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Management Model to Reduce Order Preparation Time by Applying 5S and Standard Work in a Glassworks

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Abstract

This project addresses operational delays in a small manufacturing enterprise (SME) specializing in the production of aluminum-frame glass windows. Based on a detailed diagnostic using key performance indicators such as order preparation time, the number of reworks, and the level of material waste, the main causes of inefficiency were identified as workplace disorganization, a lack of standardized procedures, and inadequate use of tools. To address these issues, a combined implementation of two Lean Manufacturing methodologies was proposed: 5S, aimed at improving order, cleanliness, and workplace efficiency; and Standard Work (SW), designed to reduce operational variability and ensure uniform execution of critical tasks. As a result of this intervention, and following validation through simulation, the total order preparation time was reduced by 47.06%, rework decreased by 53.55%, and unrecoverable waste was reduced by 64.29%, all of which significantly contributed to the overall efficiency of the production process.

Keywords
5S, Standard Work, Lean Manufacturing, Time Reduction, Process Simulation.

1. Introduction
In the current context, manufacturing companies face constant pressure to improve their productivity and operational efficiency to remain competitive in globalized markets. In particular, small and medium-sized enterprises (SMEs) often present significant gaps in resource utilization due to financial, technological, and managerial limitations (Campos et al. 2023). These gaps result in rework, idle times, and disorganization in workflow, factors that directly affect order fulfillment and customer satisfaction (Allauca and Mosquera 2022).

Within this scenario, Lean Manufacturing has been consolidated as an effective philosophy for eliminating waste, optimizing processes, and generating value (Randhawa and Ahuja 2017). Among its tools, the 5S methodology is widely recognized for enhancing workplace order, discipline, and efficiency, which leads to waste reduction and a safer working environment (Kleszcz et al. 2017; Hernández et al. 2023). Complementarily, the application of Standard Work reduces variability in the execution of critical tasks, ensuring uniformity and efficiency in production (Mor et al. 2019; Ocampo et al. 2024).

Several studies have documented tangible benefits from applying these methodologies in SMEs. For instance, Kishimoto et al. (2019) demonstrated that the use of Lean tools contributes to improving delivery punctuality in metalworking companies, while Macassi et al. (2023) reported reductions in delivery times in painting service companies through the implementation of Standard Work. Similarly, Florez et al. (2024) showed substantial improvements in productivity by integrating Lean Manufacturing and TPM in a Peruvian metalworking company.
In the Peruvian context, recent research highlights that the adoption of 5S and standardization generates direct impacts on the competitiveness of manufacturing SMEs, reducing order preparation times and costs associated with rework and waste (Díaz and Noriega 2020; Pawlak et al. 2023). This is especially relevant in strategic sectors such as the glass industry, where precision and speed in order preparation are crucial to meeting the demands of industries such as construction. Therefore, this study proposes a management model based on the application of 5S and Standard Work to reduce order preparation times in a Peruvian glass company, contributing to strengthening operational efficiency in a highly competitive environment.

3. Methods

The objective of this research was to develop a management model based on the 5S and Standard Work (SW) methodologies, aimed at addressing operational challenges such as lack of organization, inadequate use of tools, poorly functional storage spaces, and the absence of defined procedures, factors that generate idle times, rework, and production errors (Christiansen 2022; Campos Alva et al. 2023). The combined application of 5S and standardized work establishes a solid foundation in which visual discipline and process repeatability reduce waste and increase productivity in resource-constrained enterprises (Charaja Aznaran 2020). The study was conducted in a micro and small enterprise (MSE) located in Lima, Peru, dedicated to the transformation of glass and aluminum for window production.

The proposed model integrates 5S and SW to optimize the physical environment and preparation procedures. The 5S methodology was implemented to organize, clean, and standardize the workspace, thereby reducing idle times, unnecessary movements, and operational risks (Ribeiro et al. 2020; Acharya et al. 2013), a key aspect in small manufacturing firms where efficiency depends on maximizing the use of the work environment (Flores-Pérez et al. 2023). In parallel, standardized work established clear and visual instructions for each activity, improving coordination, traceability, and reducing operational variability (Henríquez-Alvarado et al. 2019; Flores-Pérez et al. 2023). Figure 1 illustrates the integration of both methodologies, their complementary approaches, and the model's inputs and outputs.

The proposal was structured under the DMAIC cycle. In the Define (D) phase, objectives were specified, and information was collected through interviews, observation, and records. In the Measure (M) phase, process mapping and the value stream mapping (VSM) tool were applied to identify real times, bottlenecks, and non-value-adding activities. In the Analyze (A) phase, problem tree and Pareto analysis were used to identify root causes. In the Improve (I) phase, 5S and SW were integrated to enhance productivity by reducing errors and ensuring uniform execution (Ríos Arévalo 2022). Finally, in the Control (C) phase, audits, KPI panels, and visual charts were implemented to evaluate compliance with standards and sustain continuous improvement through feedback and team commitment.

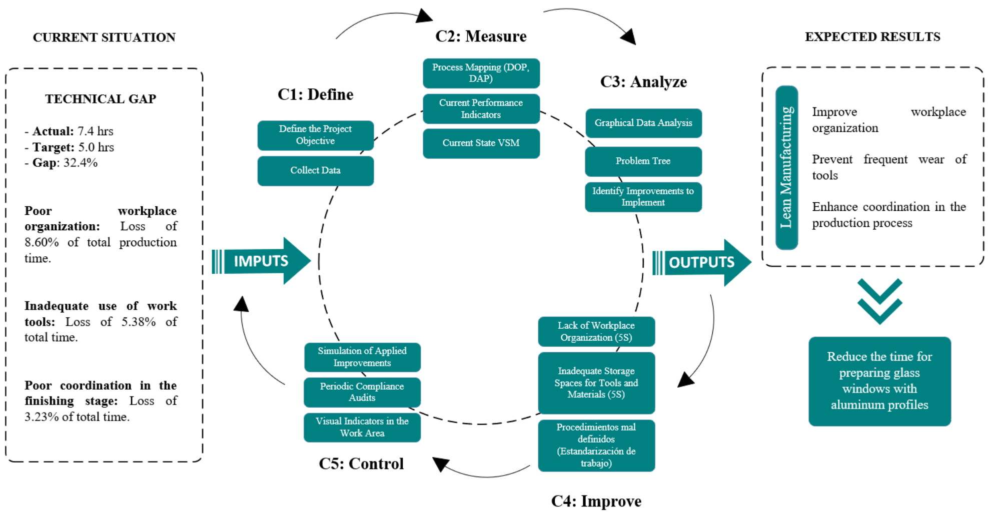


Figure 1. Proposed solution based on Lean Manufacturing under the DMAIC cycle

This study proposes a structured methodology composed of four sequential components that guide the implementation of the solution design aimed at improving order preparation times in the manufacturing of aluminum-frame glass windows. Developed within the methodological framework of the Lean Manufacturing approach, and as illustrated in Figure 2, the process consists of four main components: (1) Data Collection, (2) Implementation of the 5S and Standardized Work methodologies, (3) Process Simulation, and (4) Results Analysis. This logical sequence not only facilitates organized execution but also ensures that decisions are supported by quantifiable evidence and continuous improvement tools. A structured implementation prevents isolated or short-term improvements and promotes sustainable results in operational efficiency and product quality. A proper definition and initial structuring within the DMAIC cycle is essential to guarantee sustainable impacts (Naughton et al. 2024). Furthermore, a phased implementation allows for better consolidation of achievements and facilitates long-term monitoring (Al-Akel et al. 2018).

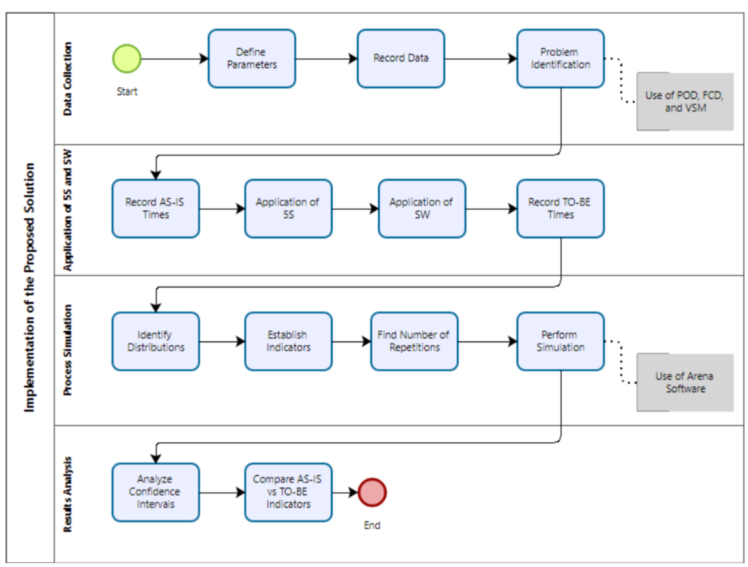


Figure 2. Structured process for the implementation of the proposed solution

4. Validation

To validate the proposed approach aimed at optimizing the order preparation process in a micro and small manufacturing enterprise (MSE) dedicated to the production of aluminum-frame glass windows, a case study was conducted within the company's operational environment. In addition to the direct implementation of improvement tools, process simulation was employed to compare performance before and after the proposal. This combination of empirical and simulated validation provided stronger evidence of the impact of Lean Manufacturing methodologies, confirming their feasibility at both operational and strategic levels.

The validation model began with the definition of the main objective: reducing order preparation times. To achieve this, 73 operational records were collected, from which a sample of 37 observations was selected through simple random sampling, ensuring equal probability for each unit (Montgomery and Runger 2018). Only complete records from the regular production shift were included, while data related to technical stoppages, mechanical failures, external interruptions, or special productions were excluded to ensure representativeness and reliability in the analysis (Patino and Ferreira 2018).

Subsequently, key performance indicators (KPIs) were reviewed to establish objective metrics and define the process baseline. The diagnosis revealed prolonged preparation times, rework, and material waste, which allowed the identification of improvement opportunities. To support this analysis, visual tools such as DOP, DAP, and VSM were employed, facilitating a comprehensive understanding of the production flow and its subsequent evaluation through simulation (Table 1).

Table 1. presents a comparison of the company's key performance indicators (KPIs)

KPI	Target	Actual	Gap
Damage rate in transport	Less than 8%	13%	5%
Order preparation delay	Less than 5 hours	7.4 hours	32.40%
Defects in glass production	Less than 10%	17%	7%
Order cycle time	1 day	3 days	2 days
On-time delivery rate	Greater than 90%	84%	6%
Number of refunds	No refunds	2	2
Incidence rate in storage	Less than 5%	7%	2%

As shown in Figure 3, the process of preparing aluminum-frame glass windows begins with the search for materials (glass and aluminum), followed by the gathering of tools and the cutting of materials according to specifications. Subsequently, the edges are polished, dimensions are verified, and the pieces are assembled. After a quality inspection, the products are carefully packaged and transferred to the finished goods warehouse for dispatch.

A detailed analysis was then conducted using a Process Analysis Diagram, as illustrated in Figure 4, which allowed the quantification of the times associated with each activity, thereby identifying bottlenecks and opportunities for improvement.

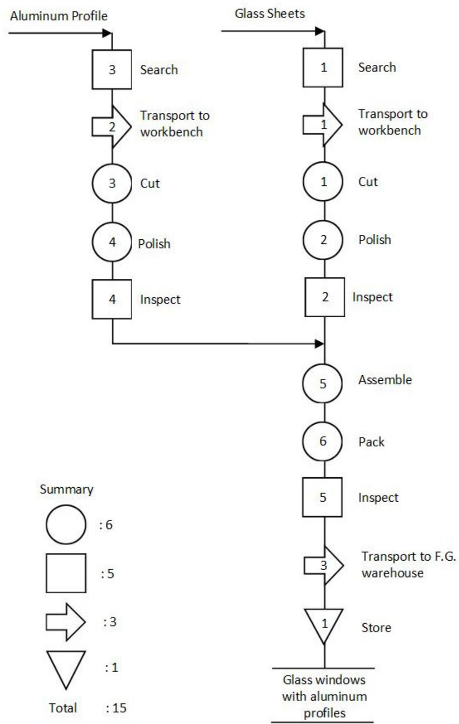


Figure 3. Process Operation Diagram for the preparation of glass windows with aluminum profiles

ANALYTICAL FLOWCHART			OPERATOR / ~~MATERIAL~~ / EQUIPMENT						
Diagram No.: 1 Sheet No.: 1			**SUMMARY**						
Object: Installed Glass			**Activity**	**Current**	**Proposed**				
			Operation	6					
Activity: Preparation of glass windows with aluminum profiles			Transport	4					
			Waiting	0					
Method: ~~CURRENT~~ / PROPOSED			Inspection	4					
			Storage	1					
DESCRIPTION	C	D(m)	T(min)	SYMBOL ○	⇨	D	□	▽	
1. Glass sheets are retrieved from the warehouse			5.8				●		
2. Glass is transported to the cutting area	1	3.8	9.1		●				
3. Glass cutting tool is retrieved			4.4		●				
4. Required area is measured and marked			10.6				●		
5. Glass is cut	1		63.7	●					
6. Glass is polished	1		42.2	●					
7. Aluminum bars are retrieved from the warehouse			2.5				●		
8. Aluminum is transported to the cutting area	1	2.8	3.9		●				
9. Aluminum cutting tool is retrieved			4.7		●				
10. Cutting area is measured and marked	1		8.7				●		
11. Aluminum is cut	1		41.2	●					
12. Aluminum is polished	1		29.7	●					
13. Glass and aluminum pieces are assembled	1		35.6	●					
14. Product is packaged	1		24.8	●					
15. Product is transported to Finished Goods warehouse	1	3.2	8.7						
16. Product is stored								●	
Total			295.6	6	4	0	4	1	

Figure 4. Process Activity Diagram for the preparation of glass windows with aluminum profiles

Based on the value stream mapping shown in Figure 5, a Lead Time (LT) of 3105.6 minutes was identified, while the Value-Added Time (VAT) accounted for only 241.4 minutes, representing merely 7.8% of the total process. This level of VAT indicates a significant operational inefficiency, even below the 10% threshold typically observed in traditional manufacturing environments (Salwin et al. 2021). This result highlights the need to apply Lean Manufacturing tools to reduce non-productive time, eliminate waste, and increase productivity, while also revealing a 32.4% gap in order preparation.

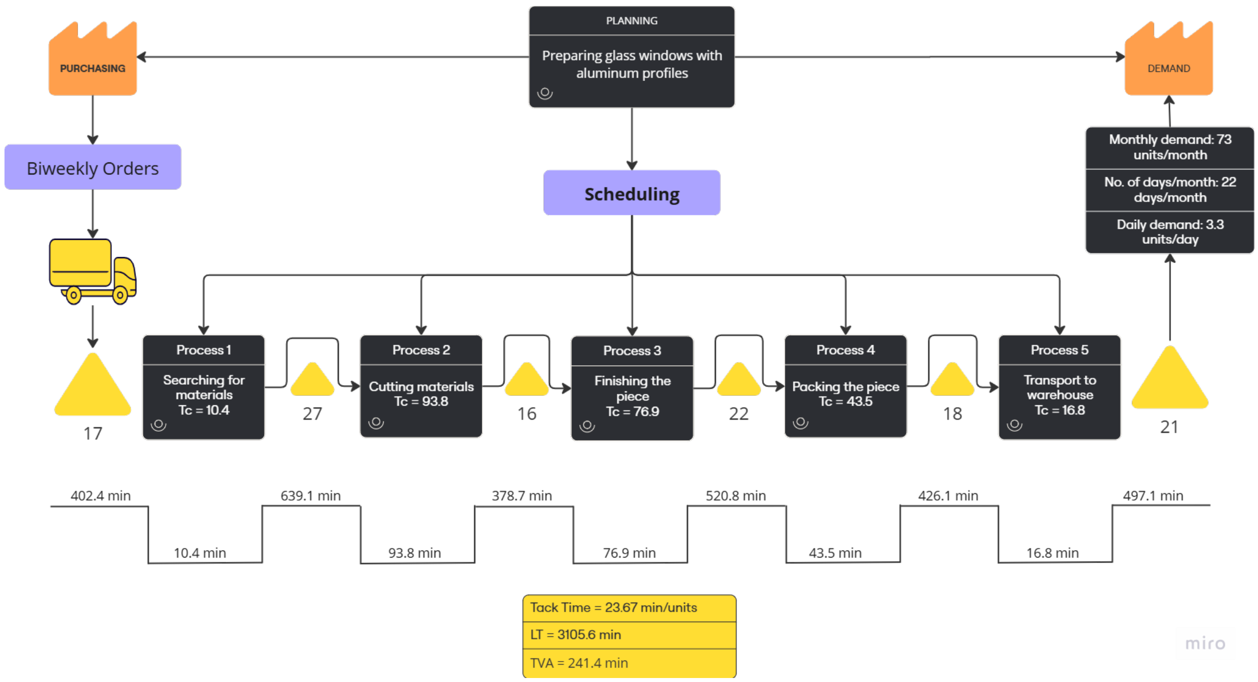


Figure 5. Value Stream Mapping of the glass window preparation process with aluminum profiles

Finally, four main root causes explaining the operational delays in glass preparation were identified: lack of organization in the workplace, inadequate storage spaces for tools and materials, inappropriate use of work tools, and poorly defined procedures. Based on these findings, a problem tree was developed to provide a structured visualization of the causal relationships among the identified factors (Figure 6). Furthermore, the problem tree integrates the Lean Manufacturing tool proposed to address each root cause, thereby facilitating the planning of specific corrective actions.

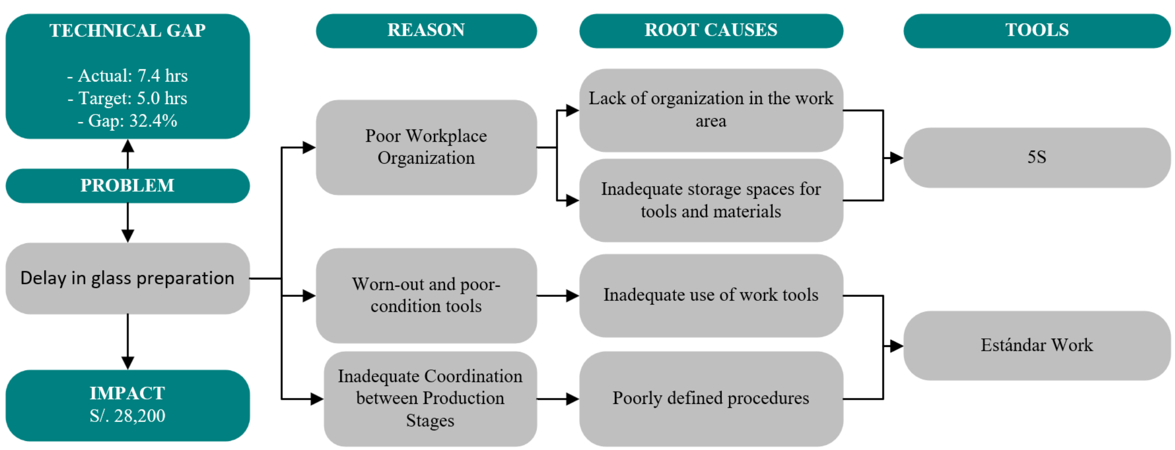


Figure 6. Problem tree diagram

Based on the prior diagnosis and the identification of the root causes of operational problems, the development of the proposed solution was conducted and subsequently validated through a computer-based simulation using Arena software. This tool enabled the comparison of system performance before and after the implementation of improvements. To achieve this, a representative model of the current process was developed, serving as the foundation for structuring the simulation diagram within the software environment. The model accurately reproduces the observed operating conditions, including both the flow of the production process and the number of operators assigned to each activity, thus allowing for a more precise analysis of workload distribution and bottlenecks. Figure 7 presents the simulation diagram used as the basis for the quantitative validation of the system.

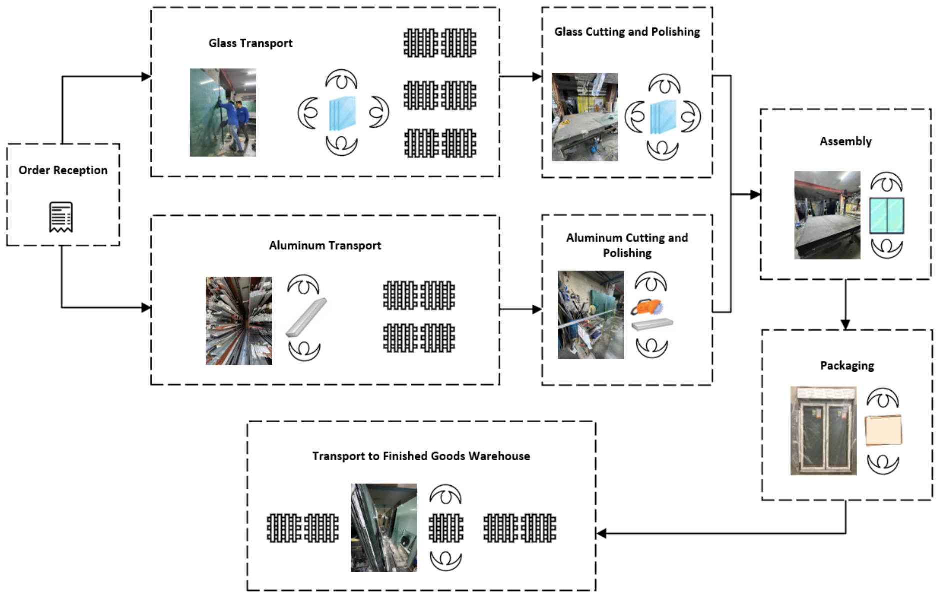


Figure 7. Simulation diagram of the baseline process

From the proposed simulation diagram, the process flow was configured within the graphical environment of Arena software. This representation enables the visualization of the operational sequence, as illustrated in Figure 8. The model defines the order as the primary entity, which is split into two parallel flows: the glass processing line and the aluminum processing line, both of which converge in the final assembly line. The modeled resources include four specialized operators in the glass line, two in the aluminum line, and two in the finishing line, as well as one workstation for glass and another for aluminum, where cutting and polishing activities are performed, and a dedicated workstation for assembly.

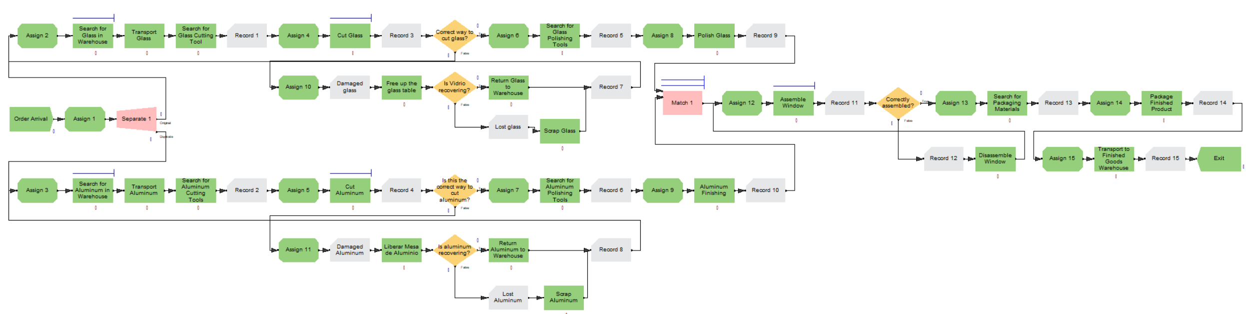


Figure 8. Base simulation model implemented in Arena.

The statistical distributions assigned to each of the activities modeled in the simulation environment are detailed below. These distributions were obtained from a sample of 37 real operating records corresponding to the process activities. The collected data was analyzed using the Input Analyzer module of the Arena software, where multiple distribution types were tested to identify the best option for each activity. The final selection was based on goodness-of-fit criteria, prioritizing distributions with p values from the Chi-square test greater than 0.10 and p values from the Kolmogorov-Smirnov (K-S) test greater than 0.15, ensuring adequate representativeness of the observed variability. This precise assignment of distributions allows the stochastic behavior of the system to be modeled with a greater degree of realism (Fernández and Beltrán, 2020). Table 2 summarizes the simulated activities, the applied distributions and their respective parameters.

Table 2. Distributions of the processes in the base model

Process	Distribution	Arena Expression	p-value (Chi²)	p-value (KS)
Order Arrival	Triangular	TRIA(1.03, 1.49, 3)	0.372	> 0.15
Search for Glass in Warehouse	Normal	NORM(20.2, 2.12)	0.128	> 0.15
Transport Glass	Triangular	TRIA(6, 9.66, 15)	0.32	> 0.15
Search for Glass Cutting Tool	Normal	NORM(9.59, 1.44)	0.324	> 0.15
Cut Glass	Triangular	TRIA(62, 105, 133)	0.209	> 0.15
Search for Glass Polishing Tools	Uniform	UNIF(5, 15)	0.645	> 0.15
Polish Glass	Normal	NORM(69.6, 18.9)	0.217	> 0.15
Return Glass to Warehouse	Triangular	TRIA(9.07, 16.5, 19)	0.4	> 0.15
Scrap Glass	Triangular	TRIA(11, 13.4, 20)	0.3	> 0.15
Search for Aluminum in Warehouse	Triangular	TRIA(6, 7.5, 11.9)	0.522	> 0.15
Transport Aluminum	Normal	NORM(11.4, 1.34)	0.135	> 0.15
Search for Aluminum Cutting Tools	Triangular	TRIA(4.3, 6.6, 8.7)	0.699	> 0.15
Cut Aluminum	Triangular	TRIA(37, 44.8, 66)	0.453	> 0.15
Search for Aluminum Polishing Tools	Triangular	TRIA(6, 7.59, 11.6)	0.284	> 0.15
Aluminum Finishing	Uniform	UNIF(23, 60)	0.393	> 0.15
Return Aluminum to Warehouse	Uniform	UNIF(5, 15)	0.5	> 0.15
Scrap Aluminum	Normal	NORM(9.46, 2.48)	0.191	> 0.15
Assemble Window	Triangular	TRIA(20, 38.1, 51)	0.178	> 0.15
Disassemble Window	Triangular	TRIA(17, 26.5, 34)	0.247	> 0.15
Search for Packaging Materials	Triangular	TRIA(3, 5.9, 8)	0.342	> 0.15
Package Finished Product	Uniform	UNIF(8, 15)	0.464	> 0.15
Transport to Finished Goods Warehouse	Triangular	TRIA(6, 8.42, 11.8)	0.475	> 0.15

Once the configuration of the base model in Arena was completed, including both the operational flow and the statistical distributions corresponding to each activity, the implementation of the proposed improvements was carried out. These improvements consisted of the application of the 5S methodology and standardized work. With the model adjusted to these improved conditions, a new data collection was performed to reflect the expected behavior of the optimized system. This information enabled the development of a second simulation scenario to compare the performance of the system before and after the intervention, thereby evaluating the actual impact of the applied Lean tools (Table 3- Table 7).

Table 3. Problems in tool searching

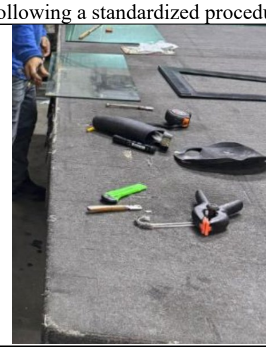
Problem (AS-IS)	Proposed Solution (TO-BE)
Workers waste time looking for the necessary tools at the beginning of the cutting process.	Workers will collect all the necessary tools at the beginning of the process and keep them within reach on the workbench, following a standardized procedure.
	

Table 4. Problems with glass searching

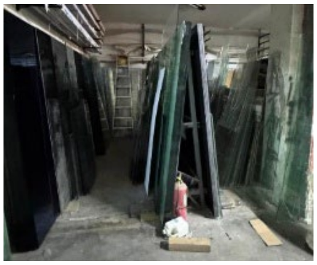
Problem (AS-IS)	Proposed Solution (TO-BE)
The lack of organization to identify and locate the type of glass causes delays.	Place a shelf with samples of the diverse types of glass to facilitate their identification in the warehouse.
	

Table 5. Disorder in the aluminum warehouse

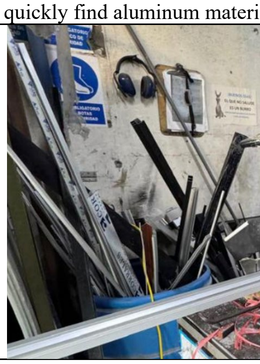
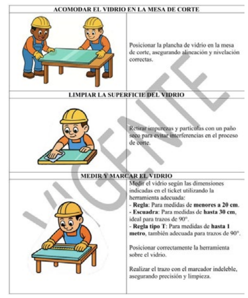
Problem (AS-IS)	Proposed Solution (TO-BE)
The disorder in the warehouse makes it difficult to quickly find aluminum materials.	Classify and label the materials by type to improve quick location and eliminate disorder.
	

Table 6. Lack of cleanliness of the workbench

Problem (AS-IS)	Proposed Solution (TO-BE)
The workbench is not cleaned properly, affecting quality and generating waste.	Establish a cleaning process at the end of each operation to maintain the quality of each process.
	

Table 7. Lack of cleanliness of the workbench

Problem (AS-IS)	Proposed Solution (TO-BE)
The lack of standardized procedures in the cutting and polishing processes, both for glass and aluminum, as well as in the assembly stage.	Create a manual with standardized procedures along with a visual guide to facilitate understanding.
	

In accordance with the previous analysis, the improved model was designed in Arena software, incorporating the proposed improvements based on 5S and Standard Work, as shown in Figure 9. This TO-BE model reflects an optimized operational environment in which unnecessary activities were eliminated, non-productive times were reduced, and key procedures were standardized.

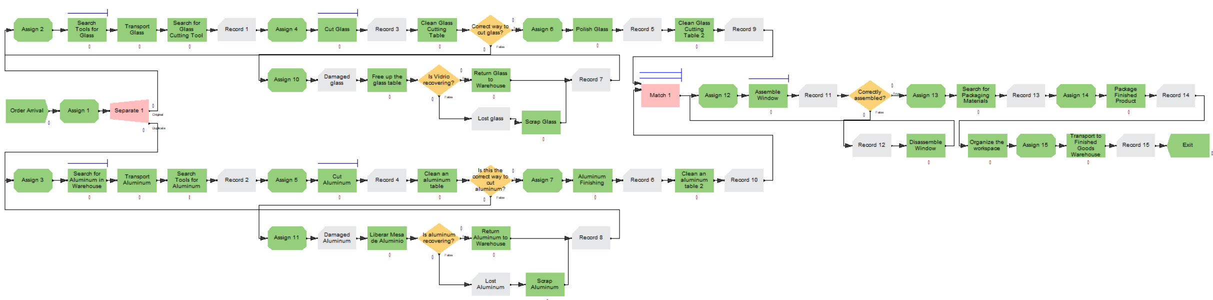


Figure 9. Improved simulation model implemented in Arena.

Based on this new configuration, data collection was carried out under the improved conditions, once again applying the Input Analyzer software to a sample of 37 records. The statistical distributions obtained allowed a more accurate representation of each activity's behavior in the new scenario. In particular, data were collected from the processes directly impacted by the implemented improvements, ensuring that the modeled changes reflect the actual operational effects. These distributions are presented in Table 8, enabling a direct comparison between the simulated times of the current model and the proposed model.

Table 8. Distributions of the processes in the improved model

Process	Distribution	Arena Expression	p-value (Chi²)	p-value (KS)
Search for Glass in Warehouse	Triangular	TRIA(4.23, 8.76, 12)	0.390	> 0.15
Search Tools for Glass	Triangular	TRIA(5, 11, 13)	0.227	> 0.15
Cut Glass	Normal	NORM(72.9, 10.8)	0.187	> 0.15
Clean Glass Cutting Table	Uniform	UNIF(2, 4.86)	0.500	> 0.15
Search for Aluminum in Warehouse	Triangular	TRIA(4.33, 5.74, 9.98)	0.243	> 0.15
Search Tools for Aluminum	Triangular	TRIA(4.57, 7.35, 8.53)	0.479	> 0.15
Cut Aluminum	Triangular	TRIA(23, 28.2, 44)	0.142	> 0.15
Clean an aluminum table	Uniform	UNIF(1.08, 3.12)	0.142	> 0.15
Organize the workspace	Uniform	UNIF(3.2, 5.86)	0.570	> 0.15

Once both simulation models were completed, including the baseline scenario (AS-IS) and the improved scenario (TO-BE), with their respective flows, statistical distributions, and input data, the key performance indicators (KPIs) were defined to evaluate the impact of the proposed solution. These indicators were selected based on their operational relevance and their alignment with the stated improvement objectives. Table 9 presents the indicators to be analyzed, along with a description of the objective of each one.

Table 9. Defined indicators for the simulation evaluation

Indicator	**Objective**
Order Dwell Time in the System	Evaluate the overall efficiency of the process flow.
Preparation Time in the Glass Line	Measure the duration of specific operations on glass.
Preparation Time in the Aluminum Line	Measure the duration of specific operations on aluminum.
Preparation Time in the Assembly Line	Determine the efficiency in the integration of components.
Damaged Glass	Identify the number of errors or failures in glass processing.
Damaged Aluminum	Identify the number of errors or failures in aluminum processing.
Scrapped Glass	Identify the amount of waste generated in glass.
Scrapped Aluminum	Identify the amount of waste generated in aluminum.
Misassembled Windows	Verify the number of errors or failures in the assembly.
Average Time Associated with the 5S Methodology	Quantify the reduced time with the implementation of 5S.
Average Time Associated with Standard Work (SW)	Quantify the reduced time with the implementation of SW

Once the indicators to be calculated were defined, the next step was to determine the appropriate number of replications required to simulate in a statistically reliable manner. To this end, 10 replications of the model were initially performed, serving as a basis to calculate the adequate number of replications necessary to obtain statistically significant results. In this formula, t represents the critical value of the Student's t distribution for a 95% confidence level and n – 1 degrees of freedom; S is the standard deviation estimated from the initial replications; e denotes the maximum standard error tolerated for the mean estimator; and n corresponds to the number of preliminary simulations, since multiple replications are essential to obtain accurate estimates in stochastic models (Law and Kelton 2015).

Formula for Calculating the Required Number of Simulation Replications:

$$\boldsymbol{n} = \left[\frac{\boldsymbol{t}_{(\boldsymbol{n}-1,1-\alpha/2)} * \boldsymbol{S}_{(\boldsymbol{n})}}{\boldsymbol{e}}\right]^{2}$$

To ensure the validity and reliability of the results obtained through simulation, rigorous control over the statistical precision of the analyzed indicators was applied. This was achieved by using 95% confidence intervals, taking as a criterion the relationship between the half-width of the interval and the mean value of each indicator. A good practice in simulation studies is to adopt a relative threshold, such that the half-width of the confidence interval does not exceed a certain percentage of the simulated mean. In this study, a limit of 5% of the mean value was adopted for the main time indicators, ensuring reliable comparisons between scenarios without incurring unnecessary computational costs (Rossetti 2015). Based on this analysis, it was determined that 50 replications were sufficient to meet the established precision criteria. Once the required number of replications was determined, the simulation models were executed in both their baseline (AS-IS) and improved (TO-BE) versions. Subsequently, a statistical comparison was performed to validate whether the differences observed between the two scenarios were statistically significant. For this purpose, the Output Analyzer module of the Arena software was used, as it is specialized in simulation output analysis and allows comparing means and verifying the existence of significant differences between scenarios (Kelton et al. 2014). Finally, to facilitate the interpretation of the results, comparative visualizations are presented, and the key information is consolidated in Table 10.

Table 10. Comparison of Confidence Intervals Between the Base Model (AS-IS) and the Improved Model (TO-BE)

Indicator	C.I. Base	C.I. Improved	C.I. Paried Difference
Order Dwell Time in the System	[472.4; 531.6]	[240.9; 247.1]	No, there is no overlap
Preparation Time in the Glass Line	[313.3; 364.7]	[134.9; 139.1]	No, there is no overlap
Preparation Time in the Aluminum Line	[131.3; 136.7]	[100.7; 103.3]	No, there is no overlap
Preparation Time in the Assembly Line	[93.4; 98.2]	[79.2; 80.8]	No, there is no overlap
Damaged Glass	[75.7; 80.9]	[40.9; 44.5]	No, there is no overlap
Damaged Aluminum	[46.4; 51.4]	[28.65; 32.15]	No, there is no overlap
Scrapped Glass	[16.6; 19.2]	[5.68; 6.96]	No, there is no overlap
Scrapped Aluminum	[14.5; 17.1]	[3.48; 4.68]	No, there is no overlap
Misassembled Windows	[35.8; 39.8]	[18.1; 20.5]	No, there is no overlap
Average Time Associated with the 5S Methodology	[96.6; 111.4]	[62.7; 62.9]	No, there is no overlap
Average Time Associated with Standard Work (SW)	[311.4; 328.6]	[195.7; 198.3]	No, there is no overlap

Since there is no overlap between the confidence intervals of the base model and the improved model in any of the evaluated indicators, it can be stated with 95% confidence that the implemented improvements generate a statistically significant reduction in both operating times and defective products. In particular, indicators such as order lead time within the system, preparation times by production line, and defects in glass, aluminum, and windows show remarkable improvements, validating the effectiveness of the redesigned simulation model and evidencing a positive impact on both efficiency and quality. Furthermore, processes directly intervened through the application of tools such as 5S and SW also demonstrate significant improvements, reinforcing the contribution of these methodologies to the overall performance of the system.

To quantitatively assess the impact of the improvement proposal, Table 11 presents the main operational indicators obtained from the simulation of both scenarios: the base model (AS-IS) and the improved model (TO-BE). This comparison makes it possible to precisely identify the benefits derived from the implementation of Lean Manufacturing tools, specifically 5S and Standardized Work, highlighting significant reductions in operating times, defects, and waste.

Table 11. Comparison of indicators between the base model and the improved model

Indicator	Unit of Measure	Base Model	Improved Model	Difference (%)
Order Dwell Time in the System	min	449	237.7	47.06%
Preparation Time in the Glass Line	min	291	126.7	56.45%
Preparation Time in the Aluminum Line	min	130.8	103.7	20.71%
Preparation Time in the Assembly Line	min	91.7	77.5	15.46%
Damaged Glass	und	79	35	55.70%
Damaged Aluminum	und	49	31	36.73%
Scrapped Glass	und	16	6	62.50%
Scrapped Aluminum	und	12	4	66.67%
Misassembled Windows	und	55	19	65.45%
Average Time Associated with the 5S Methodology	min	86.4	62.7	27.39%

Average Time Associated with Standard Work (SW)	min	301.3	191.8	36.35%

As shown in Table 11 and Figure 10, the improvement proposal generated favorable results across all analyzed indicators. First, the average total lead time of an order within the system was reduced by 47.06%, demonstrating a significant enhancement in the overall efficiency of the process. When disaggregated by production lines, a reduction of 56.45% was observed in the glass treatment line, 20.71% in the aluminum line, and 15.46% in the assembly line, which highlights comprehensive optimization across each operational stage.

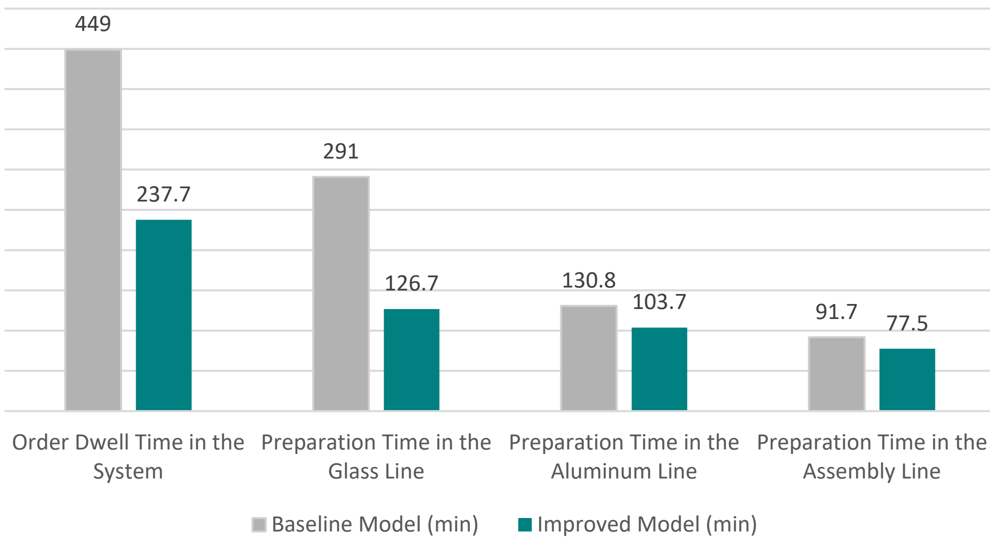


Figure 10. Reduction of operational times after implementation

Regarding defects and material losses, Figure 11 shows that the damage rate for glass and aluminum was reduced by 55.70% and 36.73%, respectively. Likewise, material waste levels also exhibited significant improvements: discarded glass decreased by 62.50%, while discarded aluminum was reduced by 66.67%. In addition, the number of improperly assembled windows declined by 65.45%, reflecting a direct improvement in the quality of the final product.

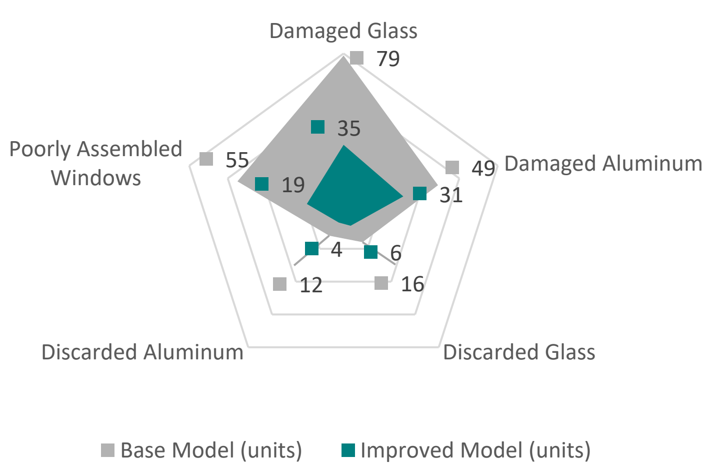


Figure 11. Reduction of defects and failures after Lean implementation

Finally, the specific impact of each implemented methodology was evaluated. Figure 12 shows that the application of 5S reduced by 27.39% the average time associated with tasks related to workplace organization and cleaning, while Standard Work led to a 36.35% reduction in the time required for the execution of critical activities, such as cutting and polishing of both glass and aluminum, as well as their assembly. These results confirm the effectiveness of the proposed improvements in terms of operational efficiency, product quality, and waste reduction.

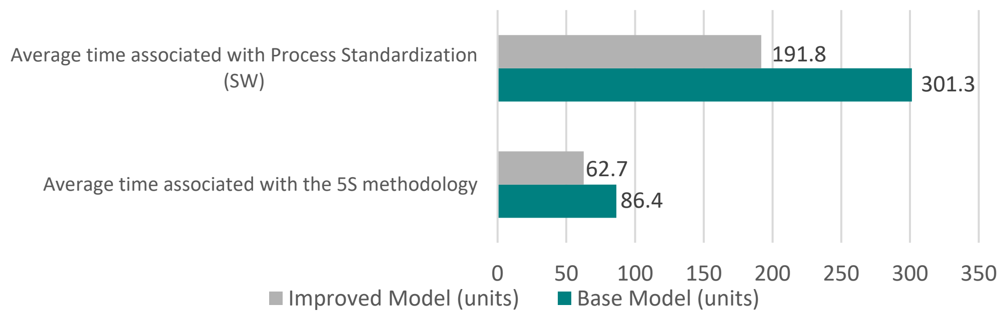


Figure 12. Proportion of operational improvement with 5S and SW

5. Discussion

The results obtained in this study reveal substantial operational improvements following the joint implementation of 5S and Standard Work. The 47% reduction in the average total preparation time, together with improvements of 56% in the glass line, 21% in aluminum, and 15% in assembly, demonstrates a significant impact across each phase of the process. These findings are consistent with previous studies in the glass sector that highlight the effectiveness of Lean Six Sigma integrated with SW, achieving productivity increases of more than 15% and reductions in waste and rework (Gómez and Morales 2023). Furthermore, the reductions of 55% and 37% in glass and aluminum damages, along with the 62–67% decrease in discarded materials, confirmed notable improvements in quality and defect reduction. This is aligned with research in agribusiness and manufacturing, where the combined application of 5S and SW raised productivity from 51% to 74% and reduced downtime from 79 to 24 minutes, while minimizing raw material waste (Wang and Yining 2019).

Similarly, the results are consistent with recent research showing the effectiveness of combining Lean Manufacturing with simulation to validate operational improvements. Ribeiro et al. (2020) reported a 48% reduction in production times in a plastics plant after implementing 5S, VSM, and standardization, using simulation as a means of quantitative validation. This supports the approach of the present study, where the integration of 5S and standardization reduced both times and defects, in line with international best practices. From a methodological perspective, the integration of simulation with Lean tools strengthens the validation of improvements by enabling the identification and quantification of benefits before real implementation (Saldaña-Romero et al. 2024).

Finally, the study contributes to the theoretical foundations of operations management by empirically demonstrating how the integration of 5S and Standard Work reinforces key Lean principles such as waste elimination, process stability, and continuous improvement. The combination of these tools with simulation not only provides quantitative evidence of performance improvement but also serves as a decision-support framework for managers seeking to sustain Lean practices over time. Therefore, this research bridges the gap between Lean theory and practice, emphasizing a systematic and data-driven approach to process optimization in the glass industry and similar manufacturing sectors.

6. Conclusions

The present study aimed to optimize the order preparation process in a small manufacturing enterprise dedicated to producing aluminum-frame glass windows, through the application of 5S and Standard Work, complemented by validation using computer-based simulation in Arena. The results demonstrated significant improvements in the main performance indicators. The initial gap in total preparation time per order, quantified at 32.4%, was substantially overcome with the implemented proposal, achieving a reduction of 47.06%. This impact was also evident in critical subprocesses, with decreases of 56.45% in the glass treatment line, 20.71% in the aluminum line, and 15.46% in final assembly. In addition, a considerable reduction in errors and waste was recorded: damaged glass decreased by 55.7%, damaged aluminum by 36.73%, discarded materials by 62.5% (glass) and 66.67% (aluminum), while defective window assemblies were reduced by 65.45%. Overall, processes associated with unrecoverable materials showed a 64.29% reduction, while operational failures (damages or incorrect assemblies) decreased by 53.55%.These results consolidate the positive impact of the implemented improvements, reflecting both optimization of production performance and a significant reduction in losses. The individual analysis of the applied methodologies showed that the implementation of 5S reduced operating times by 27.39% in activities related to order and cleanliness, mainly due to the reduction of time lost searching for tools and materials, as well as the introduction of cleaning routines in cutting and assembly areas. On the other hand, Standard Work reduced the time required to perform key activities by 36.35%, thanks to the definition of standardized and detailed procedures in complex operations such as cutting, polishing, and assembly. Together, these methodologies not only optimized operating times but also fostered greater stability in production cycles and a significant reduction in errors.

From a methodological perspective, simulation enabled the validation of comparative scenarios (AS-IS vs. TO-BE) under controlled conditions, ensuring statistical rigor of the results through fifty replications and the use of confidence interval analysis. The combination of Lean tools with simulation proved to be an effective strategy for supporting improvements before physical implementation, minimizing risks and costs.

However, future studies should address the limitations of this research by expanding the analysis to multiple cases, exploring different industrial contexts, and including economic and sustainability indicators. To ensure long-term sustainability, the enterprise should institutionalize continuous improvement through periodic audits, employee training, and visual management systems that maintain adherence to 5S and Standard Work standards.

Finally, the findings allow for the proposal of a generalizable implementation framework for SMEs, structured in four stages: (1) diagnostic assessment and process mapping, (2) selection of Lean tools and critical areas, (3) integration of Standard Work and visual management, and (4) validation through simulation or pilot testing. This structured approach can guide other small enterprises seeking to enhance productivity and quality through Lean practices while minimizing implementation risk. Therefore, this study not only provides practical evidence of operational gains but also contributes to the development of a replicable and sustainable Lean implementation model for the SME manufacturing sector.

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