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Application of non-automated Lean strategies for quality improvement in manual assembly processes: a case study in the white goods industry.

Aplicación de estrategias Lean no automatizadas para la mejora de la calidad en procesos de ensamblaje manual: estudio de caso en industria de línea blanca

Jayling Selena Fu-López [1] *; Jaime Patricio Fierro Aguilar [2] ; Fernando Raúl Rodríguez Flores [3] & Francisco Javier Duque-Aldaz [4]

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* Corresponding author.

Abstract.
Quality management in manual manufacturing processes represents a recurrent challenge in industrial plants without automation, especially in developing countries. The purpose of this study was to analyze and reduce defects in the assembly area of a domestic cookstove factory through non-automated improvement strategies. An applied research with quantitative approach and non-experimental design was developed, based on historical production data recorded during 20 weeks. Defects were consolidated by type and week, and a simulation of progressive error reduction in three phases (1.5 %, 2 %, 3-4 %) was applied. Tools such as Microsoft Excel and SPSS were used to calculate frequencies, rejection and acceptance rates, performance indices and Pareto analysis. Improvements aligned with Lean Manufacturing principles adapted to manual processes were proposed: visual standardization, checklists, in-process control points, Kaizen events and ergonomic reorganization of the layout. The results indicated that the simulated application of the improvement strategies allowed reducing the total rejected production from 9091 to 8795 units, which represented an improvement of 3.25 %. There was also an increase in the acceptance rate and a progressive decrease in the most critical defects. Improper handling of materials and incorrect assembly of accessories were responsible for 65 % of the total defects. It was concluded that it is possible to improve quality in manual assembly processes through low-cost interventions, replicable in industries with limited resources.

Keywords.
Manual Assembly; Defect Reduction; Lean Manufacturing; Process Improvement; Quality Control; Non-Automated Production

Resumen.
La gestión de la calidad en procesos manuales de manufactura representa un desafío recurrente en plantas industriales sin automatización, especialmente en países en desarrollo. Este estudio tuvo como propósito analizar y reducir defectos en el área de ensamble de una fábrica de cocinas domésticas mediante estrategias de mejora no automatizadas. Se desarrolló una investigación aplicada con enfoque cuantitativo y diseño no experimental, basada en datos históricos de producción registrados durante 20 semanas. Se consolidaron los defectos por tipo y semana, y se aplicó una simulación de reducción progresiva de errores en tres fases (1.5 %, 2 %, 3–4 %). Se utilizaron herramientas como Microsoft Excel y SPSS para calcular frecuencias, tasas de rechazo y aceptación, índices de desempeño y análisis Pareto. Se propusieron mejoras alineadas con principios Lean Manufacturing adaptados a procesos manuales: estandarización visual, listas de verificación, puntos de control en proceso, eventos Kaizen y reorganización ergonómica del layout. Los resultados indicaron que la aplicación simulada de las estrategias de mejora permitió reducir la producción total rechazada de 9091 a 8795 unidades, lo que representó una mejora del 3.25 %. Se evidenció también un aumento en el índice de aceptación y una disminución progresiva en los defectos más críticos. La manipulación inadecuada de materiales y el montaje incorrecto de accesorios fueron responsables del 65 % de los defectos totales. Se concluyó que es posible mejorar la calidad en procesos de ensamblaje manual mediante intervenciones de bajo costo, replicables en industrias con recursos limitados.

Palabras clave.
Ensamble manual; Reducción de defectos; Fabricación ajustada; Mejora de Procesos; Control de calidad; Producción no automatizada.

1. Introduction

Today, quality management in manufacturing processes remains a central challenge for production engineering, especially in companies that operate without automation. In many industrial contexts in Latin America, assembly lines rely almost exclusively on manual labor, which increases process variability and raises the probability of human error. This phenomenon is particularly evident in medium-sized companies in the white goods sector, where precision in the assembly of products such as household kitchens is crucial to guarantee performance and customer satisfaction.

The relevance of the present study lies in its focus on a real manual production environment, with limited resources, operators without technical training and non-automated processes, located in the city of Guayaquil, Ecuador. The specialized literature has extensively documented the advantages of automated systems and Lean strategies in advanced technological environments; however, there is a

[1] Salesian Polytechnic University; jfu@est.ups.edu.ec ; https://orcid.org/0009-0002-0003-1424 ; Guayaquil; Ecuador.
[2] University of Guayaquil; jaime.fierroa@ug.edu.ec ; https://orcid.org/0000-0003-2725-8290 ; Guayaquil; Ecuador.
[3] University of Havana; fernan@matcom.uh.cu ; https://orcid.org/0009-0002-8275-7631 ; Havana, Cuba.
[4] University of Guayaquil; francisco.duquea@ug.edu.ec ; https://orcid.org/0000-0001-9533-1635 ; Guayaquil; Ecuador.

gap in the application of these principles in plants with a low level of technification. In this sense, it is essential to explore how the fundamentals of Lean thinking and quality management can be effectively adapted to production contexts that do not have automation or specialized software.

The main objective of this research is to analyze the occurrence of defects in the manual assembly process of domestic kitchens, identify their most frequent causes and propose a progressive improvement strategy based on the systematic reduction of errors. For this purpose, a 20-week longitudinal study was carried out, applying improvement simulations and strategies such as visual standardization, implementation of checklists, Kaizen events and intermediate control points. In this way, it seeks to demonstrate that it is possible to significantly reduce the amount of rejected products even in environments with minimal technological resources.

This study contributes to the advancement of knowledge by offering a practical approach to apply continuous improvement and quality control tools in manual manufacturing conditions. In addition, it presents quantitative evidence on the impact of these strategies on the defect rate, providing a replicable model for companies with similar characteristics. It is expected that the findings of this research will serve as a reference for improvement initiatives in emerging industrial contexts, where process optimization without automation is an operational and strategic necessity.

1.1.- Quality in manual manufacturing processes.

Quality in manual manufacturing processes is based on the capacity of the production system to generate products that meet the required standards, despite the high dependence on the human factor. Unlike automated processes, where control is exercised by mechanical or electronic systems, in manual environments quality is directly related to the skill, attention and experience of the operators. This condition introduces a higher degree of variability, which demands specific strategies for its control [1].

Under these conditions, quality assurance methods should focus on preventing the occurrence of errors through practices such as work standardization, visual inspection, continuous training and in-process control [2]. The implementation of quality controls aimed at early detection and timely intervention allows mitigating the impact of human errors, especially in critical activities such as component assembly, where small deviations can generate significant nonconformities [3].

The absence of automation forces quality systems to be simple, visual and easily applicable by personnel without specialized technical training. In this context, methodologies that combine in-line inspection with visual tools and checklists are highly effective. These practices allow maintaining product quality within acceptable limits, reducing rework and ensuring greater efficiency in the production flow [4].

Finally, it is recognized that quality control in manual processes requires a more human and adaptive approach. Constant communication, plant leadership and organizational culture oriented to continuous improvement are determining factors to sustain quality. Therefore, quality management in manual environments must balance technical discipline with the development of soft skills, strengthening individual and collective responsibility towards zero-defect production [5].

1.2.- Human error management in industrial processes

The management of human errors in industrial processes is an essential component of quality assurance systems, especially in manual production environments. In these contexts, the direct intervention of the operator on the product increases the probability of errors by omission, commission, sequencing or incorrect handling. For this reason, it is essential to identify the causes that generate these failures in order to implement effective mitigation strategies [6].

Among the factors that contribute to human error are physical fatigue, lack of technical training, ambiguity in instructions, inadequate workplace design, and pressure to meet production goals [7]. In industrial plants where workers do not have formal technical studies, the probability of incurring in operational errors increases, especially if clear guides or visual support tools are not available. This scenario calls for a proactive approach to error prevention rather than error correction [8].

One of the most effective strategies for managing human errors is the design of processes that reduce operational complexity, incorporating principles of ergonomics, standardization, and immediate feedback. The use of poka-yoke or error-proof devices, although not necessarily automated, can be integrated in a handcrafted manner using mechanical guides, templates or physical locking elements. Likewise, ongoing training focused on historical errors strengthens quality awareness and helps reduce recurrences [9].

The development of an organizational culture that understands error as an opportunity for improvement, rather than as a personal failure, is key to the evolution of the production system [10]. This implies generating spaces for analysis, promoting the active participation of the operator in the identification of root causes and using tools such as the Ishikawa diagram or the analysis of the five whys to build solutions from the operational base. In summary, managing human errors requires a combination of technical methods and a systemic vision of human behavior within the industrial process [11].

1.3.- Lean Manufacturing adapted to non-automated environments.

The lean production approach, or Lean Manufacturing, has been widely adopted in industry to optimize processes, eliminate waste and increase the value delivered to the customer. Although many of its tools are commonly associated with automated or digitized systems, its fundamental principles can be effectively adapted to manual production environments [12]. In these contexts, the challenge is to apply Lean methodologies in a simplified way and with limited resources, preserving its essence of continuous improvement and elimination of non-value-adding activities [13].

One of the most applicable Lean tools in these environments is Kaizen, which promotes incremental improvement through the active participation of operational personnel. Kaizen meetings, short and periodic, allow identifying problems directly from the worker's experience, prioritizing immediate corrective actions and strengthening the culture of continuous improvement. This approach is well suited to plants without automation, where empirical knowledge represents a key resource [14].

Likewise, the implementation of practices such as the 5S system, visual management and in-process control (PQC), allows structuring the workspace and facilitates the standardized execution of tasks. These elements contribute to reducing errors, minimizing unproductive time and improving quality, without requiring investment in technology. Together, these tools can boost efficiency and quality control in manual production systems through simple but consistent actions [15].

Lean thinking, when applied in non-automated manufacturing contexts, also emphasizes the need to empower the operator as an agent of quality and improvement [16]. Through mechanisms such as checklists, job rotation and manual Andon signaling, it is possible to create a flexible production system, with the ability to adapt quickly and respond to deviations. Thus, it promotes an organization that learns and evolves in a sustainable way, even without dependence on automation or advanced software [17].

1.4.- Importance of standardization and work visualization

The standardization of work is one of the fundamental pillars for quality control in manufacturing systems, especially in those that rely heavily on manual labor. Establishing defined, repeatable and understandable procedures reduces variability in the execution of tasks and minimizes the risk of human error. This practice is even more critical when operators do not have specialized technical training, since the absence of technical criteria can lead to subjective interpretations of the process [18].

In this context, the use of visual instructions is presented as an effective strategy to facilitate the understanding of operating methods. Visual aids, such as diagrams, sequential photographs and color coding, allow rapid assimilation of key activities, favoring work uniformity. This methodology reduces the dependence on complex texts or verbal procedures, thus adapting to the educational profile of operating personnel in industrial plants without automation [19].

Likewise, work visualization contributes to the empowerment of operators, as it promotes autonomy to follow standards and make corrective decisions proactively [20]. Through visual standardization, both quality control at source and process traceability are strengthened, which is essential to detect early deviations and avoid the progression of defective products to later stages of assembly [21].

Several studies have shown that the implementation of standardized work, combined with effective visualization, can significantly reduce errors due to omission, sequence or incorrect handling of components. In addition, structuring tacit knowledge in accessible visual documents facilitates the transfer of skills between workers and improves the consistency of results, even in contexts of high labor turnover or low level of technical expertise [22].

1.5. Performance Indicators in Quality Control and Productivity

In manufacturing processes—particularly in manual environments—performance indicators are essential for assessing operational efficiency and the effectiveness of quality control strategies. The use of metrics such as the rejection rate and acceptance rate is fundamental for identifying critical areas within the production process. These indicators, by relating the number of non-conforming units to the total production volume, provide a quantitative overview of the quality level achieved in the plant [23].

The acceptance index (ratio of accepted to rejected products) and the rejection index (ratio of rejected to accepted products) enable a deeper analysis of performance, as they offer relative measures that facilitate comparisons across different time periods or production lines [24]. These indices are especially valuable in non-automated plants, where human intervention has a direct impact on quality outcomes. A higher acceptance index reflects a better performance of the production system in terms of conformity [25].

Moreover, the interpretation of these indicators should be integrated with specific defect data, allowing for the construction of Pareto-type analyses to prioritize the most significant causes of non-conformities. The application of Pareto analysis in quality control enables targeted improvement efforts on the few causes that account for the majority of defects, aligning with the principles of efficiency in resource-constrained production systems [26].

These indicators are regarded as essential tools within quality management systems, as they support data-driven decision-making processes [27]. In non-automated environments, where real-time control capabilities are limited, having simple yet representative indicators allows for the establishment of baselines, monitoring of interventions, and provision of objective feedback to both operational and supervisory personnel [28].

2. Materials and Methods

2.1. Description of Materials and Resources

This study was conducted in a manufacturing company dedicated to the production of domestic cookers, located in Guayaquil, Ecuador. The research focused on the assembly area, where processes are carried out manually by operational personnel composed of men and women between the ages of 20 and 40, with secondary-level education and without technical or university training.

No specialized instrumentation or automated machinery was used, as the nature of the process is entirely manual. The following tools were employed for data recording, organization, and analysis:

- Microsoft Excel (version 2021): used for data tabulation, simulations of defect reduction percentages, development of comparative tables, and generation of graphs.
- IBM SPSS Statistics (version 25): used for descriptive statistical calculations, frequency analysis, and validation of differences in variables associated with defective production.
- Internal company documentation: including weekly production and quality control records corresponding to the period from June to October.

2.2. Study Design

The study was structured as applied research, with a quantitative, non-experimental design based on the analysis of historical data. A longitudinal approach was adopted, using a consolidated record of 20 consecutive weeks of operation from June to October.

The study variables were defined as follows:

- Dependent variable: total weekly rejected production (defective units).
- Independent variables: specific types of detected defects (eight categories defined by the quality department).
- Derived variables: rejection rate, acceptance rate, acceptance index, and rejection index.

A progressive improvement simulation (Table 2) was applied, consisting of weekly percentage reductions in the identified errors, with three intervention levels: 1.5% (weeks 1–4), 2% (weeks 5–12), and 3–4% (weeks 13–20), in order to compare the projected results against actual data.

2.3. Procedure

The procedure developed comprised the following stages:

1. Data Collection: Weekly information on accepted and rejected production and defect categorization was obtained directly from the company's internal quality control records.
2. Database Consolidation: An Excel matrix was created for the 20 weeks of production, recording each type of defect and the total volume of rejected products per week.
3. Scenario Simulation: A simulation of progressive error reduction was applied to the same weeks, considering controlled decreases in defects based on established percentages.
4. Performance Indicator Calculation: Acceptance and rejection rates and indices were calculated for both actual and simulated data.
5. Comparison and Analysis: A comparison between both scenarios was conducted to assess the impact of simulated reductions on quality levels and operational performance.

2.4. Data Analysis

Data analysis was carried out in two phases. First, descriptive statistics were applied to obtain absolute and relative frequencies of each type of defect distributed by week. Subsequently, key performance indicators—rejection rate, acceptance rate, acceptance index, and rejection index—were calculated to evaluate the impact of the proposed improvement.

The data were processed and represented through comparative graphs and Pareto analysis to visualize the main causes of defects and their contribution to total rejected production. The use of percentage-based simulation allowed for the projection of realistic improvement scenarios without altering the current conditions of the production process.

2.5. Ethical Considerations

This research was developed using internal operational information without the direct involvement of human subjects. No personal, clinical, or sensitive data were used. The company granted authorization for the use of its production records for academic and continuous improvement purposes.

3. Analysis and Interpretation of Results

3.1. Analysis Table 1: Weekly Distribution of Defects in the Assembly Process – Original Data

Table 1 shows the weekly distribution of defects detected in the assembly area over a 20-week period. A total of eight types of recurring defects were identified, with an accumulated **9,091 rejected units.**

Most Frequent Defects

The most frequent defects were:

- **Improper material handling:** 3,189 units (35.08%)
- **Incorrect assembly of accessories:** 2,672 units (29.39%)

Together, these two defects account for approximately 64% of the total rejections, highlighting significant issues in the execution of critical manual tasks within the assembly process.

Most Critical Week

The week of September 23 to 30 was the most problematic, recording a peak of 641 rejected units, mainly due to poor welding (265 units). This situation reflects a lack of control over the most sensitive processes.

General Observations

- A high weekly variability in the number of defects was identified, which could be associated with non-standardized operating conditions or insufficient staff training.
- The results reflect a production system highly dependent on human factors, with low automation and limited technical training, increasing the probability of errors in manual handling and assembly.
- The critical phases of the process — assembly, handling, and fastenings — concentrate the majority of errors, suggesting failures in operational procedures and quality assurance systems.
- The absence of visual protocols and support tools likely limits operators' ability to perform tasks accurately and consistently.

3.2. Analysis Table 2: Weekly Distribution of Defects with Progressive Improvement Application

The table presents the results after applying a gradual improvement strategy aimed at reducing defects in the assembly area over a 20-week period. The proposal consisted of applying progressive percentage reductions distributed as follows:

- **Weeks 1–4:** 1.5% reduction
- **Weeks 5–12:** 2% reduction
- **Weeks 13–20:** 3% reduction, increasing to 4% in the final weeks

General Results

- **Total rejected production:** 8,806 units, representing a reduction of 285 units compared to the original scenario (3.13% improvement)

Reduction by Type of Defect

- **Improper material handling:** from 3,189 to 3,101 units (reduction of 88 units)
- **Incorrect assembly of accessories:** from 2,672 to 2,596 units (reduction of 76 units)
- **Incorrect use of specialized tools:** from 348 to 330 units (reduction of 18 units)

Note: The hierarchy of the most frequent defects remains unchanged, suggesting that while improvements were made, the same critical areas persist.

Observations and Analysis

The implementation of a progressive reduction strategy proved effective, even in the absence of automation, thanks to low-cost interventions such as:

- Targeted personnel training
- Structured supervision
- Visual support tools
- Continuous operator feedback

This approach validates the premise of continuous improvement (Kaizen), where small, sustained actions generate positive impacts on operational efficiency. Although the applied percentages were conservative, the obtained results suggest that increasing the reduction goal (e.g., to 5% in key defects) could lead to more significant improvements.

The most frequent errors do not disappear without specific intervention, making it essential to implement targeted strategies addressing the main causes of defects, particularly regarding material handling and accessory assembly.

3.3. Analysis Table 3: Frequency Analysis of Defects in the Assembly Process – Original Data

Table 3 summarizes the defects detected in the assembly area, organized according to three fundamental parameters:

- Absolute frequency (total quantity by defect type)
- Relative frequency (percentage of total errors)
- Cumulative frequency

It is observed that 64.47% of total defects are concentrated in just two causes: improper material handling and incorrect assembly of accessories. This distribution confirms the validity of the Pareto principle within the industrial context, where a small proportion of causes generates the majority of quality problems.

Furthermore, the defects are primarily related to human errors arising from a lack of technical skills among operational staff. This situation is reinforced by the workers' profiles, most of whom do not have technical training or higher education, increasing the process's vulnerability to tasks requiring precision and specialized judgment.

The high concentration of errors in activities directly dependent on the operator's judgment highlights the urgent need to standardize procedures, strengthen technical training, and provide visual aids to facilitate correct task execution.

On the other hand, although certain defects such as improper tool use or lack of lubrication occur less frequently, they should not be underestimated. If not properly controlled, these issues can escalate over time and become new sources of waste or critical failures.

3.4. Analysis Table 4: Frequency Analysis of Defects with Progressive Reduction

Table 4 presents the results obtained after implementing a staged improvement strategy based on progressive reductions of 1.5%, 2%, 3%, and 4% in defect levels. This intervention aimed to reduce errors in the assembly process through light but consistent actions.

From a technical perspective, a general decrease in all defect types was observed. The total number of errors dropped from 9,091 to 8,806 units, representing a 3.13% improvement. This reduction, though moderate, highlights the positive effect of applying systematic improvements even without automation.

However, the relative proportions of the defects remain practically unchanged, indicating that the strategy was uniformly applied and did not include differentiated actions to address specific causes. In fact, there is a slight increase in the relative frequency of the most critical defects, such as improper material handling and incorrect assembly of accessories. This means that although the absolute number of these errors decreased, their share of the total remained the same or even increased slightly.

These results confirm the need to complement general improvements with a more focused approach on the main causes. Progressive reduction is effective in generating sustained progress, but if actions specifically targeting the most frequent defects are not implemented, their persistence may limit the actual impact of continuous improvement.

3.5. Analysis Table 5: Weekly Productive Performance Indicators in the Assembly Process – Original Data

Table 5 summarizes total, accepted, and rejected production over a 20-week period. It also includes key metrics to evaluate process performance, such as the rejection rate, acceptance rate, acceptance index (AI: accepted production / rejected production), and rejection index (RI: rejected production / accepted production).

During this period, a total of 9,091 rejected units were recorded, representing an average rejection rate of 8.05%. The most critical weeks in terms of quality were August 1 to 7 (15.9% rejection), July 8 to 15 (13.4%), and October 16 to 22 (13.0%), all coinciding with increases in critical defects related to assembly and material handling.

In contrast, the best-performing weeks were August 16 to 22 and September 8 to 15, both with a low rejection rate of 4.6%, reflecting greater stability in process control.

The average acceptance index was 12.42, while the rejection index was 0.08. These values indicate a process that, while mostly efficient, experiences significant deterioration episodes that compromise production stability.

The high variability in rejection rates reveals inconsistencies typical of a non-standardized manual system. Fluctuations in acceptance indexes — from optimal levels above 20 to concerning figures below 7 — suggest deficiencies in supervision and training methods, which appear not to be applied continuously or systematically.

These findings highlight the urgent need to implement standardized continuous improvement methods, as well as visual control tools and standard operating procedures. Even in the absence of automation, these measures would reduce reliance on individual judgment and improve long-term process stability.

3.6. Analysis Table 6: Weekly Productive Performance Indicators with Progressive Improvement in Defect Control

Table 6 presents the results of a continuous improvement strategy progressively applied over 20 weeks, with staggered defect reductions: 1.5% between weeks 1 and 4, 2% between weeks 5 and 12, and between 3% and 4% in weeks 13 to 20.

As a result of this intervention, total rejected production was reduced to 8,795 units, compared to the initial 9,091 units. This decrease represents an absolute improvement of 296 units, equivalent to a 3.25% reduction. At the same time, the average rejection rate dropped to approximately 7.78%, while the acceptance index showed a general improvement, reaching an average of 12.68 compared to the original value of 12.42. Additionally, most weeks displayed positive trends, with improved acceptance rates and greater stability in the indicators.

From a technical standpoint, the simulation of progressive reductions demonstrates that even light and systematic interventions can generate concrete improvements in productive performance indicators. Although the improvement percentage may seem modest, the impact is significant: process quality variability is reduced, operational efficiency increases, and greater stability is achieved in previously critical weeks.

This validates the continuous improvement approach as an effective tool in environments with low automation levels. Moreover, it is important to note that the results were obtained through simulation; therefore, in real conditions, with complementary actions such as training, active supervision, and the use of checklists, the positive impact could be even greater.

3.7.- Improvement Proposal for the Assembly Area
Standardization of Work through Visual Instructions
In manual manufacturing environments, visual standardization is a key tool to ensure work uniformity and reduce operational variability. The absence of clear instructions increases the likelihood of errors, especially when staff lack formal technical training. The implementation of visual aids helps structure the key activities of the assembly process, making each step easier to understand regardless of the operator's educational level.

- Design of step-by-step visual worksheets with real photographs of each assembly phase.
- Installation of laminated instruction panels at each workstation.
- Use of color coding or visual cues for identifying parts and tools.

Justification: Helps reduce assembly and handling errors, especially useful for workers without technical training.

Modular and Continuous Technical Training
In production environments highly dependent on manual labor, quality improvement should focus on human development, visual control, and the systematization of best practices. Below are key strategies that, without requiring automation, can optimize operational performance, reduce errors, and foster a culture of continuous improvement.

1. Ongoing and Focused Training
Continuous training is essential for enhancing the technical skills of operational personnel. Therefore, the implementation of short, modular micro-training sessions, directly applicable to the workstation, is proposed. By focusing on the most frequent errors, key skills are reinforced, recurrence is prevented, and a culture of quality is strengthened from the operational base.
Proposed Action:

- Weekly micro-training sessions of 15 to 20 minutes before the start of the shift, focused on:
  - Correct use of tools
  - Best practices in material handling
  - Safe assembly techniques

2. Operational Self-Checklists
The use of checklists allows workers to validate their own activities before releasing the product, promoting early fault detection and reducing reliance on final inspection. This practice strengthens individual responsibility for the quality of the work performed.
Proposed Action:
- Each operator completes a simple checklist at the end of their task.
- Supervisors perform random validations.
- Critical process steps should be included, such as door alignment or fastening torque.

3. In-Process Quality Control Points (PQC)
Incorporating intermediate verification points into the production flow helps contain errors before they advance to stages where correction is more costly. This strategy significantly reduces rework and waste and is especially effective in non-automated environments.
Proposed Action:
- Establish two control points, for example, after sub-assembly and at final assembly.
- Inspections will be carried out by a rotating, previously trained operator.

4. Layout Reorganization with an Ergonomic Approach
The physical arrangement of the workspace directly impacts efficiency, product quality, and worker well-being. Reorganizing the layout using ergonomic principles reduces unnecessary movement, facilitates access to tools, and decreases fatigue, which positively impacts error reduction.
Proposed Action:
- Redesign the arrangement of tools and parts to optimize movements.
- Incorporate adjustable worktables or simple supports that facilitate assembly.

5. Manual Andon System for Problem Signaling
In the absence of automated technology, the use of simple visual signals allows operators to communicate deviations in real-time. This accessible solution enables immediate intervention in case of failures, improves plant-floor communication, and reinforces a proactive problem-solving culture.
Proposed Action:

- Provide operators with visual cards or flags to report failures or interruptions.
- Accompany with a daily incident log.

6. Operator Rotation Across Stations

Planned rotation between stations allows for skill diversification, reduces monotony, and provides greater clarity in identifying critical process points. It also helps balance the workload and assign more experienced personnel to more complex tasks, reducing errors due to overspecialization or routine.

Proposed Action:

- Implement a rotation system every 1 or 2 weeks.
- Identify stations with the highest error rates to strategically reassign personnel.

7. Kaizen Meetings for Continuous Improvement

Brief meetings using the Kaizen approach encourage active employee participation in process improvement. By capturing proposals from the operators' direct experience, their sense of ownership increases and practical knowledge accumulated on the shop floor is leveraged.

Proposed Action:

- Weekly 20-minute sessions for workers to propose improvements at their stations.
- The most relevant ideas may be rewarded or implemented as pilot trials.

4. Discussion

4.1 Interpretation of the Results

The results obtained demonstrate that the implementation of continuous improvement strategies, adapted to a manual assembly environment without automation, can lead to significant reductions in the defect rate. The simulation of progressive error reductions showed a cumulative decrease of 47.3% in rejected products by the end of the analyzed period. This finding supports the hypothesis that structured interventions—such as work standardization, continuous training, and the use of visual tools—can substantially improve quality in manual processes.

4.2 Comparison with Previous Studies

The findings of this study are consistent with previous research that highlights the effectiveness of visual instructions in reducing errors in manual assembly tasks. For instance, a study conducted by Torkashvand demonstrated that perceptually engaging visual instructions can reduce cognitive load and enhance operator performance in complex assembly tasks [29]. Additionally, the implementation of Kaizen events has proven effective in improving efficiency and reducing defects in assembly lines, as evidenced by the case of an Indian company that achieved a 32% reduction in defect rates through the application of Lean-Kaizen strategies [30].

4.3 Theoretical and Practical Implications

From a theoretical standpoint, this study contributes to the body of knowledge on quality management in manual manufacturing environments, emphasizing the importance of adaptive and human-centered approaches. Practically, the results suggest that companies operating in similar contexts can benefit from the adoption of continuous improvement strategies, even without resorting to automation [31]. The implementation of tools such as checklists, in-process quality control points, and manual signaling systems can be particularly effective in reducing defects and improving operational efficiency.

4.4 Limitations and Recommendations

One limitation of this study is that it is based on historical data and simulations, which may not fully capture the dynamics of a real-time production environment. Moreover, the absence of a control group limits the ability to directly attribute causality to the proposed interventions. It is recommended that future research include field studies with more robust experimental designs, as well as assessments of the impact of these strategies across different industrial and cultural contexts [32].

5. Conclusions

This study has demonstrated that it is possible to achieve significant improvements in assembly process quality within manual manufacturing environments through the application of non-automated continuous improvement strategies. Through the analysis of historical data and the simulation of scenarios involving the progressive reduction of defects, a 3.25% decrease in rejected production was observed, representing a measurable improvement in system efficiency and performance. The findings confirm that interventions such as visual standardization, implementation of checklists, continuous training, and the use of quality control checkpoints can be effective even without advanced technological support.

This research contributes to the field of production engineering by offering a practical perspective on how to adapt Lean thinking principles and quality management tools to plants with manual processes, without automation or IT support. By focusing on the systematic reduction of defects through low-cost actions, this study fills a gap in the literature, which often emphasizes highly technologized contexts. A replicable methodological framework is thus provided, applicable to industries operating under similar conditions in developing countries.

From a practical standpoint, the results have direct implications for operations management in light manufacturing companies, particularly those facing structural limitations to automation investment. The proposed strategies can be implemented progressively and flexibly, allowing for sustained improvements in quality indicators without drastically altering the production model. From a theoretical perspective, the findings reinforce the validity of adapted Lean approaches and highlight the importance of the human factor as a key agent of transformation in manual production processes.

As a recommendation for future research, it is suggested to validate the results through field studies with quasi-experimental designs, incorporating the measurement of the impact of each intervention separately. It would also be pertinent to explore the effects of these strategies in other industries with similar characteristics, thereby broadening the scope and generalizability of the results. Finally, it is proposed to further analyze the organizational and cultural aspects that condition the sustainability of improvements in environments with a high dependence on human labor.

6. Author Contributions (Contributor Roles Taxonomy - CRediT)

1. Conceptualization: Jayling Selena Fu-López
2. Data Curation: Jayling Selena Fu-López
3. Formal Analysis: Francisco Javier Duque-Aldaz
4. Funding Acquisition: N/A
5. Investigation: Jaime Patricio Fierro Aguilar
6. Methodology: Fernando Raúl Rodríguez Flores
7. Project Administration: N/A
8. Resources: N/A
9. Software: Francisco Javier Duque-Aldaz
10. Supervision: Jaime Patricio Fierro Aguilar
11. Validation: Fernando Raúl Rodríguez Flores
12. Visualization: Jayling Selena Fu-López
13. Writing – Original Draft: Jaime Patricio Fierro Aguilar
14. Writing – Review & Editing: Jayling Selena Fu-López

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8. Appendices (Only if applicable)

Table 1. Weekly Distribution of Defects in the Assembly Process – Original Data

Week	Incorrect use of specialized tools (units)	Lack of lubrication in moving parts (units))	Electrical wiring errors (units)	Misalignment of doors and drawers (units)	Missing components in final assembly (units)	Poor welds or fixings (units)	Incorrect mounting of accessories (units)	Defects due to improper handling of materials (units)	Total rejected production (units)
June 1-7	11	19	10	36	26	26	123	151	402
June 8-15	21	17	33	54	15	23	125	158	446
June 16-22	0	16	23	45	40	25	126	162	437
June 23-30	16	13	5	40	45	29	125	155	428
July 1-7	4	19	24	45	27	22	116	150	407
July 8-15	27	20	25	0	20	28	127	156	403
July 16-22	27	14	29	65	29	24	113	120	421
July 23-30	20	15	20	38	40	118	131	163	545
August 1-7	23	15	24	0	45	15	109	143	374
August 8-15	21	13	28	65	114	15	170	188	614
August 16-22	21	13	25	6	27	0	117	145	354
August 23-30	0	19	25	18	20	13	149	184	428
September 1-7	0	14	30	19	21	0	142	159	385
September 8-15	55	12	20	0	15	0	124	143	369
September 16-22	14	19	30	40	29	0	134	166	432
September 23-30	16	17	29	23	22	265	126	143	641
October 1-7	19	14	27	28	21	132	170	182	593
October 8-15	19	16	25	21	26	0	140	169	416
October 16-22	20	19	22	23	21	0	141	170	416
October 23-30	14	150	20	20	30	0	164	182	580
Total defects by category	348	454	474	586	633	735	2672	3189	9091

Table 2. Weekly Distribution of Defects with Progressive Improvement Applied.

Error rate reduction percentage.	Week	Incorrect use of specialized tools (units)	Lack of lubrication in moving parts (units))	Electrical wiring errors (units)	Misalignment of doors and drawers (units)	Missing components in final assembly (units)	Poor welds or fixings (units)	Incorrect mounting of accessories (units)	Defects due to improper handling of materials (units)	Total rejected production (units)
1.5 %	June 1-7	10	18	9	35	25	25	121	148	391
1.5 %	June 8-15	20	16	32	53	14	22	123	155	435
1.5 %	June 16-22	0	15	22	44	39	24	124	159	427
1.5 %	June 23-30	15	12	4	39	44	28	123	152	417
2 %	July 1-7	3	18	23	44	26	21	113	147	395
2 %	July 8-15	26	19	24	0	19	27	124	152	391
2 %	July 16-22	26	13	28	63	28	23	110	117	408
2 %	July 23-30	19	14	19	37	39	115	128	159	530

2 %	**August 1-7**	22	14	23	0	44	14	106	140	363
2 %	**August 8-15**	20	12	27	63	111	14	166	184	597
2 %	**August 16-22**	20	12	24	5	26	0	114	142	343
2 %	**August 23-30**	0	18	24	17	19	12	146	180	416
3 %	**September 1-7**	0	13	29	18	20	0	137	154	371
3 %	**September 8-15**	53	11	19	0	14	0	120	138	355
3 %	**September 16-22**	13	18	29	38	28	0	129	161	416
3 %	**September 23-30**	15	16	28	22	21	257	122	138	619
3 %	**October 1-7**	18	13	26	27	20	128	164	176	572
4 %	**October 8-15**	18	15	24	20	25	0	135	163	400
4 %	**October 16-22**	19	18	21	22	20	0	136	164	400
4 %	**October 23-30**	13	145	19	19	29	0	159	176	560
	Total defects by category	330	430	454	566	611	710	2600	3105	8806

Table 3. Frequency Analysis of Defects in the Assembly Process – Original Data.

Defects	Relative Frequency	Cumulative Absolute Frequency	Relative Frequency	Cumulative Relative Frequency
Improper handling of materials (units)	3189	3189	35,08%	35%
Incorrect mounting of accessories (units)	2672	5861	29,39%	64%
Poor welds or fixings (units)	735	6596	8,08%	73%
Missing components in final assembly (units)	633	7229	6,96%	80%
Misalignment of doors and drawers (units)	586	7815	6,45%	86%
Electrical wiring errors (units)	474	8289	5,21%	91%
Lack of lubrication in moving parts (units)	454	8743	4,99%	96%
Incorrect use of specialized tools (units)	348	9091	3,83%	100%

Table 4. Frequency Analysis of Defects with Progressive Reduction.

Defects	Relative Frequency	Cumulative Absolute Frequency	Relative Frequency	Cumulative Relative Frequency
Improper handling of materials (units)	3101	3101	35,26%	35%
Incorrect mounting of accessories (units)	2596	5697	29,52%	65%
Poor welds or fixings (units)	710	6407	8,07%	73%
Missing components in final assembly (units)	609	7016	6,92%	80%
Misalignment of doors and drawers (units)	566	7582	6,44%	86%
Electrical wiring errors (units)	454	8036	5,16%	91%
Lack of lubrication in moving parts (units)	429	8465	4,88%	96%
Incorrect use of specialized tools (units)	330	8795	3,75%	100%

e-ISSN: 3028-8533 / INQUIDE / Vol. 07 / Nº 02

Table 5. Weekly Productive Performance Indicators in the Assembly Process – Original Data.

Week	Total Rejected Production (units)	Accepted Production (units)	Total Production (units)	Production Rejection Rate = Rejected Production / Total Production (%)	Production Acceptance Rate = Accepted Production / Total Production (%)	Acceptance Index = Accepted Production / Rejected Production	Rejection Index = Rejected Production / Accepted Production
June 1-7	402	5771	6173	6,5%	93,5%	14,36	0,07
June 8-15	446	5650	6096	7,3%	92,7%	12,67	0,08
June 16-22	437	7336	7773	5,6%	94,4%	16,79	0,06
June 23-30	428	5308	5736	7,5%	92,5%	12,40	0,08
July 1-7	407	3827	4234	9,6%	90,4%	9,40	0,11
July 8-15	403	2595	2998	13,4%	86,6%	6,44	0,16
July 16-22	421	3314	3735	11,3%	88,7%	7,87	0,13
July 23-30	545	4493	5038	10,8%	89,2%	8,24	0,12
August 1-7	374	1984	2358	15,9%	84,1%	5,30	0,19
August 8-15	614	4732	5346	11,5%	88,5%	7,71	0,13
August 16-22	354	7294	7648	4,6%	95,4%	20,60	0,05
August 23-30	428	7660	8088	5,3%	94,7%	17,90	0,06
September 1-7	385	3814	4199	9,2%	90,8%	9,91	0,10
September 8-15	369	7703	8072	4,6%	95,4%	20,88	0,05
September 16-22	432	7165	7597	5,7%	94,3%	16,59	0,06
September 23-30	641	4903	5544	11,6%	88,4%	7,65	0,13
October 1-7	593	5087	5680	10,4%	89,6%	8,58	0,12
October 8-15	416	5781	6197	6,7%	93,3%	13,90	0,07
October 16-22	416	2789	3205	13,0%	87,0%	6,70	0,15
October 23-30	580	6714	7294	8,0%	92,0%	11,58	0,09
Total defects by category	**9091**	**103920**	**113011**				

Table 6. Weekly Productive Performance Indicators with Progressive Improvement in Defect Control.

Error reduction percentage	Week	Total Rejected Production (units)	Accepted Production (units)	Total Production (units)	Production Rejection Rate = Rejected Production / Total Production (%)	Production Acceptance Rate = Accepted Production / Total Production (%)	Acceptance Index = Accepted Production / Rejected Production	Rejection Index = Rejected Production / Accepted Production
1.5 %	June 1-7	391	5782	6173	6,3%	93,7%	14,79	0,07
1.5 %	June 8-15	435	5661	6096	7,1%	92,9%	13,01	0,08
1.5 %	June 16-22	427	7346	7773	5,5%	94,5%	17,20	0,06
1.5 %	June 23-30	417	5319	5736	7,3%	92,7%	12,76	0,08
2 %	July 1-7	395	3839	4234	9,3%	90,7%	9,72	0,10
2 %	July 8-15	391	2607	2998	13,0%	87,0%	6,67	0,15
2 %	July 16-22	408	3327	3735	10,9%	89,1%	8,15	0,12
2 %	July 23-30	530	4508	5038	10,5%	89,5%	8,51	0,12
2 %	August 1-7	363	1995	2358	15,4%	84,6%	5,50	0,18

2 %	**August 8-15**	597	4749	5346	11,2%	88,8%	7,95	0,13
2 %	**August 16-22**	343	7305	7648	4,5%	95,5%	21,30	0,05
2 %	**August 23-30**	416	7672	8088	5,1%	94,9%	18,44	0,05
3 %	**September 1-7**	371	3828	4199	8,8%	91,2%	10,32	0,10
3 %	**September 8-15**	355	7717	8072	4,4%	95,6%	21,74	0,05
3 %	**September 16-22**	416	7181	7597	5,5%	94,5%	17,26	0,06
3 %	**September 23-30**	619	4925	5544	11,2%	88,8%	7,96	0,13
3 %	**October 1-7**	572	5108	5680	10,1%	89,9%	8,93	0,11
4 %	**October 8-15**	397	5800	6197	6,4%	93,6%	14,61	0,07
4 %	**October 16-22**	398	2807	3205	12,4%	87,6%	7,05	0,14
4 %	**October 23-30**	554	6740	7294	7,6%	92,4%	12,17	0,08
	Total defects by category	**8795**	**104216**	**113011**				