro design of the proposed model



Figure 6. Model in Arena Software (As-Is and To-Be)

5.3 Proposed Improvements

The implementation of the proposed model, based on standard work (STW) and demand-driven material requirements planning (DDMRP), proved to be an effective solution to the identified inefficiencies. From an operational perspective, the use of standard sequences helped reduce execution errors, shorten cycle time, and facilitate staff training. These findings are consistent with those of Mendoza et al. (2023) and Krysztof (2023), who highlight the positive impact of standardization on optimizing production flow.

From a planning perspective, the implementation of automated DDMRP made it possible to synchronize demand with actual supplies. The 13.0% reduction in critical material costs observed in the simulation aligns with the findings of Carina et al. (2019) and Reis (2023), who noted that the use of this tool prevents both overstocking and stockouts. Projecting these improvements from an economic feasibility perspective, annual savings of approximately S/ 112 589 are estimated, resulting from reduced rework, optimized lead times, and the efficient use of raw materials. The initial investment in the model is recouped within a 3-month period, yielding a Net Present Value (NPV) of S/ 75 553 and an Internal Rate of Return (IRR) of 32%, far exceeding the cost of capital.

5.4 Validation

A key methodological contribution of this study, aimed at addressing the lack of digitization in the sector, was operational validation using RFID sensors at the assembly and preparation stations. Unlike traditional manual timing—used in the cutting and trimming phases—this automated data capture technology enabled the collection of

precise real-time data, minimizing observation biases and generating exact timestamps for cycle times. Additionally, the use of this technology significantly reduced the effort required for data collection; since the data was automatically recorded in a web-based file, the process of tabulating and consolidating the data to feed the Arena software was much faster and more straightforward than manual transcription.

This automated data collection not only optimized on-site time studies but also generated a highly reliable database that was integrated into Arena Simulation Software. By feeding the simulation with hybrid operational data (manual timing and RFID sensors), it was possible to validate the behavior of the production system under different workload scenarios, confirming the robustness of the standardization and planning model in the face of demand variability (Want, 2006; Gubbi et al., 2013). Finally, a technical limitation arose due to the maximum entity-processing capacity of the Arena Software license; therefore, the computational model was configured to simulate representative batches of 500 to 800 pairs. However, this limitation was statistically validated: the calculation of the required sample size for each activity yielded a requirement of fewer than 100 observations. Therefore, by processing more than 500 entities, the model exceeds the statistical sampling requirement. Since this is a discrete-event model with constant rates, the proportions of key indicators—such as Cycle Time (CT) and total productivity—remain stable, ensuring that the variations obtained are fully valid and extrapolatable to the system's behavior.

6. Conclusion

The analysis conducted revealed that the MSE under study faced critical problems related to low productivity, high rework rates, and high material costs. To address these issues and meet the research objectives, an improvement model was implemented that integrated work standardization (STW) and the DDMRP methodology, yielding results that empirically validate the impact of both tools.

First, the relationship between work standardization and labor productivity was demonstrated by a 6.1% increase in this indicator. The elimination of operational variability reduced cycle time from 178.83 to 165.41 minutes and decreased operational rework by 88%, ensuring consistent execution and better quality control. On the other hand, regarding the second objective, DDMRP demonstrated its ability to reduce material losses through precise synchronization between projected demand and supply. This resulted in a reduction in critical input costs from S/ 18 439 to S/ 16 059 in the evaluated sample, equivalent to a 13% savings.

Overall, total productivity improved by 26% (from 0.2121 to 0.2666), demonstrating that the combined application of these methodologies allows for the optimization of resources compared to the initial conditions.

Finally, the main unique contribution of this research lies in the integration of RFID sensors as a hybrid tool for validating times in footwear manufacturing. This inclusion represented a significant innovation given the lack of information technology in micro and small enterprises (MSEs) in this sector, demonstrating that digital and automated data capture, coupled with computer simulation, strengthens evidence-based decision-making and lays the groundwork for progressive and sustainable digitization.

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