

Integrated Improvement Model with MRP, HEIJUNKA and SLP to Enhance Fill Rate and Profitability in a Peruvian Food SME

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Abstract

Small and medium-sized enterprises (SMEs) in Peru's food sector face persistent profitability constraints arising from inefficient planning, elevated inventory costs, and unbalanced production processes. This study proposes an integrated improvement model that combines Material Requirements Planning (MRP), Heijunka (production leveling), and Systematic Layout Planning (SLP) in a gluten-free bakery SME. Empirical data from 2022 to 2024 reveal that labor accounted for 49.4% of total costs, the average production time per batch (24 jars) was 2.0 hours, and the unit fill rate reached only 54.6%, highlighting substantial operational inefficiencies. The proposed model is designed to improve inventory management through MRP, enhance labor efficiency via Heijunka, and shorten production cycles by implementing SLP. Validation conducted with Arena-based discrete-event simulation projects significant improvements in fill rate, production time per batch, labor cost share, and gross margin, consistent with industry benchmarks. Specifically, the analysis forecasts an increase of up to 22 percentage points in gross margin and an improvement of up to 33 percentage points in unit fill rate. Overall, the findings demonstrate the feasibility of integrating these tools into resource-constrained SMEs, thereby strengthening competitiveness and supporting sustainable growth in the food sector.

Keywords

MRP, Heijunka, SLP, Food Industry, SME, Fill rate, Profitability.

1. Introduction

Small and medium-sized enterprises (SMEs) are the backbone of Peru's manufacturing sector, driving employment and growth but struggling with low profitability, high costs, and inefficient planning (Arias-Robles et al., 2022). In the food industry, these issues intensified due to demand variability, raw material costs fluctuations, and limited financial capacity for technological investment (Handayani & Winarningsih, 2020). Consequently, SMEs face overstocking, high labor costs, poor layouts, and low service levels, undermining competitiveness and sustainability (Koundouri et al., 2022). Enhancing profitability and operational efficiency is thus vital for long-term survival.

Inventory management is a key driver of operational and financial performance. Empirical evidence indicates that Material Requirements Planning (MRP) stabilizes the availability of raw materials, reduces forecast error, and mitigates stockouts and overstocks (Collao-Díaz et al., 2024; Nurprihatin et al., 2021). Integrated with profitability analysis, it lowers inventory costs and raises gross margins in food firms (Vargas-Ruiz et al., 2023; Susanti, 2020). Labor productivity and balanced production scheduling are also critical. Tools like Heijunka reduce variability, align workloads to takt time, and improve schedule adherence (Perdana et al., 2018; Jaico-Carranza & Olivos-Valdivia, 2024). Moreover, facility layouts further affect efficiency, poor layouts designs increase transportation times and

bottlenecks, while Systematic Layout Planning (SLP) enhances labor productivity and reduces material-handling time (Casallo et al., 2022; Huarcaya-Meléndez & Platero-Mamani, 2023).

The case company, a Peruvian SME specialized in gluten-free cookies, increased sales by 53% from 2023 to 2024, but achieved only a 4.6% gross margin. Main issues were 54.6%-unit fill rate, labor costs of 49.4% expenses, and production times of 2.0 hours per 24-jar batch. To address these inefficiencies, the study proposes an integrated model combining MRP, Heijunka, and SLP, validated through Arena-based discrete-event simulation, to reduce costs, optimize resources, and financial impact assessment.

1.1 Objectives

The main objective is to improve the company's operational performance, specifically targeting the unit fill rate and gross margin, by identifying the main drivers of low productivity, high costs, and limited profitability. To support this goal these specific objectives are pursued: (1) design and specify an integrated improvement model based on MRP, Heijunka, and SLP; (2) validate the impact on key performance indicators (KPIs) - inventory cost, labor cost share, production time per batch, unit fill rate, and gross margin - through discrete event simulation comparing the as-is and to-be scenarios; and (3) demonstrate the practical relevance of these tools in an SME food-sector context, showing that operational improvements can be achieved for resource-constrained firms.

Aligning with the objectives - improving fill rate, reducing cost, and increasing profitability - this study addresses three research questions (RQs): RQ1: How do MRP-based production plans enhance fill rate in SMEs facing variable demand? RQ2: What is the effect of Heijunka on labor productivity and labor cost share in resource-constrained SMEs? RQ3: Does SLP-based layout redesign improve throughput and profitability? Together with the application of discrete-event simulation and a scientific design approach, these research questions shaped the methodological framework of the study.

2. Literature Review

The literature review was organized into thematic categories to highlight how different tools and approaches have been applied in food-sector SMEs. This structure avoids a paper-by-paper recount and instead groups find their relevance to the study's objectives.

This research draws on seven streams of literature that inform our design: (i) Food & lean — waste reduction and cycle-time improvements through methods such as Kanban, value stream mapping (VSM), and standard work, which have been shown effective in SMEs for optimizing order fulfillment and reducing bottlenecks (Perdana et al., 2018; Perez-Canchanya et al., 2023). Recent evidence from a systematic review confirms that Lean tools in food companies reduce inventories, shorten setup times, and increase productivity, consolidating their relevance in SMEs (Cusiado et al., 2024); (ii) Food & profit — financial benchmarks for gross margin and return indicators in food firms, with studies reporting sector-average gross margins around 25%, highlighting that profitability depends on efficient cost management (Handayani & Winarningsih, 2020; Arias-Robles et al., 2022); (iii) Food & MRP — inventory control and lot-sizing strategies to stabilize material availability, reduce stockouts/overstocks, and improve order fulfillment, with evidence from bakery and snack SMEs (Nurprihatin et al., 2021). Additional applications integrating MRP with Lean, MPS, and TPM in bakery SMEs report significant reductions in losses and inventory costs (Villanueva et al., 2024); (iv) Food & profit & MRP — planning models that link material requirements with financial outcomes, reducing inventory costs and improving gross margins, with reported reductions of 40–48% in raw material costs (Vargas-Ruiz et al., 2023); (v) Food & Heijunka — production leveling and takt-based balancing to improve schedule adherence, reduce variability, and increase labor productivity, with applications in food SMEs reporting shorter cycles, reduced work-in-progress (WIP), and better compliance (Alvarez et al., 2024; Abed et al., 2024); (vi) Food & SLP — facility rearrangements that lower material-handling time and internal logistics inefficiencies, improving productivity, space utilization, and reducing internal transport distances, particularly in Peruvian food firms (Huarcaya-Melendez & Platero-Mamani, 2023).

Complementary evidence shows that combining SLP with Lean tools (5S, TPM, Kanban) improves productivity and OEE in SMEs, with reported increases of up to 16% in efficiency (Arroyo-Vega et al., 2024). ; and (vii) Food & MRP & fill rate — studies highlighting fill rate as a critical service-level indicator in the food industry, where improvements in inventory management and production planning directly enhance order fulfillment performance and customer satisfaction (Collao-Díaz et al., 2024). In parallel, Lean Warehouse models integrated with DDMRP demonstrate

similar benefits, raising on-time delivery rates from 35% to 80% and underscoring the importance of material planning in service-level performance (Sotelo & Raymundo, 2024).

Collectively, these streams underscore benefits such as shorter changeovers and lead times, higher fill rates, and improved schedule adherence, which align with the objectives of this research.

3. Methods

The research follows a design–science approach comprising four stages: diagnosis, design, conceptual implementation, and evaluation. The diagnosis identified operational inefficiencies such as excess inventories, low unit fill rate, and long production cycle times. The design stage selected three tools—MRP, Heijunka, and SLP—based on the literature review and company needs. The conceptual implementation translated each tool into operational models, while the evaluation used Arena-based discrete-event simulation to compare the as-is and to-be scenarios. The model was calibrated against baseline KPIs, including inventory cost, labor cost share, production time per batch, unit fill rate, and gross margin, as detailed in Section 3.1. Figure 1 depicts the integrated improvement framework that links the diagnostic phase, technical modules, and performance indicators.

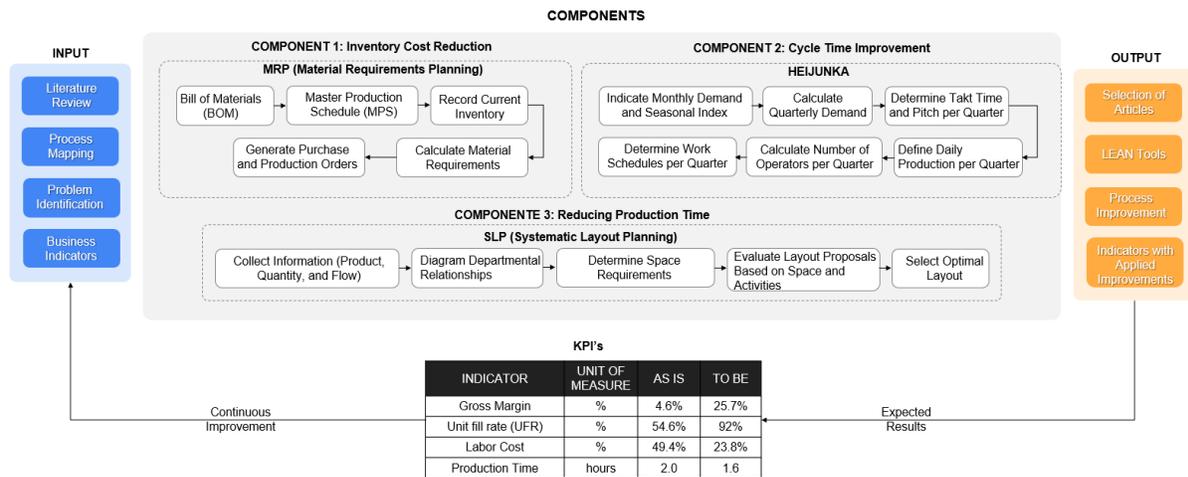


Figure 1. Integrated improvement model combining MRP, Heijunka, and SLP with expected KPIs

3.1. Diagnostic framework

A process-mapping exercise was conducted for the product (biscotti cookies), covering activities from raw-material receiving to finished-product storage. Historical data showed that between 2023 to 2024, revenues increased by 53%; however, despite this growth, the gross margin was only 4.6%, highlighting persistent profitability issues. Baseline KPIs revealed a unit fill rate of 54.6%, labor accounting for 49.4% of total costs, and an average production time of 2.0 hours per 24-jar batch. These inefficiencies—excess inventories, workload imbalances, and layout constraints—were synthesized into a problem tree, which formed the basis for designing the integrated improvement model.

3.1.1. MRP module

The MRP module was developed using the bill of materials (BOM), safety stock levels, supplier lead times, and a seasonally adjusted demand forecast. Based on these inputs, the system generated a master production schedule (MPS), planned order releases, and updated inventory projections.

The primary objective of this module was to improve unit fill rate by aligning raw-material availability with demand requirements. The baseline unit fill rate is 54.6%, with order receipts delayed by up to one half-month due to make-to-order policy in which sales are consolidated biweekly, and a production order is then issued. To improve demand planning and fulfill orders within the same half-month in which they are placed, MRP procedure is applied. In addition, the company's production plan compliance in 2024 was only 89.2%. Table 1 shows that the compliance rate reflects the gap historically observed between projected and actual production in 2024, when only 2,184 jars were produced against a projected plan of 2,448 jars. Incorporating this value ensures that the simulation captures the production variability typical of resource-constrained SMEs, rather than relying on an arbitrary assumption.

Table 1. Comparison between batch production and production plan

| Period | 1st month | 2nd month | 3rd month | 4th month | 5th month | 6th month | 7th month | 8th month | 9th month | 10th month | 11th month | 12th month | TOTAL |
|-----------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|------------|------------|-------|
| Batch production | 168 | 120 | 120 | 144 | 168 | 192 | 216 | 192 | 216 | 216 | 216 | 216 | 2,184 |
| Production Plan (Projected) | 168 | 192 | 192 | 192 | 192 | 216 | 216 | 192 | 216 | 240 | 216 | 216 | 2,448 |

This implies that just 89.2% of planned order receipts are available in the current half-month, while the remaining 10.8% is deferred as late receipts (LR) to the subsequent period. As a result, each planned order receipt is divided between timely receipts and late receipts, directly affecting the calculation of available inventory and the unit fill rate. MRP setup (Q1-2024, SKU: Chocolate and pecan biscotti cookies). Parameters: safety stock (SS) = 14 jars, lot size (Q) = 24 jars, lead time (LT) = 1 half-month. For period t (half-month), let GR be gross requirements, SR schedule receipts, LT late receipts, FI final inventory, II initial inventory, NR net requirements, OR order receipts and OL order releases. The MRP logic is formalized as follows:

$$FI(t) = II(t) + SR(t) + OR(t) - GR(t)$$

$$NR(t) = \max(0, GR(t) + SS - (II(t) + SR(t)))$$

$$OR(t) = (NR(t) / Q) * Q$$

Order releases are defined as $OL(t-1) = OR(t)$ (since $LT = 1$)

Because $LT = 1$, each period's order receipt corresponds to order release of the immediately preceding half-month. Nonetheless, given the 89.2% compliance rate, only the proportion of $OR(t)$ is received on time, with the remainder carried forward as $LR(t+1)$. Table 2 presents the resulting MPR for the first quarter of 2024 under these parameters.

Table 2. Calculation of net requirements and order releases for first quarter

| Period | Start | 1st half - Month 1 | 2nd half - Month 1 | 1st half - Month 2 | 2nd half - Month 2 | 1st half - Month 3 | 2nd half - Month 3 |
|----------------------------------|-------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| Gross requirements (OR) | 0 | 17 | 117 | 13 | 110 | 21 | 113 |
| Schedule receipts (SR) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Late receipts (LR) | 0 | 0 | 0 | 13 | 3 | 10 | 3 |
| Available inventory (final) (FI) | 29 | 12 | 2 | 23 | 2 | 12 | 0 |
| Net requirements (NR) | 0 | 0 | 112 | 5 | 91 | 16 | 105 |
| Order receipts (OR) | 0 | 0 | 120 | 24 | 96 | 24 | 96 |
| Order releases (OL) | 0 | 120 | 24 | 96 | 24 | 96 | 48 |

For each half-month, unit fill rate is calculated as jars fulfilled, defined as the minimum between the gross requirements and the sum of the order receipts and the initial inventory. The result is then divided by gross requirements, yielding unit fill rate for that period. To obtain the annual unit fill rate, the total number of jars fulfilled and the total gross requirements across the 24 half-months periods are aggregated. Finally, dividing these two quantities yields an annual unit fill rate of 87.4% (+32.8 percentage points), while planned order receipt compliance remains 89.2%, highlighting the trade-off between production reliability and customer service level.

3.1.2. HEIJUNKA module

The Heijunka module balanced production workloads by calculating takt time and pitch from demand data and translating them into a leveled daily production schedule. Standard work principles and line-balancing techniques were applied to distribute tasks evenly across workstations, thereby reducing variability and stabilizing WIP. The

entire production process is jointly performed by three operators. A production time of 2.0 hours is required to obtain 24 jars (equivalent to one production day), and under these conditions, it may be inefficient for all three operators to work simultaneously. Furthermore, labor costs are increased, and unnecessary expenses are incurred.

This hypothesis was evaluated through the application of the Heijunka method and its assessment within the work cell. Importantly, the calculation of required number of operators was not based on a static assumption; quarterly demand variability was explicitly incorporated into takt time analysis, ensuring that the estimation reflects realistic production requirements.

Table 3 presents the calculation of the required number of operators per quarter. The procedure begins with the identification and aggregation of value-adding activities (VAT) within the production process per jar, which amounts to 1.5 minutes per unit. Subsequently, the quarterly takt time is determined by dividing the monthly demand for each quarter by the average available production time per month, calculated as the product of the net daily working hours (total working hours minus break time) and the average number of production days per month (four). Finally, the ratio of the VAT and the takt time is computed, and the results are rounded up to determine the exact number of operators required, which corresponds to one operator for the entire year.

Table 3. Number of operators per quarter

| Concept | 1st Quarter | 2nd Quarter | 3rd Quarter | 4th Quarter |
|-----------------------------|-------------|-------------|-------------|-------------|
| VAT (minutes/jar) | 1.5 | 1.5 | 1.5 | 1.5 |
| Takt time (minutes/jar) | 14.6 | 11.3 | 9.7 | 9.4 |
| Number of operators | 0.1 | 0.1 | 0.2 | 0.2 |
| Rounded number of operators | 1.0 | 1.0 | 1.0 | 1.0 |

Although the company employs seven operators, only three participate in this process. Workload analysis confirmed that a maximum daily batch of four lots (24 units each) requires about eight hours of effective work, which is sufficient for a single operator. To ensure that this adjustment does not create operational risks, a multi-skilling policy is recommended so that all operators are trained to handle different product varieties, thereby ensuring flexibility and coverage in case of absenteeism. Thus, the proposal to assign one operator is not an oversimplified calculation but rather a decision grounded in demand variability analysis, workload leveling, and efficient resource utilization. Moreover, this scenario remains preliminary, as further cycle time reductions are expected from the SLP-based layout improvement, reinforcing both the feasibility and the impact of the adjustment.

3.1.3. SLP module

The SLP module analyzed interdepartmental material flows across mixing, baking, cooling, decorating, packaging, and storage operations. An activity-relationship chart (ARC) was used to generate layout alternatives, which were assessed with a weighted multi-criteria scoring system considering distance, adjacency, supervision, food-safety zoning, and scalability. The selected layout minimized material-handling and internal transportation, thereby decreasing production time. Figure 2 presents the ARC in a tabular form, which served as the foundation for graphical representations and layout redesign. This chart represents the proximity requirements among workstations, using standard codes (A = Absolutely necessary, E = Especially necessary, I = Important, O = Ordinary, U = Unimportant, X = Undesirable). Each relationship is represented by a specific color and number of lines: A (red, 4 lines), E (yellow, 3 lines), I (green, 2 lines), O (blue, 1 line), U (no line), and X (orange, zigzag). In addition, the motives for each assigned relationship include material flow (code 1), prevention of shape or temperature changes (code 2), process sequence (code 3), process supervision (code 4), and relative location flexibility (code 5).

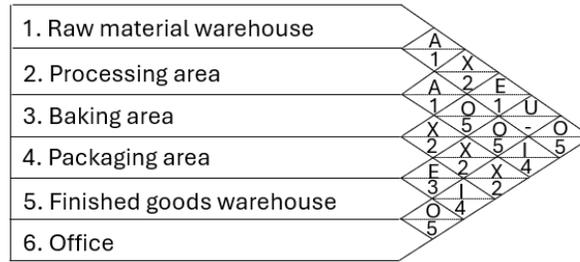


Figure 2. Activity-relationship chart (ARC) - Tabular form

Table 4 presents considerable distances between the raw material warehouse and processing area (10,61 m), the baking and packaging area (9,44 m), and the packaging area and finished goods warehouse (10,95 m), which generates inefficiencies in material flow. The proposed layout mitigates this issue by relocating only the raw material warehouse and packaging area, achieving a 12% reduction in total distance. The ARC (Figure 2) also indicates that the finished goods warehouse and office must remain adjacent to facilitate supervision, while the processing and baking areas stay fixed, as the oven depends on air duct access, fixed utilities, and zoning standards to ensure safety and continuity.

Table 4. Distance between areas (in meters)

| Distance between Areas | Raw material warehouse → Processing Area | Processing area → Baking area | Baking area → Packaging area | Packaging area → Finished goods warehouse | TOTAL |
|------------------------|--|-------------------------------|------------------------------|---|-------|
| Actual layout | 10,61 | 1,76 | 9,44 | 10,95 | 32,76 |
| Proposed layout | 8,33 | 1,76 | 8,68 | 10,12 | 28,89 |

Figure 3 and Figure 4 present the current and proposed layouts, respectively. In both, the process follows these steps: (1) Raw materials are retrieved from the warehouse and transported to the kitchen area. (2) Ingredients are weighed on a type-01 table using a precision scale. Then they are mixed in an industrial mixer and transferred to a type-02 table, where kneading is carried out. The resulting dough is processed through a dough sheeter and subsequently transferred to another type-02 table, where it is arranged on trays and cut into cookies measuring 5 cm x 5 cm. Whenever dough imperfections are identified, the dough must be reprocessed. (3) Cookies are baked in the oven and cooled on tray rack trolleys. (4) At a type-03 table, jars are labeled. Once the labeling process is completed, cookies are placed into jars on a type-02 table. (5) Finally, the jars are transferred to the finished goods warehouse.

Unlike the current layout, the proposed layout relocates the raw materials warehouse between the electrical room and the finished goods warehouse. In the processing area, tables and machines are reorganized in sequence: type-01 table → mixer → type-02 table → dough sheeter → another type-02 table. Finally, the packaging area is relocated between the washing station and the restroom. In addition to these improvements, further efficiencies are achieved through the evaluation and reduction of value-adding and non-value-adding activities. This assessment revealed idle periods during cookie cooling, which can be used for tasks such as labeling jars. With these changes, together with the improved layout, transportation times are reduced, idle times are optimized, and the production flow becomes more streamlined, resulting in an overall reduction of 0.4 hours in production time

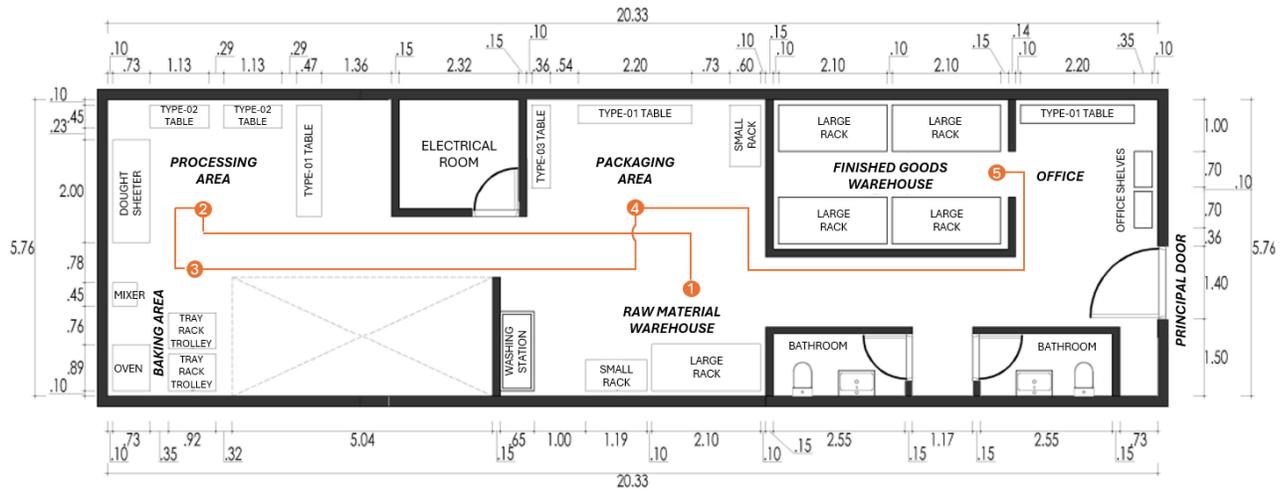


Figure 3. Actual layout - Scale 1:130

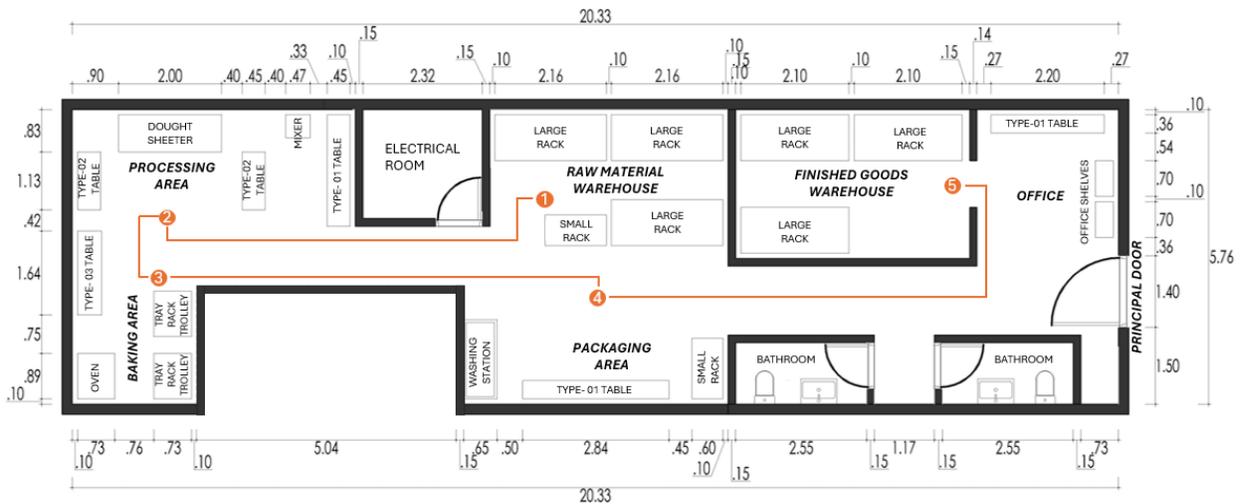


Figure 4. Proposed layout - Scale 1:130

4. Data Collection

Operational data from 2022 to 2024 were collected to evaluate the company's performance and supply inputs to the proposed model. Historical records included monthly sales, raw-material consumption, inventory levels, and cost structures. On-site time studies for mixing, baking, cooling, decorating, and packaging measured production cycle times and labor allocation, confirming that the maximum 24-jar batch required 2.0 hours of processing time. The collected data was mapped to each module of the integrated model. The MRP module used BOM, safety stocks, supplier lead times, and a seasonally adjusted demand forecast. The Heijunka module calculated takt time and pitch from demand data and translated them into a leveled daily output schedule, while labor allocation records supported line balancing efforts. For the SLP module, material flows and ACR were developed from observed movements and space needs. These data also defined baseline KPIs (Table 5) and calibrated the Arena-based discrete-event simulation model, ensuring that the as-is scenario accurately reproduced current operating conditions.

Table 5. Baseline key performance indicators (as-is scenario)

| Indicator | Value |
|---------------------------|-----------|
| Gross Margin | 4.6% |
| Labor cost share | 49.4% |
| Production time per batch | 2.0 hours |
| Unit fill rate | 54.6% |

5. Results and Discussion

This section presents the results of the proposed improvement model and discusses them in four parts. First, the numerical analysis compares the baseline and improved scenarios. Second, graphical analysis illustrates the relative magnitude of improvements across key performance indicators. Third, the proposed improvements are discussed with reference to the contributions of MRP, Heijunka, and SLP. Finally, validation through Arena-based discrete-event simulation supports the reliability of the projected outcomes.

5.1 Numerical and Graphical Results

The numerical analysis quantifies the performance gap between the baseline and the improved scenarios. Initially, the company exhibited low profitability, high labor intensity, long production cycle times, and a critically low unit fill rate.

After applying the integrated model, all KPIs improved. As shown in Table 6, gross margin rose from 4.6% to 26.1% (+21.5 percentage points), nearing the sector benchmark of 25.7%. Labor cost share fell from 49.4% to 41.9% (-7.5 percentage points), supported by workload leveling. Production time per batch decreased from 2.0 to 1.7 hours (-0.3 hours, -15%), enhancing throughput. Finally, the unit fill rate jumped from 54.6% to 87.4% (+32.8 percentage points), demonstrating a significant improvement in order fulfillment and service level (Figure 5).

Table 6. Detailed comparison of as-is, to-be and achieved KPIs, including absolute values and relative improvements

| Indicator | As-is | To-be | Achieved | Δ Improvement |
|---------------------------|-----------|-----------|-----------|----------------------|
| Gross Margin | 4.6% | 25.7% | 26.1% | +21.5% |
| Labor cost share | 49.4% | 34.2% | 41.9% | -7.5% |
| Production time per batch | 2.0 hours | 1.6 hours | 1.7 hours | -0.3 hours (-15%) |
| Unit fill rate | 54.6% | 92% | 87.4% | +32.8% |

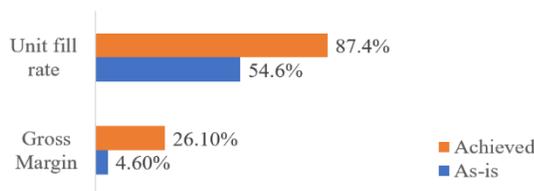


Figure 5. Performance comparison of KPIs under as-is conditions versus achieved simulation results

5.2 Proposed Improvements

Figure 6 presents the proposed methodological framework, which integrates MRP, Heijunka, and SLP to improve KPIs. To highlight the contribution of each tool, Table 7 summarizes the expected improvements by module.

Table 7. Except improvements by module

| Tool | Main improvement | Indicator improved | Result |
|------------------|--|--------------------|---------------|
| MRP | Aligns material planning with demand | Unit fill rate | 54.6% → 87.4% |
| HEIJUNKA | Balances workloads, standardizes tasks | Labor cost share | 49.4% → 41.9% |
| SLP | Optimize layout, reduces distances | Production time | 2.0 → 1.7 |
| Integrated model | Synergistic application of tools | Gross margin | 4.6% → 26.1% |

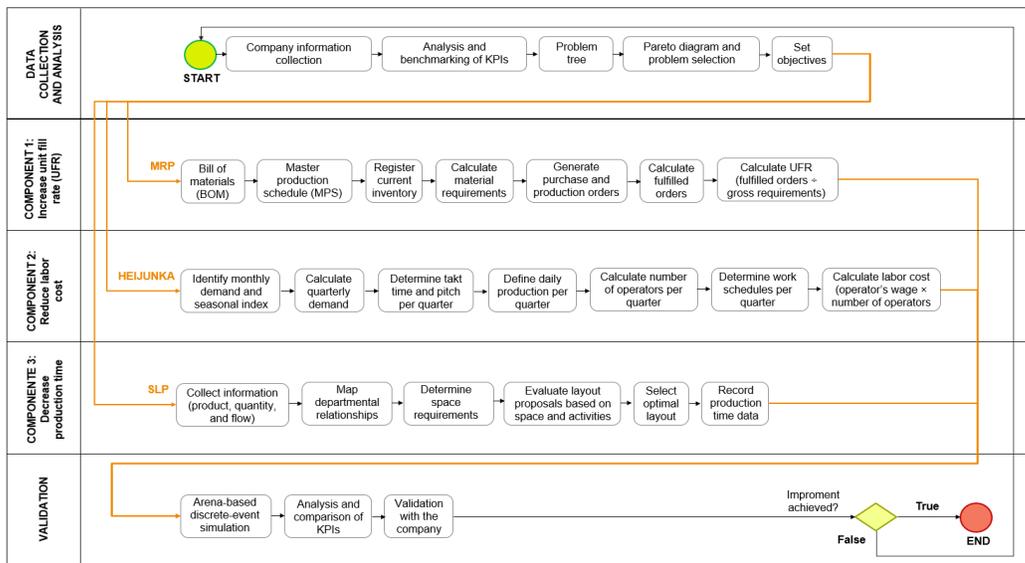


Figure 6. Methodological framework for production process improvement

The results of the to-be scenario demonstrate how the proposed tools addressed the structural inefficiencies identified during the diagnosis phase. The company initially suffered from excess inventories, experienced-based production planning, long production cycle times, and a critically low unit fill rate. By integrating MRP, Heijunka, and SLP, these issues were systematically addressed.

The MRP module provided a structured approach to inventory management. By combining the BOM, safety stock policies, supplier lead times, and seasonal demand forecasts, the model generated planned order releases that reduced overstocks and stockouts. This improvement not only optimized raw material utilization but also increased the unit fill rate from 54.6% to 87.4% (+32.8 percentage points), demonstrating that improved material planning directly enhances service level and customer satisfaction. The Heijunka module leveled production by synchronizing workloads with takt time and pitch. Through balanced task allocation and standardized work, variability was reduced and schedule adherence improved. As a result, labor cost share decreased from 49.4% to 41.9% (-7.5 percentage points), while production time per batch fell from 2.0 to 1.7 hours (-0.3 hours, -15%). These outcomes highlight the role of workload leveling in both increasing labor efficiency and stabilizing throughput. The SLP module focused on the facility layout and physical arrangement of resources. By analyzing interdepartmental flows and ARCs, alternative layouts were evaluated, and the selected option minimized transport distances and improved adjacency among high-affinity processes. This reconfiguration reduced overall production cycle time, facilitated supervision, and enabled scalability.

Layout optimization increased throughput and contributed to the increase in gross margin. The integration of MRP, Heijunka, and SLP proved to be a coherent and practical improvement model for SMEs in the food sector. MRP enhanced supply reliability and supported owner-managers in evaluating a strategic shift from make-to-order to make-to-stock policies, thereby increasing the fill rate and improving responsiveness. Heijunka contributed to higher labor productivity by balancing workloads and reducing labor costs, offering a cost-effective alternative to workforce

expansion. Meanwhile, SLP optimized process flow and space utilization, showing that layout reorganization can enhance capacity and supervision with minimal investment.

As a result, the fill rate rose from 54.6% to 87.4% and the gross margin from 4.6% to 26.1% (+21.5 percentage points), aligning performance with sector benchmarks. Beyond these numerical gains, the findings demonstrate that even in resource-constrained SMEs, the strategic application of industrial-engineering and lean tools provides owner-managers with a practical framework for making informed decisions, improving efficiency, service levels, profitability, and laying the foundation for greater competitiveness and sustainable growth.

5.4 Validation

The integrated model was validated via Arena-based discrete-event simulation, contrasting the as-is and to-be scenarios. The simulation model incorporated BOM, safety stock levels, supplier lead times, seasonal demand forecast, time studies, and resource availability. Calibration ensured that the baseline scenario accurately reproduced the current KPIs, namely gross margin (4.6%), labor cost share (49.4%), production time per batch (2.0 hours), and unit fill rate (54.6%). The to-be scenario corroborated the expected improvements, supporting the effectiveness of the proposed tools. Figure 8 presents the proposed model via Arena-based discrete-event simulation. The simulation model developed in Arena represents the company’s production system through three interconnected layers. The planning layer integrates lot sizing, evaluation of monthly and biweekly demand, and initialization of safety stock and starting inventories, enabling a realistic representation of supply and production requirements. The process layer models the production sequence, including key activities such as weighing, mixing, kneading, rolling, cutting, baking, cooling, packaging, and labeling. Each activity is represented through queues, resource allocation (operators, balance, mixer, laminator, and oven), and processing times derived from time studies and direct observation.

The model also accounts for the reprocessing of nonconforming units, reflecting actual shop-floor practices and production inefficiencies. The results layer consolidates daily and monthly production data, computes key performance indicators (KPIs) such as fill rate, production time per lot, labor cost share, and gross margin, and generates output files for comparative scenario analysis. Validation was carried out by contrasting the as-is simulation outcomes with historical company data. The model replicated that a batch of 24-jars required on average 2.0 hours of processing, that the fill rate remained at critical levels, and that labor accounted for 49.4% of total costs. These results confirm that the simulation reliably reproduces the current operating conditions and provides a robust baseline for evaluating the impact of the proposed improvements using MRP, Heijunka, and SLP (Figure 7).

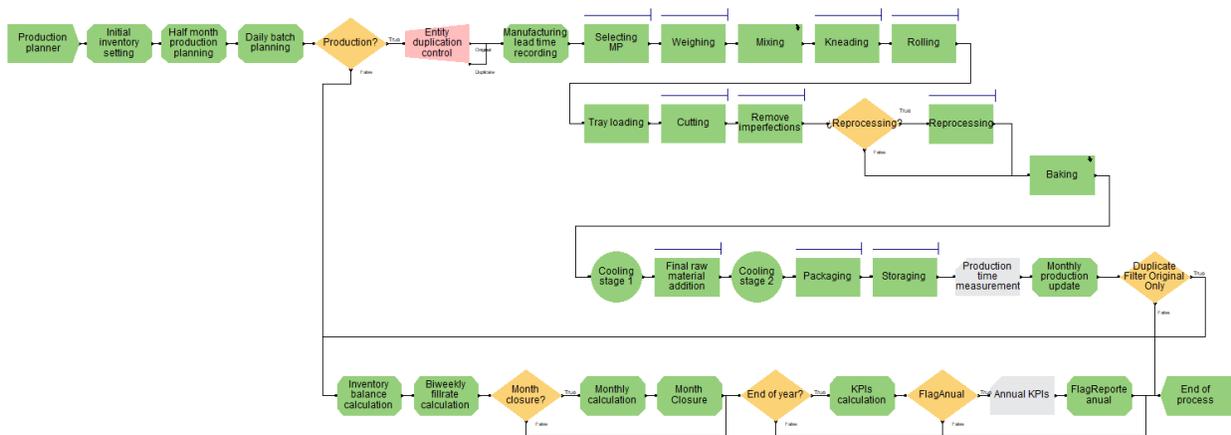


Figure 7. Proposed model

Figure 8 shows the 95% confidence intervals of the gross margin across as-is and achieved scenarios. In the as-is scenario, the baseline mean gross margin is 4.6%, whereas in the achieved scenario the mean is 26.1%. The non-overlapping intervals indicate a substantial and statistically significant improvement in gross margin following the proposed production process adjustments.



Figure 8. 95% Confidence Intervals of the Gross Margin: As-is vs. Achieved Scenarios

Figure 9 presents the 95% confidence intervals for the unit fill rate under the as-is and achieved scenarios. The as-is mean is 54.6%, indicating an inadequate demand fulfillment. In contrast, the achieved scenario reaches 87.4%, approaching the project's 92% sector benchmark. The clear separation between the intervals further emphasizes the effectiveness of the proposed strategy.



Figure 9. 95% Confidence Intervals of the unit fill rate: As-is vs. Achieved Scenarios

6. Conclusion

The research achieved improvements in the operational performance of a Peruvian food-sector SME. The most notable results were the increase in unit fill rate from 54.6% to 87.4% (+32.8 percentage points) and the improvement in gross margin from 4.6% to 26.1% (+21.5 percentage points), demonstrating a clear strengthening of service levels and profitability.

The study also identified and addressed critical inefficiencies, such as high labor cost share, long production cycle times, and imbalances in resource utilization. By integrating MRP, Heijunka, and SLP into a coherent framework, a conceptually robust improvement model was developed and tested.

Arena-based discrete-event simulation validated the model's effectiveness: in addition to gains in fill rate and gross margin, labor cost shared decreased from 49.4% to 41.9% (-7.5 percentage points) and average production time per batch was reduced from 2.0 to 1.7 hours (-15%). These results confirm the model's capacity to simultaneously enhance efficiency, cost performance, and service reliability.

In relation to RQs, the findings provide clear answers. MRP-based production plans increased the unit fill rate by 32.8 percentage points, validating their effectiveness in context of variable demand (RQ1). Heijunka reduced the labor cost share by 7.5 percentage points and enhanced workforce productivity through workload leveling, demonstrating a feasible alternative to workforce expansion in resource-constrained SMEs (RQ2). Likewise, the facility layout redesign using SLP shortened average production time per batch by 15% and optimized space utilization, which not only improved throughput but also lowered unit production costs, thereby contributing directly to the gross margin increase from 4.6% to 26.1% (RQ3). Collectively, these outcomes demonstrate that the integrated model not only fulfills the research objectives but also provides practical managerial guidance for SMEs.

This study was conducted in a single case study of a Peruvian SME specialized in gluten-free bakery products. Therefore, the findings may not be fully generalizable to other SMEs or industries with different production processes, resources constraints or other product characteristics.

Future studies could extend the model to multiple SMEs across diverse food sectors and other manufacturing industries, thereby testing its broader applicability. Moreover, the integration of digital tools - including Enterprise

Resource Planning (ERP) systems and Internet of Things (IoT) technologies - could strengthen data integration, enhance real-time monitoring, and support most-accurate decision making. Lean practices like 5S methodology could complement the model by enhancing workplace organization and sustain efficiency gains in resource-constrained SMEs. Finally, the adoption of Industry 4.0 innovations - such as smart manufacturing - offers a valuable opportunity to scale the integrated model toward more resilient and fully digitalized production systems.

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