

Relationship between Absenteeism and Productivity: Performance, Variability, and Process Robustness Using Lean Manufacturing Tools

Fabiola Hermosillo-Villalobos¹ ; Liliana Avelar-Sosa² ; Jesús Emmanuel Guerrero-Castañeda³ 

^{1,3}Universidad Autónoma de Ciudad Juárez, México, al232734@alumnos.uacj.mx, al251382@alumnos.uacj.mx

²Universidad Autónoma de Ciudad Juárez, México, liliana.avelar@uacj.mx

Abstract– *Work absenteeism is a critical external factor that affects the performance, stability, and robustness of manufacturing systems, particularly in labor intensive assembly processes, by introducing uncontrolled variability that leads to imbalances in the workload, increased cycle times, bottlenecks, and decreased productivity. From an operational and quantitative perspective, absenteeism is recognized as a recurring disturbance that compromises the statistical stability of the process. In this context, line balancing, integrated into continuous improvement methodologies such as DMAIC, emerges as an effective strategy to mitigate these effects by increasing operational flexibility and reducing dependence on specific operators. The study's results demonstrate a negative and statistically significant relationship between absenteeism and productivity, as well as a substantial reduction in variability following the implementation of line balancing, confirming its contribution to strengthening robustness and improving operational performance in the face of fluctuations in workforce availability.*

Keywords– *Work absenteeism; Productivity; Line balancing; Process variability; System robustness.*

I. INTRODUCTION

Work absenteeism is one of the external factors that directly affect the performance and stability of manufacturing systems, particularly in labor-intensive processes where the availability of human resources is critical to meeting established production levels [1]. The unplanned absence of operators modifies the effective capacity of the system and alters the standard conditions under which production processes are designed, balanced, and controlled, generating significant deviations in operational indicators and compromising process stability [2]

From an industrial engineering perspective, manufacturing systems are designed under assumptions of repeatability, stability, and constant availability of resources. When these assumptions are altered by staff absences, the system is exposed to unplanned variations that manifest themselves in increased cycle times, accumulation of work in process, bottlenecks, and decreased productivity [3]. In this context, work absenteeism becomes a factor that generates uncertainty, increases operational variability, and reduces the system's ability to maintain consistent performance over time [4].

Variability in manufacturing processes has been widely recognized as one of the main sources of operational losses and production inefficiency. Increases in the dispersion of operating times, imbalances in the workload between stations, and fluctuations in resource availability cause system instability and degrade its overall performance. The specialized literature points out that, as variability increases, production systems require higher inventory levels, longer waiting times, and greater managerial intervention to maintain acceptable production levels [5].

In this sense, work absenteeism acts as a source of uncontrolled variation, as it introduces abrupt changes in task allocation, forces improvised operational reconfigurations, and reduces the repeatability of operating conditions [6]. These alterations not only affect average production performance but also increase both short-term variation and variation between process runs, affecting statistical stability and hindering the effective application of control tools [7].

Several empirical studies have documented a negative relationship between work absenteeism and productivity, noting that its impact is not limited solely to a reduction in production volume. [8] [9] Previous research has shown that high levels of absenteeism are associated with significant increases in the dispersion of daily performance, a higher frequency of unscheduled stoppages, and a decrease in the overall efficiency of the system [10] These effects are particularly critical in assembly processes, where the interdependence between stations amplifies the impact of the absence of key operators [8]

The scientific literature has addressed the phenomenon of absenteeism from different perspectives. Traditionally, studies have focused on its organizational, economic, and psychosocial causes, analyzing factors such as work climate, worker satisfaction, ergonomic conditions, and human resource policies. However, more recent work has emphasized the need to analyze absenteeism from an operational and quantitative perspective, considering its direct influence on process variability, statistical stability, and the robustness of the production system [11]

The concept of process robustness has become particularly relevant in the analysis of modern manufacturing systems, as it

refers to the process's ability to maintain stable performance in the face of internal and external disturbances [12]. In this context, work absenteeism represents a recurring external disturbance that tests the system's ability to adapt without significantly degrading its performance. The identification of strategies to reduce the sensitivity of the process to these fluctuations is an area of growing interest in industrial engineering research.

On the other hand, line balancing has established itself as a fundamental tool in production processes and lean manufacturing to improve productivity and reduce variation, especially in assembly systems[13][14]. Line balancing aims to distribute the workload evenly among stations, minimizing idle time and reducing bottlenecks. Traditionally, this tool has been applied to respond to variations in demand and optimize the use of available resources [15].

However, by redistributing tasks and adjusting operating times, line balancing can reduce the system's dependence on specific operators and decrease the process's sensitivity to fluctuations in staff availability, thus increasing operational robustness.

In this regard, scientific literature has incorporated the joint analysis of variability, productivity, and improvement tools into structured continuous improvement methodologies, such as Six Sigma. In particular, the Define-Measure-Analyze-Improve-Control (DMAIC) cycle has proven to be an effective approach for identifying sources of variation, quantifying their impact through statistical analysis, and evaluating the effectiveness of implemented solutions in terms of process stability and performance [16].

The DMAIC approach allows statistical tools, method studies, and process improvement techniques to be integrated into a systematic and replicable structure. The use of control charts, regression analysis, hypothesis testing, and time studies facilitate understanding of process behavior and objective evaluation of the improvements implemented, providing quantitative evidence of the impact of the interventions carried out[17][18].

This research analyzes the relationship between work absenteeism and productivity by studying its behavior and the variability of the production process in a real industrial environment. It also evaluates how the application of line balancing, a tool commonly used to adjust to variations in demand, can contribute to reducing the variability caused by absenteeism and increasing the robustness of the production system[19].

The study is developed using DMAIC methodology. In the Define phase, the initial behavior of the process is characterized using $\bar{X}$ -R control charts, allowing the stability and initial variation of the system to be evaluated. In the Measure phase,

the relationship between absenteeism and productivity is quantified using statistical analysis, normality tests, and linear regression models with assumption validation. In the Analyze phase, a time study is conducted to identify operational imbalances, and the line balancing tool is applied as an improvement strategy. Subsequently, in the Improve phase, the impact of balancing is evaluated through hypothesis testing and variability analysis, and finally, in the Control phase, the stability of the improved process is verified through statistical control tools.

The results obtained show a negative and statistically significant relationship between work absenteeism and productivity, as well as a substantial reduction in variability after the implementation of line balancing, confirming that this tool increases the robustness of the process in the face of staff fluctuations and contributes to improving the operational performance of the system.

A manufacturing company located in Ciudad Juárez, known for its integration into global supply chains and dedicated to producing various devices, including skincare products for international customers, the assembly process under study is part of a production system that places high demands on quality, compliance with regulatory standards, and operational flexibility. This industrial environment is characterized by the need to adapt to fluctuations in demand, high productions volumes, and strict delivery requirements, which demand, high production volumes, and strict delivery requirements, which demand precise control of cycle times and proper synchronization between workstations.

The process analyzed corresponds to a repetitive assembly line, structured as a sequence of standardized operations that transform individual components into a finished product in accordance with customer specifications. This process involves a combination of manual activities performed by operators and interaction with various industrial equipment, such as heat sealers, ultrasonic welders, functional testing equipment, and laser printing machines. Each workstation performs specific task that must be completed within well-defined time limits to meet the established takt time, thereby ensuring a continuous production flow.

However, the assembly process exhibits significant variability in cycle times between workstations, with several of them operating at values close to or even exceeding the takt time. This situation highlights imbalances on the production line and the presence of bottlenecks that affect the continuous flow of the process, reducing the overall efficiency of the system.

This problem is exacerbated by absenteeism, which reduces the effective availability of human resources and forces the unplanned reassignment of operators or redistribution of workloads. As a result, cycle time variability increases, certain stations become overloaded, and existing imbalances in the production line are accentuated [20].

II. METHODOLOGY

The research is carried out using the Define-Measure-Analyze-Improve-Control (DMAIC) methodology, widely used in continuous improvement projects due to its structured, data-based approach to reducing variability and improving the performance of production processes, as well as the incorporation of the lean manufacturing tool line balancing.



Fig. 1 Diagram of the methodology used in this study.

A. Step Define Phase: Identification of absenteeism in the process

During production runs, operational information was collected on the number of scheduled operators, number of absences, and number of parts produced per time interval. Based on this data, two key process indicators were calculated: the absenteeism rate and productivity. Absenteeism was determined as the percentage ratio between the number of absent operators and the total number of assigned operators, while productivity was calculated as the quotient between the parts produced and the product of the hours worked by the number of available operators. These indicators made it possible to standardize process performance and establish a quantitative basis for statistical analysis.

The data were then organized chronologically and analyzed using Xbar-R control charts with Minitab 17 software. A rational subgrouping strategy was applied, forming subgroups of five consecutive observations generated under homogeneous operating conditions, such as the same work shift and the same manual assembly process characteristics. The use of $\bar{X}$ -R charts was justified by their ability to simultaneously evaluate the stability of the process average and intragroup

variability, facilitating the identification of sources of variation associated with operational performance.

B. Step Measure phase: Quantification of the relationship between absenteeism and productivity and process variation

The measurement phase is carried out using Minitab statistical software. In the first stage, the productivity variable is represented using a box plot, with the aim of identifying the presence of outliers and evaluating the initial distribution of the data. Subsequently, a simple linear regression model is established to analyze the relationship between the independent variable, absenteeism percentage, and the dependent variable, productivity.

During model fitting, the option to store residuals is enabled, which are used to verify statistical assumptions. In particular, the assumption of normality is evaluated by analyzing the residuals, and homoscedasticity is verified using the residuals versus fits graph.

Additionally, a scatter plot is constructed to graphically represent the relationship between the two variables, incorporating the regression equation obtained. Finally, the statistical significance and performance of the model are evaluated through analysis of variance (F statistic and p-value), as well as the calculation of the coefficient of determination (R^2), the adjusted R^2 , the correlation coefficient, the standard error of the estimate, and the variance inflation factor (VIF) in order to validate the consistency and explanatory power of the model.

C. Step Analyze phase: Application of the line balancing tool

To apply the line balancing tool, the process begins by identifying the takt time, which is determined based on the relationship between customer demand and available production time. Next, a time study is conducted to assess whether the process stations comply with the established takt time and to identify possible imbalances in the line.

Next, a detailed analysis of the process characteristics is carried out, breaking down the activities of each station into value-added (VA) activities, auxiliary (AW) activities, non-value-added (NVA) activities, and unproductive time. Based on this analysis, activities that do not add value and, as far as possible, auxiliary activities are reduced or eliminated, prioritizing those that add value to the product.

Once the activities have been optimized, the working times are redistributed among the stations so that their cycle times are as close as possible to the takt time, ensuring that the last station has the shortest cycle time and that the rest of the stations remain close to the required system rhythm. Subsequently, the analysis of the balanced process activities is repeated to verify

whether there is an increase in the proportion of activities that add value.

Finally, to address the variability generated by absenteeism, an operational strategy is established in which new or less experienced operators start at the station with the shortest cycle time. In the event of an additional absence, these operators are progressively assigned to the next operation with the shortest cycle time, which allows for their gradual training in the process and helps to reduce the impact of absenteeism on online performance.

D. Step Improvement phase: Line Balancing as alternative solution

For the improvement phase, information is collected for 30 production runs in the initial scenario, in which there is no operator. These results are compared with 30 additional runs obtained under a new scenario, in which line balancing is applied and the strategy of assigning the new operator to the station with the shortest cycle time is implemented.

Using Minitab software, a paired t-test is performed to determine whether there is statistically significant evidence of differences in the output variable production between the two scenarios. Likewise, a two-variance comparison test is carried out to assess whether the strategy of assigning operators to the station with the shortest cycle time is reflected in a lower dispersion of the data, which would statistically confirm the reduction in process variability.

E. Step Control phase: Verification of line balancing implementation

At this stage, the main objective is to ensure the sustainability of line balancing as a tool for continuous improvement, guaranteeing its permanence and effectiveness over time. To this end, work methods and operating times at each station are reviewed and standardized, incorporating adjustments that allow the line to remain balanced under normal operating conditions and in the event of variations in demand or staff availability.

Likewise, checklists are developed for the start of the process, aimed at confirming that the assignment of operators, the sequence of operations, and cycle times are aligned with the established takt time. These lists allow for the standardization of initial verifications and strengthen the operational structure of the process.

In addition, visual management tools are implemented that facilitate their use by production personnel, allowing for clearer and more direct monitoring of line performance, such as takt time compliance indicators, load per station, and work balancing. The integration of these supports seeks to reinforce

the operational discipline established in the previous stages, promoting a more orderly execution of the process.

III. RESULTS AND DISCUSSION

A. Define Phase: Identification of absenteeism in the process

During the Define phase, the initial stability of the process was evaluated using $\bar{X}$ -R control charts showed on Fig. 2, employing rational subgroups of constant size. The results showed the presence of special causes in both the mean chart and the range chart, indicating that the process is not operating under statistical control. Significant increases in intragroup variability were identified, as well as atypical fluctuations in productivity levels. This behavior reflects the process's high sensitivity to external disturbances, with employee absenteeism being one of the critical factors identified. The detection of these signals confirms the need to further quantify the impact of absenteeism on productivity.

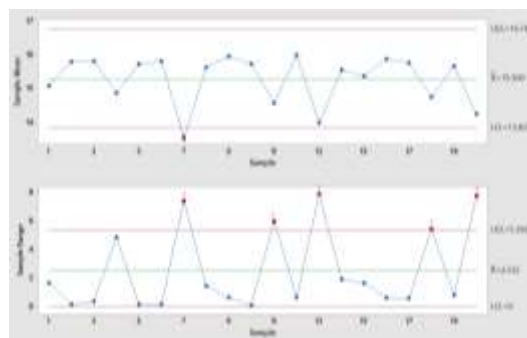


Fig. 2 Xbar-R control chart Productivity.

B. Measure phase: Quantification of the relationship between absenteeism and productivity and process variation

Fig. 3 presents a box plot of productivity, which shows a considerable level of variability in process performance, suggesting high sensitivity to external disturbances, such as operator availability. However, no outliers are shown. Fig. 4 shows the probability plot of the regression model residuals, indicating an approximately normal distribution with no systematic deviations, which supports the assumption of normality. Fig. 5 presents the graph of residuals versus adjusted values, where the random dispersion around zero and the absence of discernible patterns confirm the assumption of homoscedasticity. This condition implies that the variances of the residuals remain constant across all levels of the fitted values, indicating that the model errors are uniformly distributed and do not depend on the magnitude of the predictions. Consequently, fulfillment of this assumption supports the statistical validity of the model, ensuring that parameter estimates are efficient and that inference procedures, such as hypothesis testing and confidence intervals, are reliable.

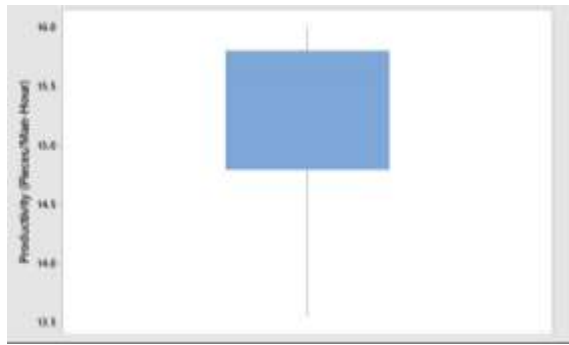


Fig. 3 Box plot Productivity.

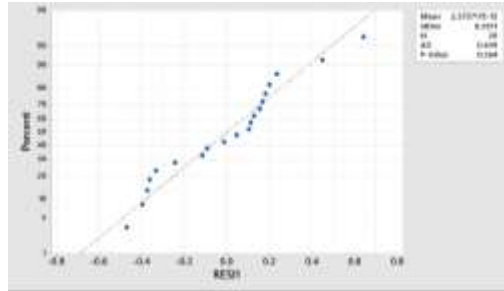


Fig. 4 Normality test for Probability Plot of Residues.

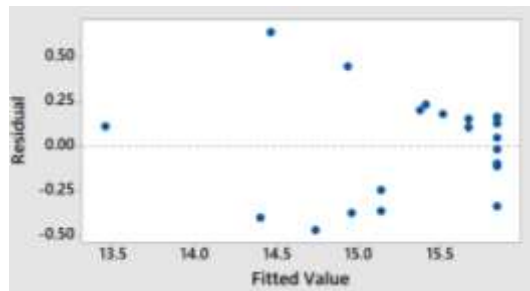


Fig. 5 Residuals versus Fits for Homoscedasticity.

Fig. 6 shows a clear negative relationship between absenteeism and productivity. As the level of absenteeism increases, productivity consistently decreases, indicating that workforce availability has a direct impact on system performance. The downward trend suggests that even moderate increases in absenteeism result in measurable productivity losses.

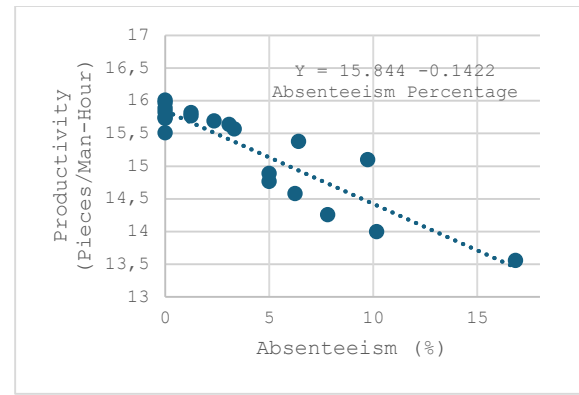


Fig. 6 Relationship between productivity and absenteeism.

When performing simple linear regression analysis to evaluate the relationship between the percentage of absenteeism and the response variable. The results of the analysis of variance indicate that the regression model is statistically significant ($F = 85.65$; $p < 0.001$), which shows that the percentage of absenteeism significantly explains the variability observed in the dependent variable.

The coefficient of determination showed a high value ($R^2 = 82.63\%$), indicating that the model explains 82.63% of the total variability of the response variable. The adjusted R^2 was 81.67%, while the predictive R^2 reached 78.45%, suggesting adequate predictive power of the model. The correlation coefficient was 0.9090. The standard error of the estimate was 0.3052, reflecting a moderate dispersion of the data around the regression line.

The analysis of the coefficients revealed that the percentage of absenteeism has a negative and statistically significant effect on the response variable ($\beta = -0.1422$; $t = -9.25$; $p < 0.001$). This indicates that for each percentage point increase in absenteeism, the dependent variable decreases by an average of 0.1422 units, with all other factors remaining constant. The constant term of the model was statistically significant ($\beta = 15.8442$; $p < 0.001$), indicating that, in the absence of effects from the independent variables, there is a baseline value for the response variable that is relevant within the model. Regarding multicollinearity, no issues were detected, as the variance inflation factor (VIF) had a value of 1.0. This result is significant, given that VIF indicates the absence of correlation among the independent variables. In practical terms, this implies that each explanatory variable contributes unique information to the model, without redundancies or overlaps with other variables. Consequently, the coefficient estimates are stable, precise, and easily interpretable, avoiding inflations in standard errors that could affect statistical significance. Overall, the absence of multicollinearity reinforces the robustness of the model and the reliability of the inferences derived from it.

C. Analyze phase: Application of the line balancing tool

Fig. 7 shows the initial cycle times per station compared to the takt time for an assembly process. Significant variability is observed between stations, with several of them having cycle times close to or greater than the takt time, which indicates imbalances in the production line and the potential presence of bottlenecks. These conditions directly affect on-time delivery (OTD) performance, as uneven workload allocation limits the system's ability to consistently meet demand and delivery commitments, in addition to contributing to high levels of waste.

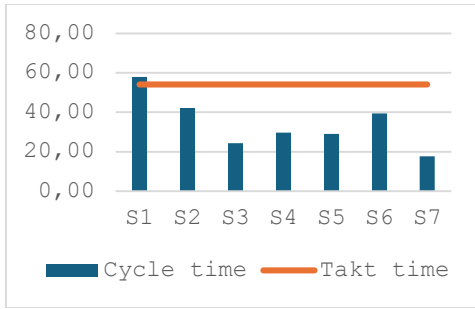


Fig. 7 Initial scenario time study.

Fig. 8 shows the distribution of value-added (VA) activities, auxiliary work (AW), non-value-added (NAV) activities, and idle time by station. The results show a high proportion of non-value-added activities and idle time, particularly in some seasons, which highlight operational inefficiencies and opportunities for improvement. This uneven distribution contributes to process variability and explains the imbalances observed in cycle times in the initial scenario.

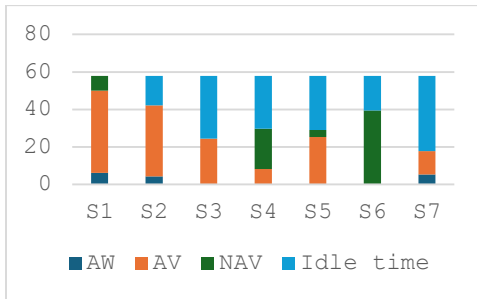


Fig. 8 Distribution of AV, AW, NAV, and Idle time activities in the initial scenario.

Fig. 9 shows that the takt time (orange line) remains virtually constant, reflecting the production rate imposed by system demand. The cycle times for stations S1, S2, S3, and S4 are slightly below the takt time, indicating that these stations are meeting the required rate. This condition suggests a functional balance in the process.

Station S5, on the other hand, has the shortest cycle time, clearly below the takt time. This station was strategically defined as the point of incorporation for new or less experienced operators, taking advantage of its greater operational slack. In

addition, an additional test team was incorporated, increasing the number of available teams from two to three, which contributed significantly to the reduction of cycle time at this stage. This modification allowed the workload to be redistributed and the process to be adjusted to a five-station configuration, improving the balance of the line and the overall alignment with the established takt time.

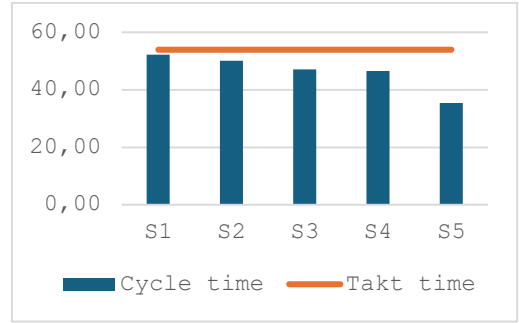


Fig. 9 Line balancing application.

Fig. 10 shows the distribution of AV (value-added) activities, AW (auxiliary or support) activities, NAV (non-value-added) activities, and idle time for each process station (S1–S5) within the line balancing application.

In general terms, AV activities constitute the largest proportion of total time at all stations, indicating that most of the operational effort is focused on the direct transformation of the product, as well as a greater participation of these activities in relation to their initial stage.

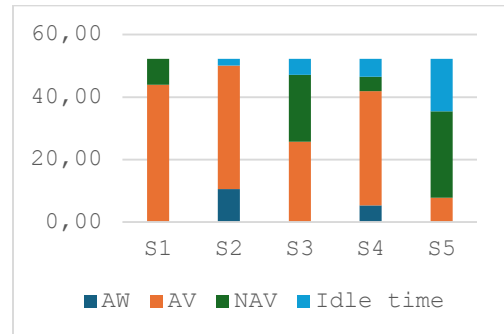


Fig. 10 Distribution of AV, AW, NAV, and Idle time activities in the line balancing application.

D. Improvement phase: Line Balancing as alternative solution

Table I presents the results of the paired t-test and hypothesis testing to compare process productivity before and after the implementation of line balancing. Both data sets have the same size as the sample size ($N = 30$), ensuring direct comparability of the observations. The average productivity after balancing is significantly higher than that recorded in the

initial state, and the low standard deviations observed in both cases indicate reduced variability and consistent measurement of process performance.

The paired difference analysis shows a negative mean value, consistent with the formulation of the alternative hypothesis ($\mu_{\text{before}} - \mu_{\text{after}} < 0$), confirming an increase in productivity after the intervention. The p-value obtained ($P < 0.001$) allows us to reject the null hypothesis with a high level of statistical confidence. Additionally, the comparison of the means shows that the increase in productivity from the initial state to the productivity once line balancing was implemented represents an approximate increase of 63%, which reinforces the practical relevance and impact of line balancing as an effective strategy for improving the performance of the production system.

TABLE I
PAIRED T-TEST AND HYPOTHESIS TEST BALANCING BEFORE AND AFTER

Sample	N	Mean	St Dev	SE Mean
Productivity before	30	7.763	0.1417	0.0259
Productivity after	30	12.7177	0.0997	0.0182
Difference	30	-4.9547	0.1501	0.0274
Null hypothesis	$H_0: \mu_{\text{before}} - \mu_{\text{after}} = 0$			
Alternative hypothesis	$H_1: \mu_{\text{before}} - \mu_{\text{after}} < 0$			
P-Value	$P < 0.001$			

Fig. 11 presents the comparative analysis of productivity variances before and after the implementation of line balancing, using a 95% confidence interval (CI), tests of equality of variances, and complementary graphical representations.

The confidence interval for the variance ratio ($\sigma^2_{\text{before}} / \sigma^2_{\text{after}}$) is below the reference value of 1, indicating that productivity variability after balancing is lower than that observed in the initial state. This result is consistent with the Bonett and Levene statistical tests, whose p-values ($P < 0.05$) show significant differences between the variances of both states, allowing us to reject the hypothesis of equality of variances. In practical terms, this suggests that line balancing not only increased the average level of productivity but also contributed to stabilizing the process, reducing the dispersion of results.

Additionally, the confidence intervals for the standard deviations show less dispersion in productivity after the intervention, which is reinforced by the box plots, where a more

compact and consistent distribution is observed after balancing. Taken together, these results confirm that the application of line balancing had a positive effect on both increasing productivity and reducing process variability, strengthening the operational robustness of the system analyzed.

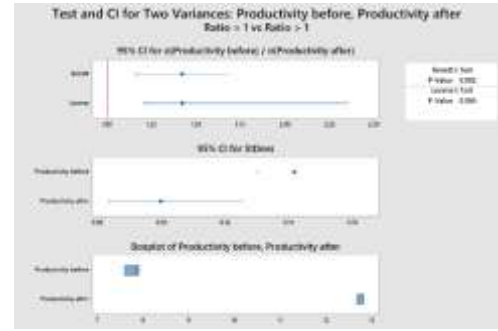


Fig. 11 Test and CI for Two Variances: Productivity before, Productivity after.

E. Control phase: Verification of line balancing implementation

Work plans were updated to incorporate standardized procedures aimed at maintaining line balance and operational control of critical stations in the assembly process. In particular, specific activities were defined for the verification and ordering of workstations, ensuring that tools, devices, and materials are available and in adequate condition to meet established cycle times.

Likewise, routines were established for reviewing and cleaning the devices and auxiliary elements used at each station, employing standardized methods that minimize variations in the execution of operations. These activities were scheduled periodically, while basic checks of work devices are performed at the beginning of each production run to ensure cycle time stability.

Finally, a production board was set up as a visual management tool for recording the line's performance on an hourly basis, including deviations in cycle times, accumulation of work in progress, and events affecting flow. This practice allows for continuous monitoring of line balancing and facilitates timely communication with the interdisciplinary team to adjust task assignments or the sequence of operations, maintaining optimal operating conditions.

IV. CONCLUSIONS

The evidence presented in the literature confirms that workplace absenteeism has a significant negative impact on the productivity of manufacturing firms [21]; however, this effect is not uniform but depends on factors such as the level of automation, the interdependence between tasks, and the composition of the workforce[22]. In this regard, the results of the present study are consistent with these findings, as it is

empirically demonstrated that absenteeism has a negative and statistically significant influence on productivity, explaining more than 80% of its variability. This strong relationship suggests that the analyzed process exhibits characteristics of high sensitivity to absenteeism, likely associated with its labor-intensive nature and the limited capacity for immediate replacement of operators.

Likewise, the literature highlights that the greatest impacts of absenteeism occur in production systems with high interdependence among workers, where the absence of a single operator can cause disruptions at multiple stations[23]. This behavior is consistent with the study's findings, which identified an initial condition of statistical instability, the presence of special causes, and high intragroup variability. Such conditions reflect a system vulnerable to external disturbances, where absenteeism not only reduces available capacity but also amplifies imbalances on the line and contributes to the creation of bottlenecks, affecting the continuous flow of the process.

On the other hand, previous research indicates that in highly automated environments, the effects of absenteeism may be less noticeable, especially in quality indicators [24]. However, the context analyzed in this study, characterized by manual processes and reliance on operator's specific knowledge, contributes to absenteeism having a more pronounced impact. Consequently, the results obtained not only validate absenteeism as a critical source of operational disruption but also reinforce the need to implement structured improvement strategies that increase the resilience of the production system, particularly through flexible work arrangements.

The application of the line balancing tool in the Analysis phase was consolidated as an effective mechanism for addressing the inefficiencies identified in the initial diagnosis. The redistribution of workloads, the reconfiguration of the process into five stations, and the incorporation of an additional testing team allowed for better alignment between cycle times and takt time. Likewise, the strategic use of operational slack at specific stations, particularly for the incorporation of less experienced operators, contributed to the reduction of bottlenecks, non-value-added activities, and idle times, increasing the proportion of value-added activities along the line.

From the perspective of the improvement phase, the results obtained in this study confirm that line balancing is an effective strategy for increasing productivity and stabilizing system performance. Statistical evidence based on the paired t-test showed a significant increase in productivity of nearly 63% compared to the initial state, which falls within the range reported in the literature [25][26][27]. This finding reinforces the consistency of line balancing as a robust tool, regardless of

the type of industry or method employed, whether through traditional approaches, simulation, or hybrid methodologies.

Additionally, the significant reduction in productivity variability, evidenced through analysis of variance, provides a key element that complements the benefits reported in previous studies. While the literature has documented improvements in efficiency, reduction in the number of operators, and decreases in cycle times, the present study also emphasizes the improvement in process stability, suggesting a transition toward a more controlled and predictable system. This aspect is fundamental in production environments, as the goal is not only to maximize average performance but also to minimize operational variability that can compromise system reliability.

However, it is important to note that, although multiple studies have implemented practices such as workload redistribution elements there is limited evidence directly linking line balancing to the mitigation of absenteeism effects[28][29][30]. In this regard, the result of the present study contributes to discussion by demonstrating that balancing the process and identifying the simplest stations where new operators can be integrated not only improve productivity but also increases its robustness.

Finally, the actions established in the Control phase ensure the sustainability of the improvements achieved. The standardization of work plans, the definition of periodic verification and cleaning routines, and the implementation of visual management tools provide a structured framework for maintaining line balance and detecting performance deviations in a timely manner. Overall, this research confirms that integrating statistical analysis of absenteeism with line balancing techniques within a DMAIC approach is an effective strategy for increasing productivity, reducing variability, and strengthening the operational resilience of manufacturing systems.

From a managerial perspective, the results highlight the importance of adopting a proactive approach to managing absenteeism by integrating workforce planning with the design of the production system. Rather than reacting to operator absences, organizations must anticipate them through strategies that increase operational flexibility. In this regard, line balancing establishes itself not only as a tool for improving productivity but also as a mechanism for strengthening the system's robustness. Therefore, it is essential that managers promote practices such as cross-training, the efficient redistribution of workloads, and the design of workstations with varying levels of complexity to facilitate the rapid onboarding or replacement of personnel. Likewise, the implementation of structured methodologies such as DMAIC allows for systematic identification, analysis, and control of the main sources of variability, fostering data-driven decision-making.

In general terms, although the study was conducted in a labor-intensive environment, its results can be extended to other industrial sectors with similar characteristics, particularly those with low or moderate levels of automation and high interdependence between tasks.

Industries such as electronics, medical devices manufacturing, and consumer goods can benefit from the application of these approaches. While in highly automated environments the impact of absenteeism may be less evident, the principles of line balancing, standardization, and variability reduction remain relevant. Taken together, this approach provides a solid foundation for improving productivity, stability and operational resilience across various manufacturing contexts.

VI. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This study was conducted using a sample from the assembly line of an industrial manufacturing company, which is one of its main limitations. Although the methodology used and the analytical approach can be replicated in other production processes—such as injection molding, metal treatments, or painting processes—the results must be interpreted taking into account the operational particularities of each process. In this sense, the findings show a broader potential for application in different industrial environments, provided that the necessary adaptations are made to the specific production context.

For future research, it is recommended to broaden the scope of the study by incorporating other lean manufacturing tools, as well as applying the proposed methodology to different types of industrial processes. This would allow the results obtained to be validated and generalized, strengthening their relevance and contribution to continuous improvement in manufacturing systems.

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