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Beyond Spatial Optimization: An Integrated Multi-Method Framework for Manufacturing Layout Redesign

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Abstract

Ineffective plant layouts can account for 20–50% of total operating expenses, a challenge particularly acute for Small and Medium-sized Enterprises (SMEs) in developing nations where resources are limited. This study addresses these constraints by proposing an integrated, low-cost framework for layout redesign for a Bolivian paper manufacturer facing congestion and excessive transport distances. The methodology combines time studies, Discrete-Event Simulation (DES), Factory Physics, Systematic Layout Planning (SLP), and the Analytic Hierarchy Process (AHP) to diagnose and select optimal configurations. Two alternatives were obtained: (i) a machinery redistribution to minimize distance, and (ii) a layout integrating increased transport automation. Results demonstrate significant operational improvements. The first alternative increased throughput by 12.88%, reduced travel distance by 36.91%, and decreased WIP by 19.00%, while the second alternative increased throughput by 25.18%, reduced travel distance by 39.26%, decreased WIP by 29.25%, and improved cycle time by 8.00%. This research confirms that combining structured management tools offers a robust, transferable pathway to operational excellence without requiring complex algorithms or substantial capital investment.

Keywords
Plant layout, Production optimization, Multi-method approach, Factory Physics, Simulation, SMEs.

1. Introduction
Finding an optimal plant layout is a problem that has been extensively studied by both practitioners and academics, who have developed a broad range of methodologies over more than seven decades of research (Koopmans & Beckmann, 1957). Plant layout can be understood as the way in which an organization's physical assets should best support the achievement of its objectives. In manufacturing and industrial engineering, this involves the facilities' arrangement of departments, workstations, machinery, equipment, and operators to achieve an efficient workflow (Tompkins et al., 2010). Thus, among the most developed and commonly used approaches today is the Systematic Layout Planning (SLP). This basic approach is usually complemented by algorithmic methods, discrete-event simulation, Reed's facility layout procedure, or heuristic, metaheuristic, and evolutionary approaches (Kikolski & Ko, 2018; Al-Zubaidi et al., 2021). Therefore, these unified methodologies aim to optimize the relationships among the various factors and processes within a production plant, such as material flow, proximity between areas, and efficient use of space. The goal is reducing travel distances and unnecessary movements (Wang et al., 2016).

As a result, the design and optimization of plant layout require continuous review whenever new work methods are adopted, new technologies are incorporated, or additional equipment is installed. The incorporation of these elements and modifications significantly alters the operating conditions of the production system (Al-Zubaidi et al., 2021). Likewise, a suitable organization of workspaces helps reduce workers' physical effort, improves ergonomic conditions, and allows for a flexible arrangement that adapts to future changes and operational modifications (Kikolski & Ko, 2018).

However, despite significant methodological advances, SMEs in developing countries face obstacles and limitations in implementing complex or high-cost solutions (Haraguchi et al., 2019). For example, in Bolivia, the scarcity of technology and resources, along with insufficient technical training, constitute a critical barrier to the nation's industrial development (Herbas-Torrico et al., 2022). In similar contexts, these constraints are exacerbated by a shortage of financial resources and a limited availability of specialized human capital. Although Industry 4.0 solutions offer substantial improvements for industries, their adoption is not completely feasible for many SMEs. These organizations are often financially constrained and cannot access external funding sources. As Bakhtiari et al. (2020) point out, SME owners perceive financial resources as the most critical determinant of their businesses' success. This reality highlights the need for integrated, robust, and low-cost methodological frameworks. Possible approaches must demonstrate that significant productivity improvements are achievable without resorting to overly sophisticated technologies or high investments that could jeopardize operational continuity.

Our research proposes and validates an integrated, low-cost methodological framework for redesigning the plant layout of a manufacturing SME to improve its operational performance without requiring substantial investments. Specifically, the research proposes studying a manufacturing company experiencing flow problems, excessive transport distances, and inefficient use of space. Our analysis focuses on the production line for the most in-demand notebook product in a paper-and-notebook factory to demonstrate the maximum possible impact of the proposed improvements. To this end, the production line was diagnosed using time studies and material flow analysis. Subsequently, the system's performance was simulated, and redistribution alternatives were designed using SLP and Factory Physics. The optimal alternative was selected using the AHP.

2. Literature review
As mentioned above, plant layout is the process of arranging the elements that shape industrial production systems in physical space to efficiently achieve production objectives. It is considered one of the most relevant design decisions within an organization's operations strategy, due to its direct impact on costs, productivity, and material flow (Jacobs & Chase, 2018). The literature indicates that an inadequate spatial configuration can significantly increase travel distances, cycle times, and work-in-process, thereby affecting the overall performance of the system (Pérez-Gosende et al., 2021). Recent decades have witnessed the emergence of sophisticated algorithmic approaches, including genetic algorithms (Tam, 1992), simulated annealing (Matai, 2015), particle swarm optimization, ant colony optimization, and, more recently, digital twin-based methods (Gou et al., 2021). That achieved strong optimization performance in well-resourced settings; their practical adoption remains constrained in resource-limited SMEs (Bakhtiari et al., 2020), motivating the need for accessible, integrated methodological frameworks such as the one proposed in this study.

2.1 Systematic Layout Planning (SLP)

One of the most widely used approaches to plant layout design is SLP (Muther, 1961). SLP is a systematic, multi-criteria, and yet intuitive procedure for addressing layout problems in various types of manufacturing plants. It is based on a structured analysis of relevant production system information using five input points: Product (P), Quantity (Q), Route (R), Services (S), and Time (T). Together, they enable the development of solutions that meet operational requirements. Within SLP, the analysis of relationships between activities is fundamental. In this phase, the sequence, quantity, and cost of product movements between operations are determined using supporting graphical representations such as flowcharts and flow material graphs (Rodrigues Vaz et al., 2025). The goal is to have setups in which the highest-flow activities are as close together as possible, reducing unnecessary travel. For SLP, a Proximity Value Table is used, which classifies the proximity between departments with the following codes:

- ***A - Absolutely Necessary:*** Needs to be directly adjacent.
- ***E - Especially Important:*** Important to have nearby.
- ***I - Important:*** Reasonable to have nearby.
- ***O - Ordinary/Normal:*** Normal closeness.
- ***U - Unimportant:*** No specific need to be nearby.
- ***X - Undesirable:*** Should be separated to prevent hazards or noise.

This tool, called the Activity Relationship Chart, prioritizes relationships and facilitates the generation of relationship diagrams.

2.2 Factory Physics

In the context of plant layout redesign, Factory Physics provides the analytical link between spatial decisions and production performance. Rather than treating layout as a purely geometric problem, plant redesign must adhere to the fundamental laws of production flow. In this context, Factory Physics establishes scientific principles for analyzing manufacturing systems (Hopp & Spearman, 2011). This allows the layout designer to evaluate how material flow and waiting times affect the system's main operating variables. Specifically, this methodology identifies three fundamental performance metrics: Throughput (TH), Work in Process (WIP), and Cycle Time (CT), which are related by Little's Law:

$$WIP = TH \times CT$$

This relationship was mathematically proposed by Little (1961) and constitutes the first law of factory physics. Its usability and impact in layout design stem from its applicability to almost any steady state production system (Pound et al., 2014; Hopp & Spearman, 2011). From this perspective, reducing transport distances through layout redesign directly impacts CT. Also, if the WIP level remains constant, the decrease in total cost (TC) mathematically implies an increase in TH. Therefore, spatial optimization not only reduces material handling costs but can also translate into quantifiable increases in production. In particular, the best-case, worst-case, and practical worst-case scenarios provide reference curves that enable the estimation of how far the real system is from its theoretical and practical limits (Hopp & Spearman, 2011). Factory Physics facilitates the evaluation of whether a real production line is close to its optimal performance or exhibits inefficiencies.

2.3 Internal benchmarking

Internal benchmarking occurs when an organization identifies and adopts best practices within its own boundaries. The goal is to learn from internal best practices and address challenges that can be overcome (Piran et al., 2021). This makes it possible to identify whether the line is operating near its potential (Pound et al., 2014). Instead of comparing the company against external manufacturing systems, this approach compares the actual system with its own theoretical reference conditions, the best-case, worst-case, and practical worst-case scenarios:

- The *best-case scenario* analyzes ideal conditions, identifying the minimum CT and the maximum achievable production level.
- The *worst-case scenario* evaluates the minimum line's performance at its minimum capacity.

- The *practical worst-case scenario* assumes an intermediate performance level between the best- and worst-case scenarios, providing a realistic assessment of the potential for improvement (see Figure 1).
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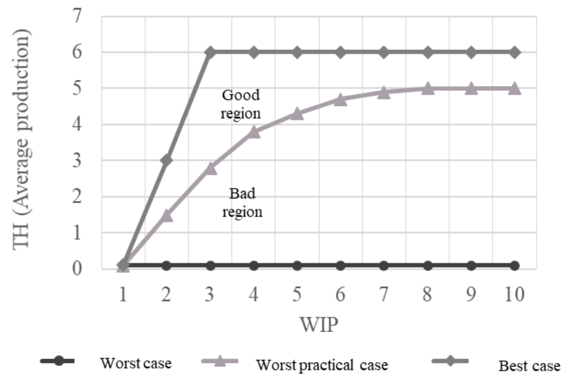


Figure 1. Internal Benchmarking TH vs WIP

In this research, internal benchmarking serves as a diagnostic tool that translates the simulation results into interpretable curves. The best-case scenario represents ideal flow conditions with minimal delays; the worst-case scenario reflects a highly congested and inefficient system; and the practical worst-case scenario provides a realistic lower bound that is more representative of actual manufacturing behavior. Consequently, benchmarking is used to assess whether the proposed layout alternatives produce meaningful operational improvement.

2.4 Simulation

Simulation is used as a controlled experimental environment to test the system's layout design and proposed alternatives without interrupting operations and risking the real system. Currently, simulation has largely replaced traditional methods due to its applicability across different types of systems, lower costs than physical models, and flexibility in analyzing different time scales (Calvet et al., 2020). In this study, discrete-event simulation enables the estimation of key performance indicators, which later allow evaluating how layout changes affect system behavior. Consequently, simulation complements Factory Physics by providing a dynamic representation of the production line and validating whether the proposed redesigns improve flow efficiency. Thus, simulation allows for quantifying and visualizing the effect of each alternative and provides references needed for comparison. Its main value lies in enabling the controlled, low-cost observation of the operational consequences of each layout option.

2.5 Analytic Hierarchy Process (AHP)

Selecting among plant distribution alternatives often involves conflicting criteria, such as investment cost, job security, future flexibility, and ease of implementation. In plant redesign, the best alternative from a flow perspective is not always the most feasible in economic or operational terms. To address these challenges, multi-criteria methods like the Analytic Hierarchy Process (AHP) provide a systematic and structured decision-making framework (Yang & Kuo, 2003). Its implementation involves constructing a hierarchical structure that integrates the objective, criteria, and alternatives. This process includes judgment matrix construction, priority vector calculation, and consistency verification to enable final decision-making (Nenzhelele et al., 2023). In this study, AHP is employed to integrate quantitative and qualitative criteria and to compare the current layout with proposed alternatives based on factors such as distance traveled, machinery relocation cost, and production rate. Through pairwise comparisons, the method assigns relative weights to each criterion and checks for consistency in a transparent and replicable selection process (Saaty & Vargas, 2012). Ultimately, AHP is used in the final stage to synthesize the results of simulation and Factory Physics, supporting the selection of the most suitable plant layout when multiple criteria must be considered simultaneously.

3. Methods

The proposed methodology is presented as a low-cost, integrated framework for plant layout redesign that combines qualitative and quantitative tools. In the first stage, a diagnostic assessment of the production line's current state was conducted, identifying material flows, physical constraints, congestion levels, and distances traveled. This assessment was complemented by a time study that enabled characterization of the standard operating time parameters and the tolerances required for subsequent modeling. Next, the baseline layout was modeled using Siemens Tecnomatix simulation to evaluate performance in terms of throughput, cycle time, and WIP under variable conditions. This stage allowed for the establishment of a reliable point of comparison for the proposed improvements. Based on these results, redistribution alternatives were developed using SLP, prioritizing the proximity of activities with high material flow and minimizing transport distances. Following this, the generated alternatives were quantitatively evaluated through simulation and analyzed according to Factory Physics principles to verify the consistency between CT reductions and TH increases. Finally, the AHP was used to select the most suitable alternative, considering operational and strategic criteria such as implementation cost, distance traveled, and production rate (see Figure 2).

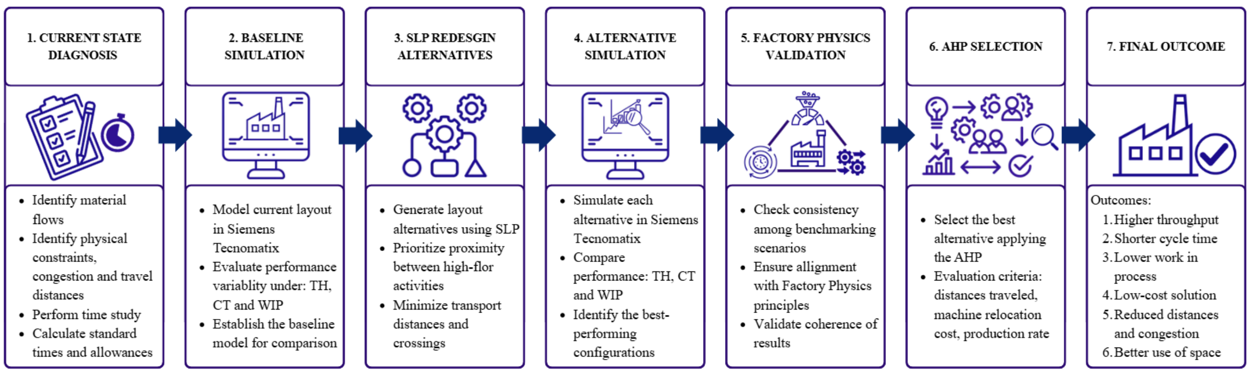


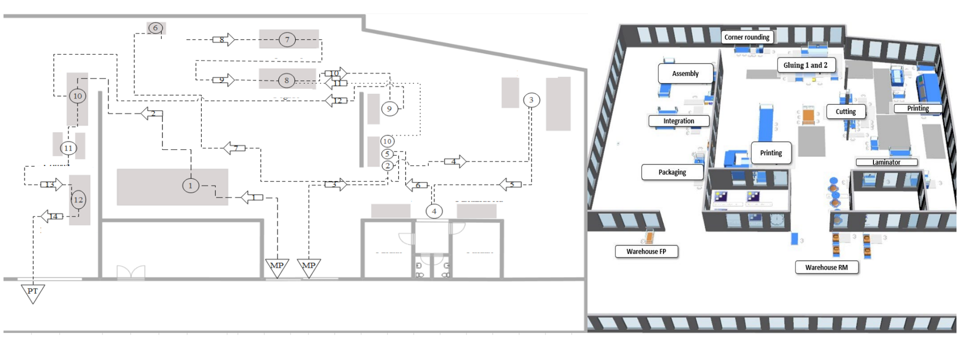
Figure 2. Integrated methodology for plant layout redesign and evaluation

4. Results and discussion

4.1 Baseline process analysis

To facilitate understanding of the production process, a route diagram detailing the entire manufacturing process was created in Figure 3. It shows 26 processes, 9 raw materials, and 9 WIP storage points. The diagram distinguishes the main activities of the system: 13 operations, 14 transports, and storage activities, using standard symbols.

The time study was conducted using the continuous reading method, recording the duration of each activity of the process. To calculate the average times for the 29 processes, M-estimators were used for operations that did not exhibit a normal distribution. Normal time was determined by evaluating operator performance using the Westinghouse method, which considers skill factors, effort, environmental conditions, and consistency (Niebel & Freivalds, 2009). The analysis also considered the variability associated with the existence of three work shifts in certain operations. The standard time per operation was calculated from the normal time, incorporating the work allowances established by the International Labor Organization (ILO, 1992). These allowances and their percentages were integrated into the final standard times, which are detailed in Figure 2 by operation and transport, taking into account the parameters required for the simulation.



1	Printing and cutting
3	Printing 1
2,5	Cutting 1
4	Laminator 1
6	Corner rounding
7	Gluing 1
8	Gluing 2
9	Cutting 2
10	Assembly
11	Integration
12	Packaging

Figure 3. Baseline manufacturing process route and simulation model showing the spatial distribution, operations, and transport activities across the production facility.

With the standard times defined for operations and transportation (see Figure 4), a virtual simulation model of the production system was developed. This model enabled the validation of the process under analysis. To this end, a Student's t-test was used to compare the model results with the data observed during actual operation (Herbas-Torrico & Luján-Sainz, 2024). The simulation model was validated against observed daily production using 30 simulation runs. The analysis yielded a p-value of 0.685 ($p > 0.05$) and a t-value of 0.41 with 29 degrees of freedom. The 95% confidence interval for the difference in means was (-0.1464, 0.219), which includes zero. Therefore, no statistically significant difference was detected between the simulated and observed mean daily production. These results suggest that the model adequately represents the current system used to evaluate the proposed redesign alternatives.

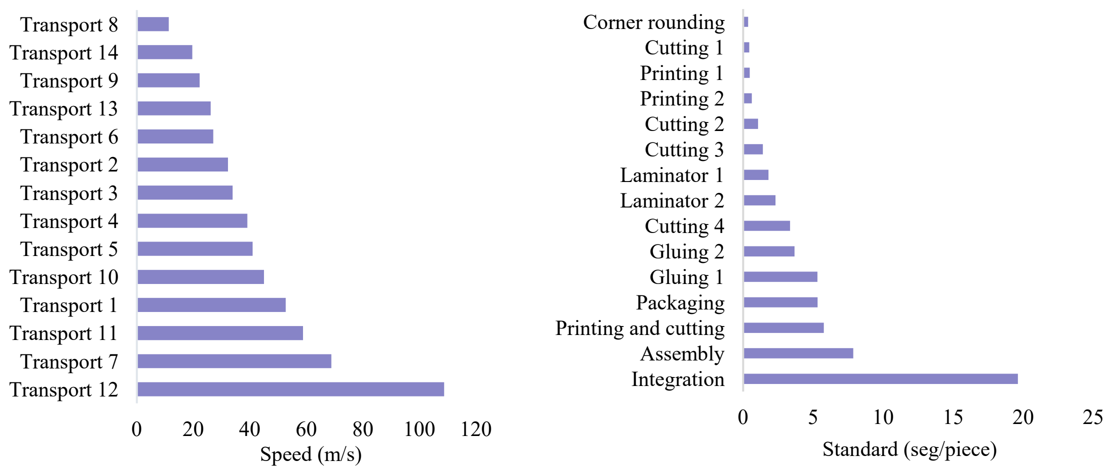


Figure 4. Standard times for production operations and transport activities calculated using the Westinghouse performance rating method.

4.2 Layout redesign and improvement alternatives

The validated simulation results are presented in Figures 5 and 6. Specifically, three work shifts were included in a single day. Additionally, the production line had 27 operators, whose activities were classified into five categories: setup, work, transport, movement, and waiting. The results also show that workers spend an average of 65% of their time waiting, indicating low labor utilization. Ideally, most of the time should be dedicated to production and transport activities. Furthermore, waiting times were identified at all workstations, reaching an overall average of 51% of the total time. We also found that the main system constraints occur in the laminating and binding operations, which generate bottlenecks due to 1) direct operator dependence, 2) the accumulation of large batches, and 3) the need for high minimum batch sizes.

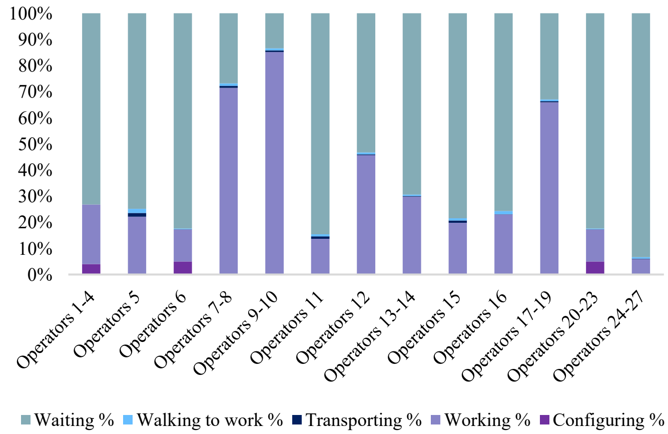


Figure 5. Operator activity distribution in the baseline simulation model.

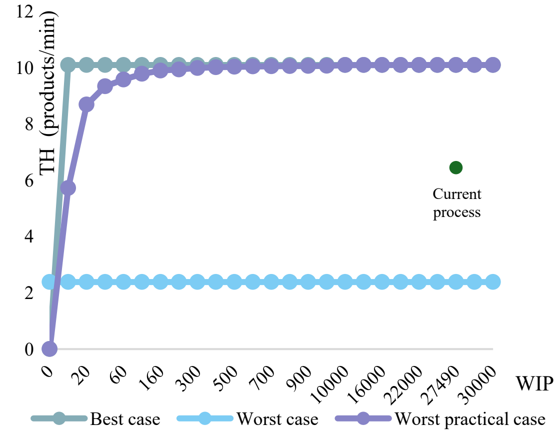


Figure 6. Factory Physics internal benchmarking of the baseline production line.

Statistical analysis revealed a production rate of 8,499 products per day, equivalent to 6.44 products per minute. As shown in Figure 6, internal benchmarking revealed that the production line is operating in a low-performance zone, characterized by a high accumulation of WIP and a low production rate. This condition is primarily due to long waiting times in most operations, leading to high WIP and inefficient workflow

4.2.1 Relational diagram and plant redistribution

Next, following Muther's SLP methodology, a relational diagram was developed to analyze the required proximity between workstations (see Figures 7 and 8). This analysis enabled a reorganization of the process flow and a reduction in unnecessary movement, downtime, and product accumulation.

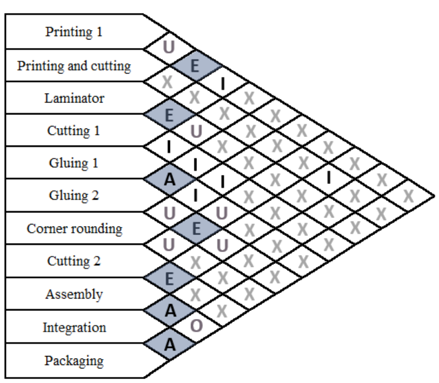


Figure 7. Activity Relationship Chart based on Muther's SLP method.

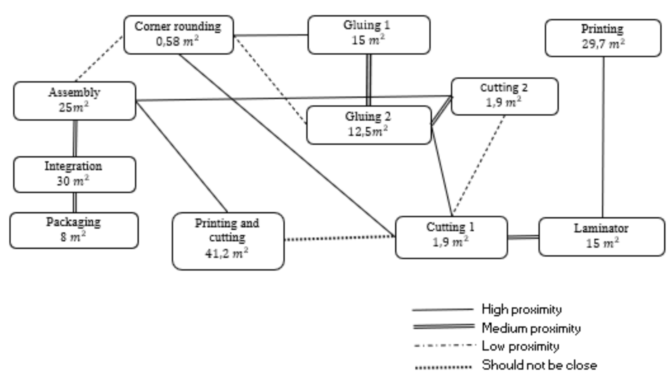


Figure 8. Spatial Relationship Diagram derived from the SLP analysis.

4.2.2 Proposal 1: Process redistribution

The first proposal generated increases in effective working time across several key operations. Specifically, corner rounding, gluing 1, gluing 2, cutting, laminating, binding, and printing, significantly reducing unproductive times (see Figures 9 and 10).

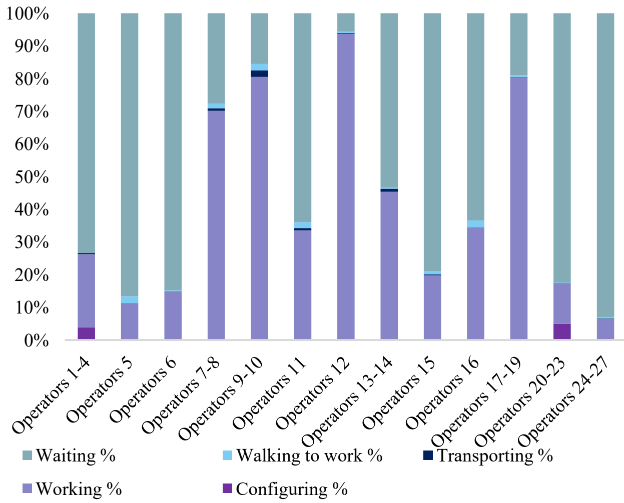


Figure 9. Operator activity distribution in the Proposal 1 simulation after reorganizing high-flow workstations.

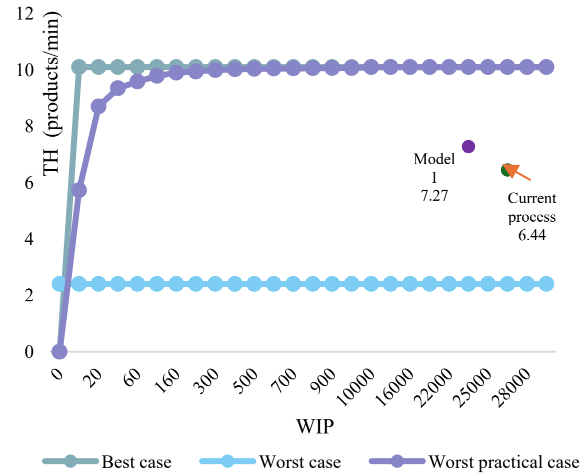


Figure 10. Factory Physics internal benchmarking of Proposal 1, showing an upward performance shift relative to the baseline.

After implementing the proposed improvements in the simulation, internal benchmarking showed quantitative gains in the main key performance indicators, as evidenced in Figure 10. CT decreased to 100.9 minutes, representing a 5.08% improvement. Simultaneously, TH increased to 7.27 products per minute, a 12.88% increase. The most significant change was observed in WIP, with a 19.00% reduction to 22,241 products per day. However, the system status analysis indicates that the production line remains in a low-performance operating zone, highlighting the need for further optimizations.

4.2.3 Proposal 2: Optimized redistribution and automation

Based on the first proposal, a second alternative was developed to reduce the cubic space occupied and transportation by implementing a new machinery layout and automation for internal transfers. Specifically, two conveyor systems were introduced: one in the gluing area and another connecting the integration and packaging stations. These conveyors replaced manual handling activities. According to Stevenson (2021), automated services are increasingly important; automation helps reduce costs, increase productivity, and improve quality and consistency. This proposal enabled increased utilization of critical machines, reaching levels exceeding 90% for gluing and assembly (as shown in Figures 11 and 12).

The results of the internal benchmarking of the selected alternative show a comprehensive optimization of the flow (see Figure 12). The CT was reduced to 97.85 min (an 8.00% improvement), and the TH was increased to 8.06 products/min (a 25.18% increase). The most notable impact is in WIP, with a 29.25% reduction, thereby improving system fluidity. These indicators suggest this proposal as the best solution. Table 1 below presents a comparative analysis of both proposals against the current line's baseline scenario.

The results indicate a substantial improvement in the overall performance of the production system after implementing both improvement proposals. The second alternative stands out for its greater benefits in efficiency, productivity, and operational fluidity. Regarding the distance traveled within the production line, Proposal 1 achieved a 36.91% reduction while Proposal 2 achieved a 39.26% reduction in internal movement. This directly contributes to optimizing material flow and reducing unproductive time. This result shows a notable improvement in the spatial organization of the process. Regarding space utilization, both proposals achieved approximately 4% reduction in occupied volume (3.83% and 3.73%, respectively), indicating a more efficient layout of machinery and workstations. This improvement enhances accessibility, safety, and operational flexibility without compromising production capacity. CT also shows significant reductions in both proposals, with a 5.08% improvement in Proposal 1 and an 8.00% improvement in Proposal 2. This reflects greater synchronization across operations and reduced waiting times, which directly impact the system's responsiveness and overall productivity.

Figure 11. Operator activity distribution in the Proposal 2 simulation, showing a significant reduction in waiting time.

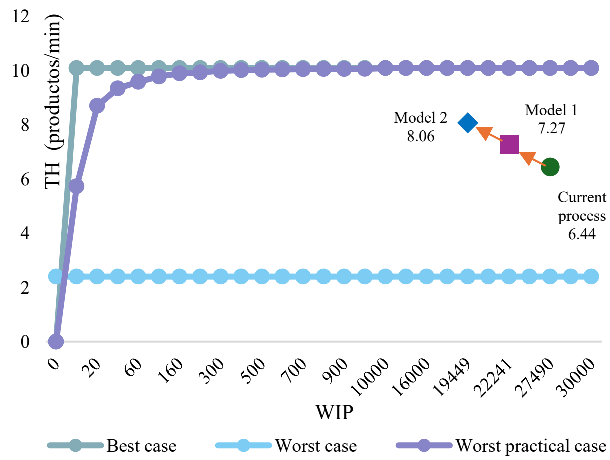


Figure 12. Factory Physics internal benchmarking of Proposal 2, showing a significant upward shift relative to both the baseline and Proposal 1.

Likewise, WIP shows a substantial reduction, especially in the second proposal, where a reduction of 29.25% is achieved. This reflects a more continuous and stable flow, less operational congestion, and better utilization of available resources. Finally, the average daily production rate shows a significant increase of up to 25.18%, confirming the effectiveness of the implemented redistribution and automation strategies. These results confirm that the proposed modifications enable improved system performance without requiring additional production resources. Overall, the results indicate that the second proposal is the best alternative, offering the best balance between productivity, operational efficiency, and work-in-process control (Table 1).

Table 1. Comparison of performance indicators between the current situation and the proposed improvements

Indicator	Current Situation	Proposal 1	Improvement (%)	Proposal 2	Improvement (%)
Distance traveled (m)	298	188	36.91% ↓	181	39.26% ↓
Occupied cubic space	369.50	355.30	3.83% ↓	355.70	3.73% ↓
CT (min)	106.30	100.90	5.08% ↓	97.85	8.00% ↓
WIP (products)	27,490	22,241	19.00% ↓	19,449	29.25% ↓
Daily TH (products/day)	8,500	9,595	12.88% ↑	10,640	25.18% ↑

4.3 AHP-Based selection of the optimal layout

Based on the proposed options and previously obtained results, the AHP was used to select the optimal alternative for redistributing the production line (see Figure 13). This enabled a structured, objective evaluation of alternatives, considering criteria relevant to the company. In this way, the objective of the analysis was to select a new plant layout, evaluating three alternatives: the current situation (A0), the first improvement proposal (A1), and the second (A2). In accordance with the company's strategic criteria, three main evaluation factors were considered: (a) total distance traveled during the production process, (b) the cost of mobilizing the machinery, and (c) the production rate. Once the problem hierarchy was established, pairwise comparison matrices were constructed using Saaty's fundamental scale to determine the relative importance of each criterion (Saaty and Vargas, 2012). The results of the analysis showed that the criterion with the greatest relative weight is the production rate, at 67%, followed by the cost of mobilization and the distance traveled. Next, the alternatives for each criterion were evaluated, and the corresponding eigenvectors were obtained.

Aggregating these results enabled the overall prioritization of the alternatives, showing that the second proposal (A2) has the highest total weighting (61%) and is the best option for redistributing the production line. Although alternative A2 has the highest mobilization cost, its high production rate and significant reduction in internal movement more than offset this investment, guaranteeing substantial improvements in operational efficiency, productivity, and overall system performance. Consequently, the AHP analysis provided a solid, objective basis for decision-making, confirming that the second proposal is the most suitable alternative, offering the best balance among productivity, logistical efficiency, and economic viability (see Figure 14 for a reference to the final simulation). To ensure methodological rigor, the reliability of judgments was assessed by calculating the consistency of each pairwise comparison matrix. For the criteria matrix (production rate, mobilization cost, and travel distance), the maximum eigenvalue (λ_{max}) was 3.045, the Consistency Index (CI) was 0.023, and the Consistency Ratio (CR) was 0.039. Additionally, pairwise comparisons of the alternatives (A0, A1, A2) under each criterion yielded consistency ratios of 4% for distance, 5% for cost, and 8% for production rate. The model's Overall Consistency Ratio was 0.06, which is well below the 0.10 threshold proposed by Saaty, confirming the validity of the assigned priorities and the selection of Alternative 2 is logically consistent.

The magnitude of the improvements obtained in this study compares favorably with results reported in the layout redesign literature. Regarding travel distance, the selected proposal achieved a 39.26% reduction, which is consistent with reductions between 21% and 50% per product line documented in food processing facility redesigns using structured layout frameworks (Wanniarachchi et al., 2016) and substantially exceeds the 14% material movement reduction reported in SLP-based applications for small-scale manufacturing (Goyal & Verma, 2019). Regarding throughput, the selected proposal resulted in a 25.18% increase in daily production, comparable to the 29.4% production capacity gain reported by Gou et al. (2021) using a digital twin-based optimization approach in a welding production workshop, while requiring substantially lower resource and infrastructure levels. Regarding WIP, the selected proposal achieved a 29.25% reduction, which is consistent with prior applications of the same integrated framework in a Bolivian food manufacturing context, where WIP decreased by up to 52% and travel distance by 59% in the most optimized redesign scenario (Herbas-Torrico & Lujan-Sainz, 2024). Collectively, these comparisons confirm that the proposed methodology delivers competitive operational improvements while remaining accessible to SMEs in developing economies.

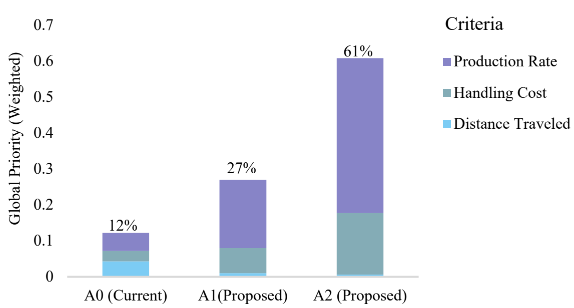


Figure 13. Comparative performance indicators and AHP-based global priority weights for the baseline process and layout proposals.

Figure 14. Siemens Tecnomatix simulation model of Proposal 2, reflecting the optimized spatial configuration.

5. Conclusion, recommendations, and limitations

Our study shows that substantial operational improvements in manufacturing SMEs are attainable through a structured, low-cost, and replicable methodology, without the need for complex mathematical models, proprietary software, or large capital expenditures. By integrating time studies, Discrete-Event Simulation (DES), Factory Physics, SLP, and the AHP into a single coherent framework, the proposed approach addresses a persistent gap in the industrial engineering literature: the lack of integrated multi-method studies that translate classical layout theory into measurable, validated outcomes for resource-constrained manufacturing environments.

The results are clear. The selected alternative achieved a 25.18% increase in daily throughput, a 39.26% reduction in travel distance, a 29.25% decrease in WIP, and an 8% improvement in cycle time, all without introducing new production resources. These figures confirm that the system transitioned from low performance to a much more efficient configuration. It is important to note that these improvements were achieved without resorting to advanced or expensive optimization methods. The Facility layout literature documents a range of sophisticated approaches (Matai, 2015; Perez-Gosende et al., 2021; Gou et al., 2021) that have demonstrated strong performance in manufacturing environments. However, as Perez-Gosende et al. (2021) and Kikolski and Ko (2018) note, these methods typically require specialized computational infrastructure, real-time sensor integration, or advanced technical expertise that SMEs in developing economies rarely possess (Bakhtiari et al., 2020). The present study claims that comparable operational improvements are attainable through a structured integration of classical engineering tools, without proprietary platforms or algorithmic complexity. This finding is further reinforced by prior evidence from a Bolivian food manufacturing context, where the same integrated framework yielded cycle time reductions and WIP decreases across different redesign scenarios (Herbas-Torrico & Lujan-Sainz, 2024), confirming the transferability and practical value of this approach across different SME sectors and industrial contexts. The application of Factory Physics in layout redesign is a key focus of this work. Although it is a well-established production methodology (Hopp & Spearman, 2011), its practical use for diagnosing and comparing scenarios during a layout design or improvement allows plant managers to see how spatial decisions directly affect flow and inventory, something that the SLP method alone does not enable with such precise visualization.

Despite these considerations, the study offers a focused and effective application of the proposed methodology. The model was implemented on a single production line within a single company, allowing the analysis to remain focused and directly aligned with the organization's immediate operational needs. Given the available time and the objective of generating a timely economic benefit, the study appropriately prioritized the product with the highest demand. Likewise, the new design was successfully adapted to the available space and integrated with the locations of other installed lines, ensuring continuity in overall operations. For future work, this methodology could be extended to settings with multiple products, across manufacturing sectors, and in diverse developing-country contexts, including Latin America, Sub-Saharan Africa, and South Asia. Furthermore, future research should incorporate a sensitivity analysis to assess how fluctuations in demand, processing times, transport speeds, or operator availability impact system performance. In addition, rather than relying on complex technological solutions, the next stage could examine how Lean Manufacturing principles may further strengthen and complement this approach.

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