

Process Optimization in Metalworking SMEs by Implementing Lean Manufacturing Tools: (An Approach to Improving Operational Efficiency)

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Abstract

The metal-mechanical industry, particularly the small and medium-sized enterprises (SMEs), plays a critical role in economic development globally, especially in Latin America and Peru. Previous studies have highlighted the importance of this sector in fostering industrial growth and innovation. Despite its significance, SMEs in this sector face numerous production challenges, including deficiencies in machine setups, operational errors leading to rework, and inadequate inventory management, which disrupt supply chains and affect overall efficiency. This research aimed to address these urgent challenges by proposing a Lean Manufacturing-based production model tailored for SMEs in the metal-mechanical industry. The proposed model incorporated Lean Manufacturing tools such as Poka Yoke, SMED, 5S, Kanban, and A3 reports to streamline production processes and enhance operational performance. The model focused on reducing setup times, minimizing operational errors, and optimizing inventory management. Through a structured implementation of these tools, the model sought to eliminate waste and improve production efficiency, thereby ensuring timely order fulfillment and high product quality.

Key findings from the study showed significant improvements in several performance indicators. The on-time delivery rate improved from 66.40% to 87.85%, setup times were reduced by 30.11%, productivity increased by 28.00%, and cycle times decreased by 23.77%. These results demonstrate the effectiveness of the proposed Lean Manufacturing model in addressing the critical production issues faced by SMEs in the metal-mechanical sector. The impact of this research extends beyond operational improvements. Academically, it contributes to the existing body of knowledge on Lean Manufacturing applications in SMEs, providing a robust framework for future studies. Socioeconomically, the enhanced production efficiency and reliability can lead to increased competitiveness and sustainability for SMEs, fostering economic stability and growth within the region. In conclusion, this study calls for further exploration and validation of Lean Manufacturing tools in diverse industrial settings. The demonstrated success of the proposed model highlights the potential for broader application, encouraging researchers and practitioners to continue innovating and refining production processes to meet evolving market demands and technological advancements.

Keywords

Lean Manufacturing, Operational Efficiency, Metalworking SMEs, Process Optimization, Inventory Management.

1. Introduction

The sector of small and medium-sized enterprises (SMEs) in the metal-mechanical industry holds significant importance globally, in Latin America, and specifically in Peru. SMEs in the metal-mechanical sector play a crucial role in driving economic growth, innovation, and employment opportunities (Pech et al. 2021). These enterprises are often the backbone of industrial development, contributing to technological advancements and fostering competitiveness within the manufacturing sector (Xing et al. 2022). In Latin America, SMEs in the metal-mechanical industry are vital for regional economic stability and job creation, serving as key players in the industrial landscape (Bahrpeyma & Reichelt 2022). In Peru, the metal-mechanical sector, predominantly composed of SMEs, forms a substantial part of the country's industrial fabric, supporting local production and supply chains (Tzakova et al. 2023). The resilience and adaptability of these SMEs are essential for the overall economic health of the region, making them a focal point for research and development initiatives (Kalsoom et al. 2021).

The production challenges faced by SMEs in the metal-mechanical industry are multifaceted, with issues arising from deficiencies in machine setup during product changes, operational errors leading to rework, and inadequate inventory planning causing supply chain disruptions (Gera 2023). The setup time required for machines when transitioning between different products is a critical bottleneck for many SMEs, impacting overall production efficiency and flexibility (Lee et al. 2021). Operational errors, such as incorrect machine settings or process deviations, often result in rework and quality issues, affecting both production timelines and costs (Kim 2022). Moreover, inadequate inventory management practices lead to supply chain inefficiencies, causing delays in production due to material shortages and impacting customer satisfaction (Moon et al. 2022). Addressing these production challenges is paramount for SMEs in the metal-mechanical sector to enhance operational performance and maintain competitiveness in the market (Javaid et al. 2021).

Resolving the production challenges faced by SMEs in the metal-mechanical sector is of utmost importance to ensure sustainable growth, operational efficiency, and market relevance (Fedullo et al. 2022). By optimizing machine setup processes, reducing operational errors, and implementing effective inventory management strategies, SMEs can enhance their production capabilities and meet customer demands more effectively (Althubiti et al. 2022). Improving production processes not only increases operational efficiency but also boosts overall profitability and customer satisfaction, positioning SMEs for long-term success in the industry (Zhang et al. 2023). Embracing lean manufacturing principles and tools can significantly aid SMEs in streamlining their operations, eliminating waste, and enhancing productivity (Chumnumporn et al. 2022). Therefore, addressing these production challenges is crucial for the continued success and growth of SMEs in the metal-mechanical sector (Pascu et al. 2022).

Despite the growing body of literature on lean manufacturing and its application in SMEs, there remains a knowledge gap regarding the implementation of lean tools such as Poka Yoke, SMED, 5S, Kanban, and Reporte A3 specifically in the context of the metal-mechanical industry (Sverko et al. 2022). While studies have highlighted the benefits of lean practices in improving operational efficiency and reducing waste in various manufacturing settings, there is a need for research that focuses on the tailored application of lean methodologies to address the unique challenges faced by SMEs in the metal-mechanical sector (Jabbar et al. 2022). This research aims to bridge this gap by proposing a production model based on lean manufacturing principles, integrating tools such as Poka Yoke, SMED, 5S, Kanban, and Reporte A3 to enhance production processes and drive operational excellence in SMEs within the metal-mechanical industry (Bandar & Islam 2022).

2. Literature Review

2.1 Application of Kanban Methodology in SMEs in the Metalworking Sector

The Kanban methodology has been extensively studied in various business contexts, including its application in small and medium enterprises (SMEs) in the metalworking sector. According to (Do & Lee 2022), implementing the Kanban methodology in the production process of SMEs in the metalworking sector has proven effective in improving efficiency and inventory management. This methodology, based on visualizing and controlling production through cards, has enabled companies to optimize their processes and reduce waiting times, resulting in increased productivity and profitability. Furthermore, the application of Kanban in manufacturing environments has been associated with increased flexibility and responsiveness to market demand.

In a related study, Siachou et al. (2021) highlight that implementing Kanban in SMEs in the metalworking sector has not only improved operational efficiency but has also facilitated communication and collaboration among different departments within the company. This methodology has allowed for better coordination of production activities, reducing bottlenecks and optimizing workflows. Additionally, the adoption of Kanban has led to greater transparency in processes, facilitating the identification and resolution of issues more promptly.

2.2 Application of 5S Methodology in SMEs in the Metalworking Sector

In the realm of SMEs in the metalworking sector, the 5S methodology has garnered interest due to its potential to enhance organization and cleanliness in the work environment. According to (Iqbal & Suzianti, 2021), implementing the 5S methodology in companies in this sector has proven effective in reducing waste, improving occupational safety, and enhancing operational efficiency. The 5S methodology, based on five principles: sorting, setting in order, shining, standardizing, and sustaining, has enabled SMEs in the metalworking sector to optimize their workspaces and enhance product quality. Furthermore, Zhu et al. (2021) point out that implementing the 5S methodology in SMEs in the metalworking sector has had a positive impact on organizational culture, fostering individual responsibility and teamwork. This methodology has promoted awareness of the importance of maintaining a tidy and clean work environment, leading to increased efficiency and productivity in operations. Additionally, the standardization of processes through the 5S methodology has facilitated the formation of positive habits among employees, improving quality and safety at work.

2.3 Application of SMED Methodology in SMEs in the Metalworking Sector

The SMED (Single-Minute Exchange of Die) methodology has been extensively studied in the context of SMEs in the metalworking sector with the aim of optimizing machine setup times. According to (Mourtzis, 2022), implementing the SMED methodology in these companies has significantly reduced tool change times and improved production flexibility. This methodology focuses on identifying and eliminating non-value-added activities during tool changeovers, leading to increased efficiency and adaptability to market demands. In a related study, Gröger et al. (2021) emphasize that the implementation of the SMED methodology in SMEs in the metalworking sector has contributed to a reduction in operating costs and improved resource utilization. Optimizing machine setup times has enabled these companies to increase their production capacity and respond more promptly to customer needs. Additionally, the implementation of SMED has fostered a culture of continuous improvement in organizations, driving innovation and competitiveness in the sector.

2.4 Application of Poka Yoke Methodology in SMEs in the Metalworking Sector

The Poka Yoke methodology, known for its focus on error and defect prevention in production processes, has been studied in SMEs in the metalworking sector. According to (Bhanja 2023), implementing Poka Yoke in these companies has proven effective in reducing errors and rework in production. This methodology is based on designing mechanisms that prevent errors, leading to improved product quality and reduced costs associated with defects. Furthermore, the application of Poka Yoke has enhanced process efficiency by minimizing the need for inspections and subsequent corrections. In a complementary study, Guerra & Camargo (2023) highlight that the Poka Yoke methodology has had a positive impact on the quality culture of SMEs in the metalworking sector. Implementing Poka Yoke devices has promoted early error detection and immediate correction, strengthening customer confidence in the quality of products delivered by these companies. Additionally, the adoption of Poka Yoke has raised awareness of the importance of defect prevention at all levels of the organization, fostering a work environment focused on excellence and continuous improvement.

2.4 Application of A3 Report Methodology in SMEs in the Metalworking Sector

The A3 Report methodology, used for problem-solving in production processes, has attracted interest in SMEs in the metalworking sector. According to (Abanina 2022), implementing the A3 Report in these companies has facilitated problem identification, root cause analysis, and the implementation of effective solutions. This methodology, based on structured information presentation in an A3 format, has enabled SMEs in the metalworking sector to enhance their ability to systematically and collaboratively address operational challenges. Moreover, the implementation of the A3 Report has promoted greater transparency in problem management, facilitating communication and teamwork in resolving critical situations.

In a related study, Hickey et al. (2022) emphasize that the A3 Report methodology has contributed to improved decision-making efficiency in SMEs in the metalworking sector. The clear and concise structure of the A3 Report has allowed work teams to quickly identify problems, set clear objectives, and develop effective action plans. Additionally, the implementation of the A3 Report has fostered a culture of continuous improvement in these companies, driving innovation and proactive problem resolution in the production process.

3. Methods

3.1 Basis of the Proposed Model

Figure 1 shows the production model based on the Lean Manufacturing philosophy, which focused on the elimination of waste and the continuous improvement of production processes. This philosophy sought to maximize operational efficiency by identifying and reducing activities that do not add value, such as reproaches, defects, unnecessary movements, excessive waiting and inventories. The model followed a sequential structure that began with waste identification using Value Chain Mapping (VSM) to visualize and analyze the flow of materials and information. Subsequently, methodologies such as 5S were implemented to organize and maintain jobs, Kanban to improve production management and provisioning, and Poka Yoke to prevent human errors. In addition, the A3 report was used for structured problem solving and the SMED method to reduce machine setup times during product changes. The main objective of the model was to optimize order fulfillment, improve product quality and reduce operating costs, achieving greater production efficiency and improved customer satisfaction through timely delivery of high quality products.

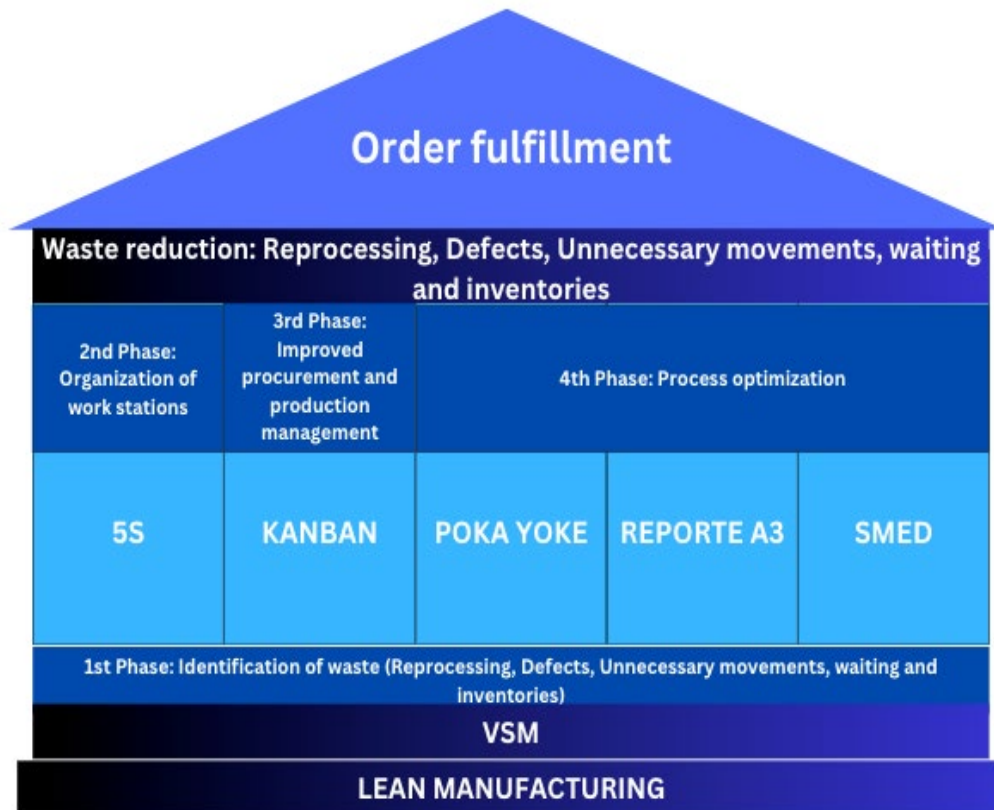


Figure 1. Proposed Model

3.2 Description of the model components

The attached production model was based on the Lean Manufacturing philosophy, which focuses on waste disposal and continuous improvement of production processes. This model was implemented in several stages, each with a

specific set of tools and methodologies designed to address different aspects of production and improve overall efficiency.

In the first stage, they focused on identifying waste. The main tool used was Value Chain Mapping (VSM), which allowed visualizing and analyzing the flow of materials and information throughout the production process. This technique helped identify activities that did not add value and could be eliminated or improved to increase efficiency. According to Rother and Shook (2003), the VSM is crucial to understanding the current state and designing a more efficient future state. The identification of waste included reprocessing, defects, unnecessary movements, excessive waiting, and inventories (Liker 2004).

The second phase focused on the organization of jobs through the implementation of the 5S methodology, which consists of five principles: classifying, ordering, cleaning, standardizing, and maintaining discipline. This methodology was essential to create a more orderly and efficient work environment, reducing lost time and improving worker morale (Hirano, 1995). The implementation of 5S not only improved operational efficiency but also fostered a culture of discipline and continuous cleaning (Gapp, Fisher, & Kobayashi 2008).

In the third phase, production management and procurement were improved through the use of the Kanban system. This visual system allowed for more accurate control of material flow and helped reduce lead times and inventory levels (Sugimori et al., 1977). The Kanban is a fundamental tool for just-in-time production (JIT), facilitating a rapid response to customer demands and minimizing excess inventories (Ohno 1988).

The fourth stage was aimed at optimizing processes through the application of tools such as Poka Yoke and the A3 report. The Poka Yoke, developed by Shigeo Shingo, is an error prevention technique that helps prevent defects in the production process through fail-safe mechanisms (Shingo, 1986). This tool was crucial to ensure product consistency and quality. On the other hand, the A3 report, a structured problem-solving technique, allowed to document and analyze problems in a systematic way, facilitating the implementation of effective solutions (Sobek & Smalley 2008).

Finally, the SMED (Single-Minute Exchange of Dies) method, developed by Shigeo Shingo, was implemented to reduce machine setup times during product changes. This methodology allowed greater flexibility and efficiency in production, since the change times were significantly reduced, which allowed responding more quickly to variations in market demand (Shingo, 1985). The implementation of SMED also contributed to the reduction of inventories and the improvement of production capacity (Feld 2001).

The main objective of this production model was to optimize order fulfillment, improve product quality and reduce operating costs. By reducing waste and improving operational efficiency, greater customer satisfaction was achieved through timely delivery of high-quality products (Womack & Jones, 1996). This holistic approach not only sought to increase productivity, but also foster a culture of continuous improvement within the organization, aligning with the fundamental principles of Lean Manufacturing.

In summary, the production model based on Lean Manufacturing implemented a series of clearly defined stages and supported by various tools and methodologies, such as VSM, 5S, Kanban, Poka Yoke, A3 report and SMED. Each of these tools played a crucial role in improving efficiency and reducing waste, contributing to a more agile and effective production system. This approach allowed not only to meet the operational objectives of the organization, but also to provide significant added value to the final customer, thus achieving a competitive advantage in the market.

3.3 Model Indicators

To assess the efficacy of the suggested production model, specific indicators were established to oversee and regulate the outcomes of its implementation in the case study.

Cycle Time: Measures the total time required for the production of a required unit.

$$Cycle\ time = \frac{Total\ production\ time\ in\ a\ period}{Number\ of\ units\ produced\ in\ a\ period} \quad (1)$$

On time Delivery rate: Measure the level of fulfillment in order delivery on the agreed date.

$$\text{Cycle time} = \frac{\text{Number of orders delivered on time}}{\text{Total number of orders delivered}} \times 100 \quad (2)$$

Productivity: Measures the number of units produced per man-hour used.

$$\text{Productivity} = \frac{\text{Number of units produced}}{\text{Total man hours employed}} \quad (3)$$

SETUP Time Measures the average total time required for the execution of SETUP activities on the production line.

$$\text{SETUP Time} = \frac{\text{Total SETUP time in a period}}{\text{Number of SETUPs performed in a period}} \quad (4)$$

4. Validation

4.1 Component: Initial Diagnosis

Figure 2 shows the problem tree that summarizes the diagnosis made in the case study to identify the reasons and root causes that generated the research problem. The main problem identified was the inability to comply with orders deliveries, which resulted in a significant economic impact of USD 17,678 per year, equivalent to 5% of revenues. This problem was due to a technical lag compared to the industry standard, which has a delivery compliance rate of 95 per cent, while the case study had a compliance rate of 66.4 per cent. First-tier causes included excessive reprocessing in the assembly area (42%), delays in configuration operations (37%) and lack of stock (21%). In turn, these causes were associated with second-level root causes, such as excessive assembly failures (19%), errors in press configuration (23%), excess press stops during setup (20%), delays in finding fitting parts (17%) and errors in programming materials purchases. The identification and quantification of these factors provided a solid basis for the development of improvement strategies in the production process.

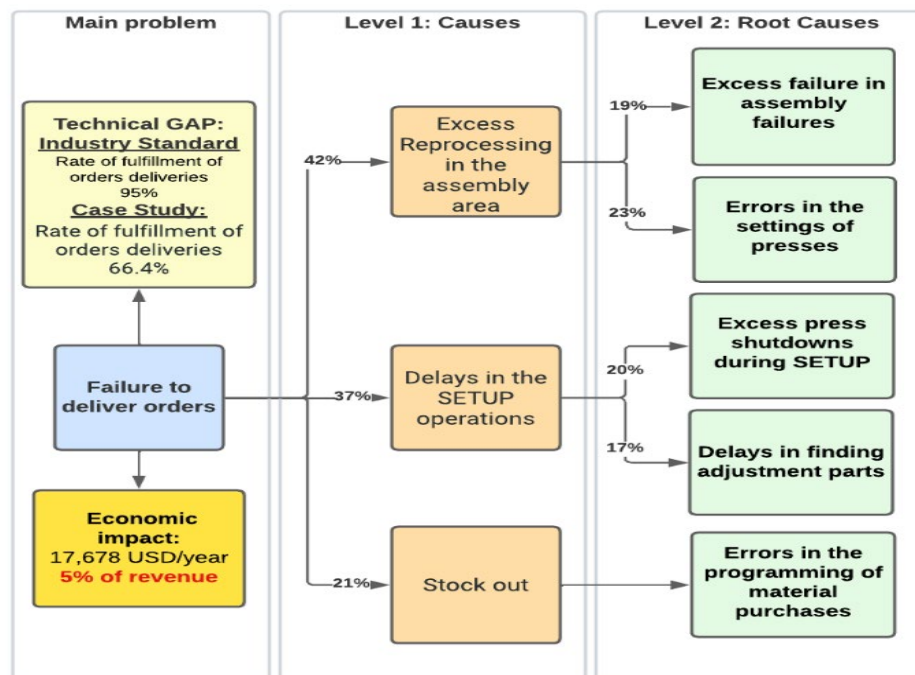


Figure 2. Problem Tree

4.2 Validation process

The validation of the proposal was carried out through a simulation using Arena Simulator version 14.0 software, which allowed to represent the current situation of the case study and to evaluate the improvement model in an environment like the actual process. In this sense, two scenarios have been addressed: the first, called "AS IS", simulates the current process before implementing the proposed model, while the second, "TO BE", represents a scenario with the proposed improvements. After the simulation, the results are compared using the indicators defined to evaluate the proposed model. The current system was developed for the simulation where entities, attributes, and system-wide activities were identified as shown in Table 1.

Table 1. Matrix of entities, attributes, and activities of the real system

Entities	Attributes	Activities
Order tin plate 0.571 Kg.	Arrival time	Log in Form tail i (i=1 to 8) Occupy cutter Occupy press A1 Occupy press A2 Occupy press B1 Occupy press B2 Occupy assembly operator Occupy welder operator Occupy baking operator Get out of the system
Cutting machine (manual)	Service time 1	Expect 0.571 kg aluminum plate. Produce cuts of iron
A _i press (i=1, 2) (manual)	Setup time A1 Setup time 2 Setup time A2	Expect cuts of iron
B _i press (i=1,2) (manual)	Setup time 3 Setup time B1 Setup time 4 Setup time B2 Setup time 5	Pressing frames with a lid Expect cuts in the lid Press Cap Wait for cover frames
Assembly operator (manual)	Setup time 6	Wait Cover Assemble Lid of iron
Soldering iron operator (manual)	Setup time 7	Expect assembly of iron cap Weld together
Galvanized furnace (manual)	Setup time 8	Expect welded iron cap assembly Galvanize final product

After identifying all the elements involved in the system, an analysis of the times of each process was made through the Input Analyzer tool, which allows determining the distribution of the times and the optimal sample size in each case. The results of the analysis show in Table 2.

Table 2. Time analysis results with Input Analyzer

Times involved (Attributes)	Validated distribution	Validated optimal sample size
Tiempo de llegada	TRIA(8.09,12.1,14)	425
Tiempo de cortado	NORM(36.7,1.25)	407
Tiempo de setup A1	NORM(28.4,0.885)	302
Tiempo de prensado A1	NORM(128,1.1)	392
Tiempo de setup A2	NORM(28.4,0.885)	302
Tiempo de prensado A2	NORM(128,1.23)	357
Tiempo de setup B1	NORM(28.4,0.885)	302
Tiempo de prensado B1	NORM(136,1.1)	384
Tiempo de setup B2	NORM(28.4,0.885)	302
Tiempo de prensado B2	NORM(134,1.2)	362
Tiempo de ensamble	NORM(102,1.33)	409
Tiempo de soldadura	NORM(134,1.29)	411
Tiempo de galvanizado	NORM(104,1.12)	381

Figures 3 and 4 below show the simulation systems As-Is and To-Be respectively and which were developed for validation through simulation in the software Arena Simulator v.14.

Figure 3. is presented in APPENDIX -A

(Figure 3. Simulation of the current situation of the case study)

Figure 4. is presented in APPENDIX-B

(Figure 4. Simulation of the improved case study situation)

5. Results

Table 3 shows the key results of the validation of the proposed Lean production model. There was a significant improvement in the rate of delivery on time, which increased from 66.40% to 87.85%, representing an increase of 32.30%. In addition, the setup time was reduced from 27.93 minutes to 19.52 minutes, achieving a decrease of 30.11%. Productivity also improved, from 25 units per hour to 32 units per hour, representing an increase of 28.00%. Finally, the cycle time was reduced from 2.44 minutes to 1.86 minutes, reflecting a decrease of 23.77%.

Table 3. Results of the validation of the proposed model

Indicator	Unit	As-Is	To-Be	Results	Variation (%)
On timeDelivery rate	%	66.40%	90%	87.85%	32.30%
SETUP Time	min	27.93	18	19.52	-30.11%
Productivity	Unit/MH	25	35	32	28.00%
Cycle time	min	2.44	1.75	1.86	-23.77%

6. Conclusions

The study presented in this paper aimed to address the significant production challenges faced by small and medium-sized enterprises (SMEs) in the metal-mechanical sector, specifically focusing on issues related to machine setup times, operational errors, and inventory management. The primary findings revealed substantial improvements in key performance indicators following the implementation of a Lean Manufacturing model. The on-time delivery rate increased from 66.40% to 87.85%, reflecting a 32.30% improvement. Setup times decreased by 30.11%, productivity increased by 28.00%, and cycle times were reduced by 23.77%. These outcomes demonstrate the model's effectiveness in enhancing operational efficiency and production reliability.

Reflecting on the importance of this research, it is evident that optimizing production processes within SMEs is crucial for maintaining competitiveness and ensuring sustainable growth. The metal-mechanical sector plays a pivotal role in economic development, and by addressing inefficiencies, these enterprises can better meet market demands and improve their profitability. The study underscores the necessity of adopting Lean Manufacturing principles to streamline operations and reduce waste, which in turn contributes to higher customer satisfaction and better market positioning.

The contributions of this research to the field of Industrial Engineering are manifold. Firstly, it provides empirical evidence supporting the efficacy of Lean Manufacturing tools such as Poka Yoke, SMED, 5S, Kanban, and A3 reports in improving production processes within SMEs. The study also highlights the importance of a tailored approach to implementing these tools, considering the unique challenges faced by SMEs in the metal-mechanical sector. By integrating these methodologies, the research offers a comprehensive framework that can be adapted by similar enterprises to achieve operational excellence.

In conclusion, this study not only addresses a critical gap in the existing literature but also provides practical solutions for enhancing production efficiency in SMEs. Future research should focus on exploring the long-term impacts of Lean Manufacturing implementation on SMEs and investigate additional tools and techniques that could further optimize production processes. Moreover, expanding the scope of research to include different industrial sectors could provide a broader understanding of the applicability and benefits of Lean Manufacturing across various contexts. This would contribute to the development of more robust and versatile production models, ultimately fostering innovation and efficiency in the manufacturing industry.

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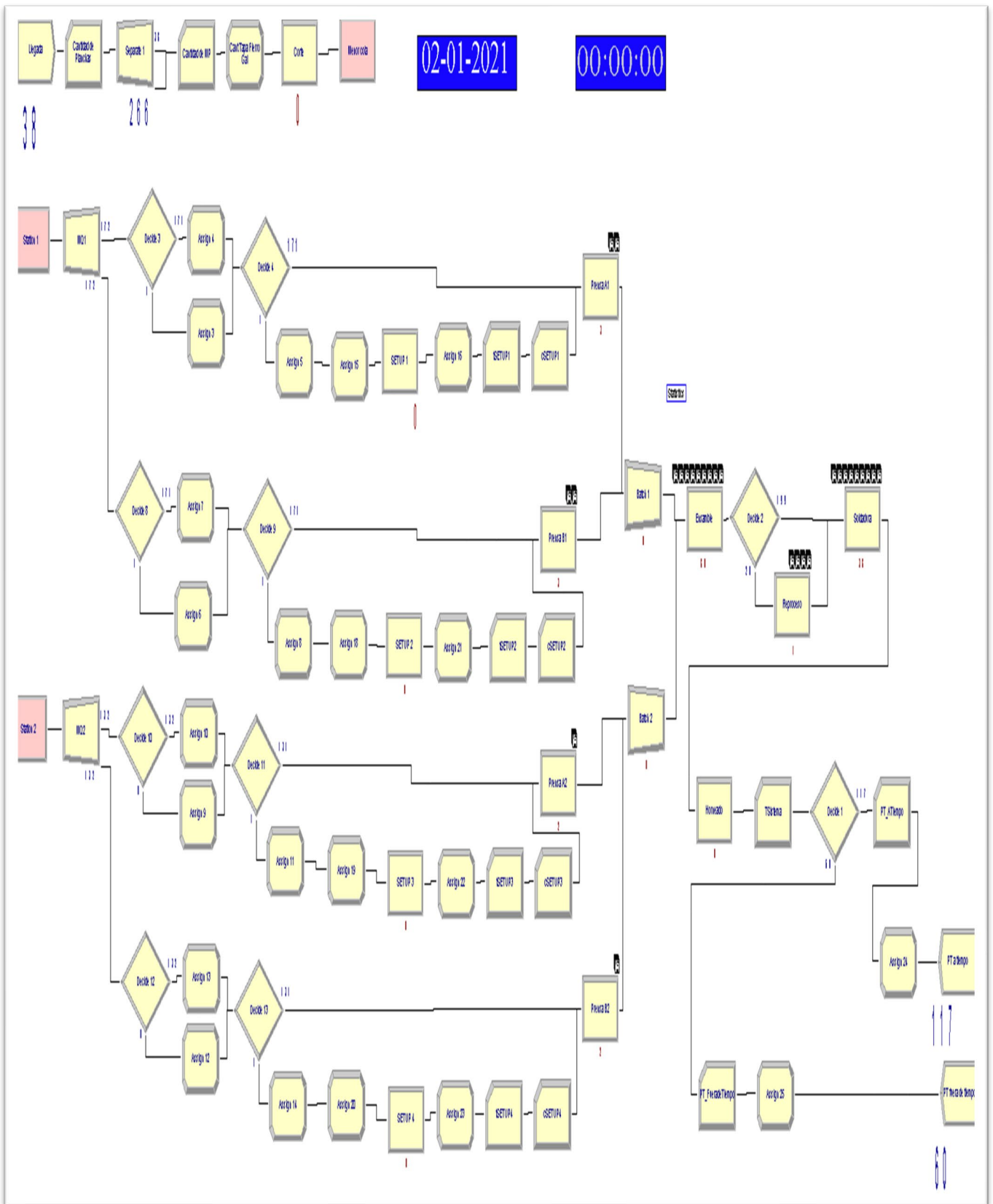
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Biographies

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APPENDIX-A



APPENDIX-B

