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Production Model Based on Lean Manufacturing and SLP to Increase Efficiency for a Company in the Metal Mechanical Sector

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Abstract

For a developing country like Peru with a rapidly growing manufacturing sector, the metal mechanic is one of the main driving forces because they provide machinery and tools for the rest of the sectors. However, this growth has been stopped by capacity limits and a wide range of troubles and delays that occur during the process, most of the Peruvian companies don't have developed methodologies like the companies abroad whose production efficiency is good. As a response to this problem, we have developed a production model based on System Layout Planning and Lean manufacturing tools such as Total Productive Machine, 5S, and Kanban. As a result of implementing these methodologies, we have increased the efficiency of the system flow so that there won't be too many delays and increase the productivity of the whole process.

Keywords
Production, efficiency, System Layout Planning, Total Productive Machine, 5S, Kanban, productivity.

1. Introduction
It is worth highlighting the importance of the metalworking industry concerning other industrial sectors since it provides inputs and machinery to other manufacturing industries to produce consumer goods (such as household appliances, electronic devices, and lighting, among others), as well as to sectors such as mining and agriculture. Therefore, this industrial branch, due to its technological and value-added potential, constitutes an important link in the productive structure of the economy (PRODUCE 2022). The need to conduct this research lies in doing something to help solve the common problems Peruvian companies have. The main problems to be solved are the ultiple idle times and delays that occur during the process, the high rate of bad products that must be reworked, and the disorganization and prioritization. This causes economic losses that seriously affect the companies. The objective of this research is to minimize delays in productive processes and improve the company's distribution by reducing the search time for tools and the transfer of workers from one station to another Through an innovative proposal using standardization tools for work, materials planning, and simulation of results (Campos Villanueva 2021).

1.1 Objectives

General Objective

To design and propose feasible improvement solutions to achieve the reduction of idle or misused times, thereby increasing efficiency and productivity during processes in a metal-mechanical sector company, using Lean Manufacturing and SLP tools.

Specific Objectives

● Reduce the high waiting times for productive activities by 15% to align more closely with companies practicing good practices and avoid unnecessary over-processing.
● Decrease defective products and rework by 10% using TPM tools to prevent the economic impact of these issues from affecting us.
● Implement a structuring and training process for personnel to organize administration efficiently through the Kaizen 5S tool.
● Reorder the current process layout to speed up the flow of production and reduce the time of production by 15% with the SLP.

2. Literature Review

For this research, we only used the Scopus, and Mendeley database, as well as the Web of Science. Adding the results obtained from each typology gives us a total of 358 results, of which we choose the 40 closest to the concept that is related to our title and the objective of our research. Likewise, we verified that these articles are not more than 5 years old and to measure their quality and originality, Scimago was used, accepting articles up to Quartile 4 (Q4). We seek to distinguish the appropriate articles according to their characteristics and show in a more organized scheme the body of knowledge that supports the state of the art that has been determined in the research.

Typology 1: Efficiency and Metal-Mechanic Industry

The main article is based on research conducted for a company like ours that faced similar problems. This factory did not conduct a standardization study or facility design. This study should be conducted to address the challenges, especially poorly distributed workstations and delayed tool retrieval, which account for 85% of the causes. Standardization is crucial for maintaining consistency during productive activities and thereby increasing efficiency (Casallo & Lucero et al. 2021). To address the problem, the 5S tools were applied, complemented with SLP, MRP, and work standardization. This study has improved the on-time delivery percentage. Furthermore, by combining planning and standardization tools, distribution has been enhanced, process times reduced, and the distances covered by each operator decreased (Maradiegue & Álvarez et al. 2021). Below, diagrams of the tool application process can be observed.

Regarding this typology, various authors converge to apply similar tools to address issues like those visualized in this typology. In a success case presented by (Shuaiyin & Zhang et al. 2021), the use of the Internet of Things is highlighted and how it can contribute to better energy management and the identification of deficient processes. Once these deficient processes are identified, tools such as SLP and 5S can be applied, which, with the assistance of artificial intelligence, optimize organizational processes. Regarding efficiency within the metal-mechanic sector, methodologies such as Value Stream Mapping (VSM), kanban, jidoka, and 5S are also discussed. Kishimoto & Medina et al. (2020) agree with the anchor article that Lean tools greatly support continuous improvement, but in this case, the 5S takes a different approach that complements Kanban and Heijuka. Thus, authors differ on which tools are best suited for any given situation.

Typology 2. Lean Manufacturing

This study evaluates the conditions within the operational environment of a metal-mechanical plant, characterized by significant delays in deliveries. To tackle this issue, an investigation is conducted to identify the root causes. Subsequently, a simulation is carried out, and the findings are discussed, with a particular focus on their economic implications. Notably, in 2018, penalties totaled $15,822. If the plant persists in prioritizing production quantity over improving operational efficiency, it faces potential consequences such as reduced effectiveness in product delivery and compromised quality. Timely deliveries are a crucial metric in the manufacturing sector, influencing sales and the overall market standing of the company. This, in turn, affects the customer's perception of the company, leading them to explore alternatives that better meet their needs (Arbieto & Vásquez et al. 2020).

The examination centers on a metal-mechanical enterprise in the Villa El Salvador Industrial Park, specializing in the production of chairs, folders, tables, and various other items with a metal framework. The company has adhered to its production procedures with minimal modifications over the years, indicating a degree of obsolescence in the process and, consequently, a decline in overall productivity. Recently, the company has experienced a decline in sales, coupled with a significant increase in delivery delays.

To propose the new model, the following methodologies were employed: VSM, SLP, SMED, and Process Flow Diagram (PFD). Once integrated, a proposed model for efficient space utilization to reduce lead time was developed. Tests demonstrated a 6.79% reduction in delivery time due to a combined 21.82% reduction in downtime (Altamirano & Marcelo et al. 2020). This implies that delivery days could be reduced by this percentage, enabling the company to meet order delivery deadlines. Converging authors such as Ruiz Sotelo & Munive Quiroz et al. (2020) agree that the SMED tool and 5S focus on continuous improvement in production, quantitatively measuring time reduction in setups and emphasizing waste reduction. They highlight the importance of eliminating production problems and their impact on product quality. Additionally, Altamar & Noriega et al. (2021) share the view that SMED consists of techniques elaborated to carry out die changes in less than 10 minutes. Following the principles of Single-Minute Exchange of Die (SMED), reducing setup durations allows the organization to operate with more compact batches, leading to shortened process durations, enhanced delivery timelines, and reduced work in progress and finished product inventory.

Typology 3: SLP

The problem to address is the prioritization of certain orders over others and the delayed maintenance of machinery, leading to production line stops and process delays. The main impact of this problem is the low productivity of the plant, resulting in financial loss and missed opportunities for companies to reach their maximum potential. They may also lose customers and face fines due to poor product delivery. To avert this situation, there is a planned implementation of an effective model rooted in Total Productive Maintenance and Systematic Layout Planning. The emphasis is on enhancing productivity in companies within this sector by addressing both machinery and human resources (Seminario & Araujo et al.2021). Systematic Layout Planning (SLP) serves as a methodical design planning instrument aimed at optimizing plant layout, extensively explored by international scholars to tackle planning challenges in various industries. This tool facilitates the examination of logistical connections among different operations, enabling the identification of design-related issues. In a company-based investigation, it was illustrated that restructuring the work sequence and production flow through the application of SLP led to a nearly 40% decrease in travel distances and a subsequent boost in production.

Total Productive Maintenance (TPM) elucidates the concept that through comprehensive engagement, it becomes possible to manage the entire process, eliminate inefficiencies, enhance equipment utilization, and optimize overall benefits. Articles discussing this methodology underscore the significance of addressing the six major losses, namely time, quantity, setup, speed, quality, and performance. The assessment of its application often involves the use of Overall Equipment Effectiveness (OEE), a metric employed to enhance machine performance and cut down production costs. OEE integrates machine condition metrics into a measurement system, deriving values from the availability level, process efficiency, and product quality index (Collao & Quiroz et al. 2021).

The proposed solution is founded on the combined implementation of TPM and SLP tools, to enhance machinery productivity in a Peruvian SME within the metal-mechanical sector. This approach tries to solve issues such as the lack of preventive maintenance and the current suboptimal plant layout within the studied company. The implementation of Lean tools proved viable, resulting in a productivity increase of 7.69%, surpassing the initial goal. Additionally, a reduction of the process path by 75.64 meters led to a 27.83-minute decrease in cycle time. In simulation, this translates to a reduction of approximately 32.92 days per year. Regarding contributions and the state of the art in this typology, several authors converge with the ideas of this article. Among them, Seminario & Araujo et al. (2021) agree that SLP allows for improving plant design by identifying issues, resulting in a nearly 38% reduction in travel and increased production. Likewise, Arbieto & Vásquez et al. (2020) concur that using SLP led to a reduction in lead time and identified unproductive time reduction.

Typology 4. Resources and Efficiency

Current worldwide consumption indicators of various resources and the associated hazardous emissions are surpassing the Earth's natural regeneration capacity, rendering current industrial practices unsustainable. Consequently, the acceleration of international resource utilization and environmental destruction is occurring at an alarming pace, leading to an environmental footprint of 1.7 Earths in 2019. Increasing the demand for eco-friendly products and putting legislative pressure are compelling companies to adopt more environmentally sustainable practices. Proposing the sustainable development of businesses involves focusing not only on profit but also on contributing positively to the planet by utilizing resources efficiently.

The development of worldwide supply and value chains over the past few decades has revealed that enhancement-leading actions targeting local entities within manufacturing systems as isolated processes are insufficient for achieving significant global improvements (Blume 2020). To address the complexity of current value chains and global supply networks, a holistic concept is suggested for analyzing and enhancing the efficiency of industrial resources. This concept supports decision-making to promote resource efficiency in manufacturing value chains, aiming to contribute to sustainable development. The results obtained from the analysis encompass the value chain and product life cycle, along with a proposed model for improving resource usage, leading to a 25% reduction in harmful emissions.

Similarly, according to Franchi & Silva et al. (2021), the absence of maintenance tools like TPM can severely impact efficiency and effective management, resulting in substantial losses for companies that lack or improperly apply them. Nakajima (1988) outlines Japan's maintenance history, progressing through corrective, preventive, and predictive maintenance phases, ultimately evolving into the TPM program (da Costa 2015). The primary goal of TPM is to enhance the efficiency of equipment across its entire lifespan, ensuring ideal conditions are sustained to avoid unforeseen breakdowns, reduce speed losses, minimize downtime, and prevent quality imperfections.

Typology 5: Improvement of efficiency in delivery time

Timely delivery is characterized as the proportion of orders delivered on schedule to the total number of orders placed. This metric serves as an indicator of how effectively a company adheres to the specified dates outlined in contracts. In today's fiercely competitive markets, marked by continuous technological advancements and growth, the speed of processes is a pivotal factor in ensuring product success. Particularly in make-to-order environments, where production commences after a customer places an order and operates within defined time constraints, enhancing process speed is imperative for maintaining competitiveness (Kishimoto & Medina et al. 2020).

To pinpoint issues, various indicators were established, and the Value Stream Map (VSM) was employed, along with the Pareto diagram, to identify the root causes of the problem. Implementation of tools such as 5S, Kanban-ConWIP, and Heijunka followed. The research proposal centers on introducing a production management model in a metal-mechanical company in Peru and evaluating its impact on the company's on-time delivery rate. After just one month of operating under the proposed model, the company's on-time delivery rate surged from 35% to 80%. The model, designed for global applicability, serves as a template for companies in analogous sectors (Sotelo & Raymundo et al. 2020). The implementation of the proposed strategies, tested in a pilot plan at the welding and rolling stations, demonstrated an approximate 46% increase in on-time deliveries, constituting a significant improvement to the issue at hand.

3. Methods

System Layout Planning (SLP): This tool is developed by analyzing the level of standardization and the distribution of machines and equipment throughout the plant to identify improvement opportunities. The goal is to find the optimal process flow to avoid unnecessary and overly long stretches that slow down our process. Additionally, it aims to measure standard times for each activity based on the capacity of each machine to ensure a smooth and consistent process. Standardization is crucial for maintaining consistency during productive activities and thereby increasing efficiency (Casallo & Lucero et al. 2021). Furthermore, by integrating planning and standardization tools, improvements have been achieved in distribution, reducing the time for each process, and minimizing the distances traveled by products and materials (Maradiegue & Álvarez et al. 2021).

Total Productive Maintenance (TPM): To implement TPM, the process begins by identifying maintenance and operational failures in equipment and machinery. Following this analysis, constant training of operators is initiated to involve them in maintenance activities and enable them to identify faults or performance declines in their equipment. This empowers them to perform preventive maintenance themselves, ensuring the quality of processes. Both machinery and human resources are analyzed to increase productivity and foster greater participation (Seminario & Araujo et al. 2021). Articles referencing this methodology emphasize the importance of addressing the six major losses: time, quantity, setup, speed, quality, and performance. To assess its implementation, Overall Equipment Effectiveness (OEE) serves as a metric aimed at improving machine performance and cutting down on production costs. OEE integrates machine condition metrics into a measurement system, with values derived from the calculation of availability, process efficiency, and the product quality index (Franchi & Anholon et al. 2021).

5S: The 5S tool is applied to establish order and cleanliness at each workplace to improve working conditions and consequently enhance the productivity of each worker. The development of the 5S tool begins with the analysis of the workplace and the identification of undesirable practices, followed by the establishment of cleaning and organizing schedules. Additionally, policies for order, cleanliness, standardization, and discipline are defined to align with the continuous improvement approach. A fresh approach emerges by merging the 5S and SMED processes, as both methodologies adhere to comparable principles and can deliver outstanding outcomes. This fusion is additionally strengthened by the Kaizen tool, fostering collaboration and leadership within production chains. This simultaneous implementation of both tools, rather than a sequential approach, reduces the implementation time and positively impacts the organization. (Llontop & Mamani et al. 2021) focused their study on time reduction, particularly in sectors using extruders, ovens, etc. The constant pursuit of continuous improvement and the establishment of processes aim to accelerate production at each workplace.

Kanban: To begin the implementation of this methodology, it is necessary first to identify and classify each task performed in the production process. Each phase of the process is organized to identify its requirements and conditions, categorizing each process into one of three phases: "pending," "in progress," and "completed." By implementing a card system indicating the requirements and status of each process, better coordination and communication within the plant can be achieved, allowing for prioritization based on available time. In examples and successful cases analyzed by typologies, tools such as 5S, Kanban, and Heijunka were implemented. The research proposal focuses on implementing a production management model in a metal-mechanical factory in Peru and analyzing its impact on the company's on-time delivery index. Within a month of operating under the proposed model, the company's on-time delivery rate escalated from 35% to 80%. This model, designed for global use, serves as an example for companies in similar sectors (Sotelo & Raymundo et al., 2020). All of this is aimed at improving process speed efficiently, a crucial factor for maintaining competitiveness in the market (Kishimoto & Medina et al. 2020).

4. Data Collection

To enhance the knowledge of the company, we collected data about the current situation of the production system. We found a great industry leader to compare our situation.

Table 1. Technique gap

Period (months)	Current production (2022)	Standard (Good practice)
1	1502	2954
2	1302	3000
3	1727	2893
4	1758	2917
5	1544	2950
6	1037	2893
7	1572	2958
8	1514	2974
9	1521	2923
10	1360	2904
11	1365	2905
12	1017	2865

They have a standard production of stoves monthly and similar capability, however, their production system is more developed, and their efficiency is one of the highest in Lima. In comparison, we only produce approximately 60 stoves per day. To describe better the situation, we have elaborated a technique gap..As seen in Table 1, we figure out that the technique gap is 50.99%. This is a huge disadvantage for our company, but with the tools proposed, we can shorten the gap. From this table, we also can acknowledge that our capability is only working at 39.2%, so this is our efficiency in production as well. With SLP and Kanban, we will revert this bad situation. About the defective production, we have the current situation with data from last year.

Table 2. Number of defective products

Period (months)	Current production (2022)	Defective percentage	Number of bad products

1	1502	7.52%	113
2	1302	9.91%	129
3	1727	6.95%	120
4	1758	4.89%	86
5	1544	6.15%	95
6	1037	8.49%	88
7	1572	2.99%	47
8	1514	3.90%	59
9	1521	3.55%	54
10	1360	6.25%	85
11	1365	5.49%	75
12	1017	9.05%	92
Total	17219	6.06%	1043.00

From what we observe in table 2, the percentage of bad products is 6.06%, a percentage we will reduce using the TPM. Besides these indicators, we also have:

Elapsed time during the journey: The time is measured from the beginning of the production process until the final product is obtained. Measurement is done per unit produced. SLP and 5S will be applied for the reduction of this time.

Machine availability level: This indicator represents the amount of time spent working compared to the total hours available. It allows us to visualize the availability for production for each machine. It can be calculated as follows: $Machine\ availability = 100\% * \frac{Operating\ hours}{Total\ hours\ available}$

Number of projects completed on time: This indicator allows us to visualize the number of projects successfully finished and delivered on time compared to the total number of projects. It demonstrates the success rate in accepting and completing projects within the specified timeframe.

5. Results and Discussion

5.1 Proposed improvements and results

SLP: From the analysis of the current distribution of the workshop and understanding each activity in the production process, an improved layout design is proposed to contrast it with the current workshop layout, previously presented in the stage of developing the solution proposal for this study. This is done to obtain the variation in productivity. The analysis is presented below:

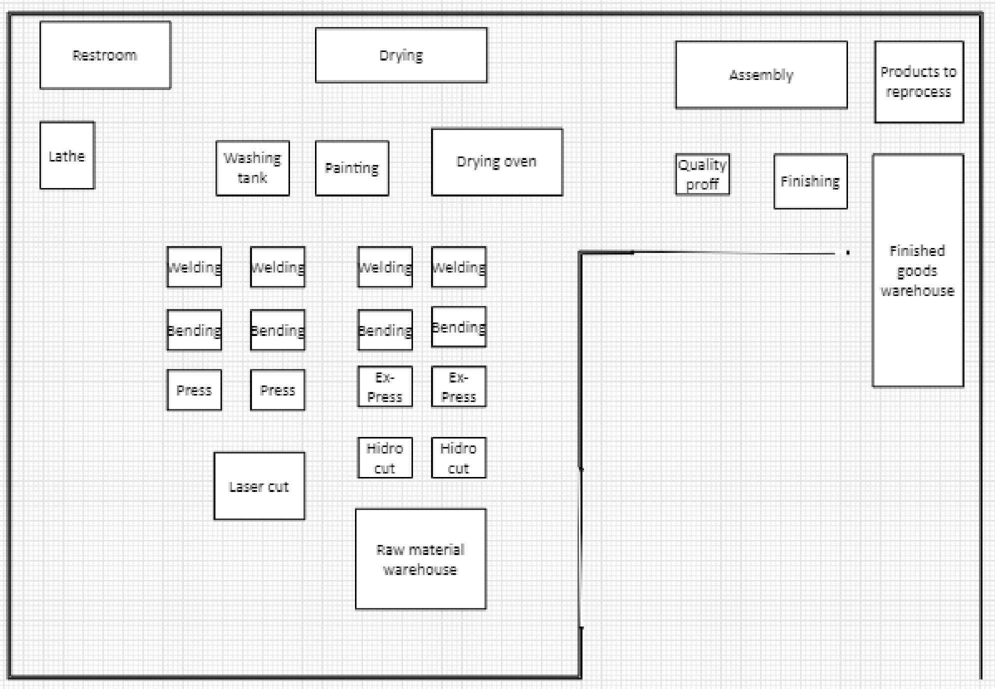

Figure 1. Proposed design of the plant

As a result of the proposed improvement seen in Figure 1, within the same simulated time, 70 kitchens were produced in 8 hours, thereby increasing efficiency by 16%. The time from bending to welding was reduced from Normal (3, 0.5) to Normal (1, 0.5), and delays in reaching the washing stage were eliminated.

Table 3. Proposed product Journey Matrix

	Blending	Soldering	Washing	Drying	Painting	Oven drying
Blending		2 meters				
Soldering			2 meters			
Washing				3 meters		
Drying					2 meters	
Painting						2 meters
Oven drying						
			Total			11 meters

The journey length before the implementation was 20 meters, as seen in Table 3, for the part with more delays in the production process. Using the SLP will help us reduce this journey and optimize the production flow to 11 meters.

TPM: About the implementation of the TPM tool, the most important part is the training of the employees, and we elaborated a program for this training. This program will be displayed like this:

First session: Basis of the TPM
Second session: Essential elements of the TPM
Third session: Autonomous maintenance
Fourth session: Inspection training
Fifth session: Quality maintenance
Sixth session: Security and environmental training

After finishing the program, we gathered the results after the simulation of the implementation. The results we obtained are:

Table 4. Results of TPM

Machine availability	
Total time available	2496 hours/year
Stopped time	100 hours/year
Operating time	2204 hours/year
Improved availability	95.66 %
Performance	
Projected production	21828 stoves/year
Theorical production	23040 stoves/year
Improved performance	94.74 %
Quality	
Acceptable products	21020 stoves/year
Processed products	21828 stoves/year
Quality percentage	96.30 %
Overall Equipment Effectiveness (OEE)	87.28 %

After simulating the implementation of TPM, we went from producing only 70 stoves a day with SLP to 76 stoves in the short term applying the TPM training in our plant. As seen in Table 4, our OEE went from 60.26 % before TPM, to 87.28%.

5S

a. Seiri (Select): The first stage involved categorizing work tools and materials. For this purpose, a record was used to classify everything found in the warehouse. This included tools such as screwdrivers, gas installation pipe cutters, etc., and materials like 1% zinc, bouquet, knobs, paints, pipes, etc. The aim was to record the quantity of necessary items and their frequency of use.
b. Seiton (Sort): Then, in this stage, the materials most required in production were placed in order of weight and size closest to the warehouse door. And with respect to the tools, they were placed in labeled briefcases, each one; finally, the safety accessories were placed in order with their respective names of each operator.
c. Seiso (Cleanliness): At this stage, an exhaustive cleaning of the raw materials and finished products warehouse was carried out. To keep the environment pleasant and clean for the operators, a meeting was

established where the importance of this stage was communicated, with which a record was prepared for each operator to clean and thus take turns every week.

d. Seiketsu (Standardization): The penultimate stage consisted of supervising each workstation to give preventive maintenance to the machinery. Afterward, a procedure was developed so that both warehouses, both raw materials and finished products, are for inputs and outputs (FIFO). Likewise, a record is established for weekly cleaning, which would later become daily. In addition to following up on the previous 3s.

e. Shitzuke (Discipline): Finally, at this stage, all operators, and external and internal employees are reminded that this tool is essential for continuous improvement. Thus, we encourage them continuously to follow the process and remind them of everything by putting phrases and goals all over the place.

As a result, we collected the data and elaborated a table with the scores of every S type in the current situation, based on our analysis and then the score after the implementation.

Table 5. 5S Implementation

S type	**Current situation**	**After the implementation**	**%**
1s = Seiri	5	8	62.5
2s = Seiton	3	8	37.5
3s = Seiso	5	7	71.4
4s = Seiketsu	4	6	66.7
5s = Shitzuke	5	8	62.5
Total	**22**	**37**	**59.5**

After having implemented the 5's tool, we can see from Table 5 that there is an improvement percentage of 59.5%. Since before there was a waste of time of 6 to 8 minutes trying to find each material and/or tool, now with the implementation it is enough to enter the warehouse and observe the classification of what was made.

KANBAN: As the last tool we have the one whose function is to implement each process with colored cards. Kanban cards have a specific design with standards for each activity in production (Mourato, 2021). On this occasion, although the change is necessary throughout the plant, the Kanban cards will only be necessary for the improvement of the company in 2 of the stations in which the most flow problems arise, which are the painting station and the folding one.

Table 6. Card Template

<table>
<tr><td colspan="3">KANBAN Card</td></tr>
<tr><td>Name of the product</td><td></td><td>Process</td></tr>
<tr><td>Materials/tools</td><td></td><td></td></tr>
<tr><td rowspan="2">Previous process</td><td rowspan="2"></td><td>Details or Suggestions</td></tr>
<tr><td></td></tr>
<tr><td>Subsequent process</td><td></td><td></td></tr>
</table>

After elaborating the Kanban template seen as Table 6, we visited the company on September 27 and taught them how to use it, after two weeks, and an improvement was observed in the two workstations, thus optimizing the flow in processes where more waiting times originated, specifically in the painting and baking stations. On the other hand, there was increased efficiency in the arrival of other components such as rumble strips, ears, knobs, etc.

Thanks to Kanban, the flow of tools was streamlined throughout the production process, leading to completed projects increasing from 75% to 90%. This improvement was attributed to the training of operators and the streamlined processes.

As a total result of the whole implementation process, we elaborated a final Dashboard showing all the results.

Table 7. Results Dashboard

Tools	Indicator	Unit	Previous situation	Result
SLP	Time traveled	Minutes/stove	8	6.8
TPM	Availability	Percentage	84.62%	95.66%
5S	Idle time	Minutes	8.3	2.1
KANBAN	Finished projects	Percentage	75%	90%

5.2 Validation

Validation of the proposed improvement has been carried out in two ways, through the implementation of a pilot and through simulation of the system in the Arena Software.

Validation through pilot: For the 5S implementation, we made a pilot to see the effects on the employee's productivity. First, we divided the warehouse by segments (type of tools) of function. For example, all the painting and rust thinners together.

Figure 2. 5S pilot

Validation through Arena simulator: For the rest of the tools, we used to software Arena to simulate the application. The simulation had 10 repetitions and simulated eight hours of work using the following process. And the result is:

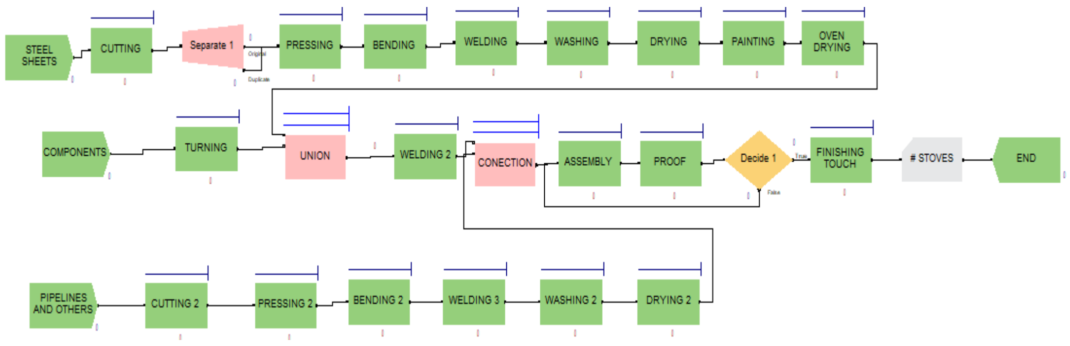

Figure 3. Arena Simulation

6. Conclusions

- In conclusion, we can say that Lean manufacturing tools have significantly helped improve production efficiency. We transitioned from manufacturing 60 kitchens per day to 75 kitchens daily, resulting in a 25% improvement. This enhancement will contribute significantly to the company's profitability.

- It is crucial to keep your operators well-equipped and trained, given the hazardous activities within the production process that could impact their integrity. Adequate training not only allows the operator to enhance performance but also encourages responsible use of machinery and tools, as they better understand the consequences. This will also prevent future fines or complaints of negligence that could severely damage the company's reputation. Performance increased from 77.4% to 89.74% thanks to TPM.

- Thanks to the implementation of the Japanese 5S tool, all wastes generated after each activity throughout the plant were successfully reduced. This included the relocation of unnecessary or infrequently used materials and tools, and process standardization aimed at achieving better efficiency. After implementation, the result showed a reduction of over 59%.

- Through the Kanban tool, visibility in the activities of each bending and painting process, which were causing long waits, was improved. Limits were set to avoid multitasking. After creating cards for each workstation there was an improvement from 75% to 90%.

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Biographies

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