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CASE STUDY

Enhancing inventory accuracy in dairy industries: integrating DMAIC and action research for optimizing logistics performance

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ABSTRACT

Goal: The goal is to analyze the application of Lean Six Sigma and DMAIC in the inventory management of a dairy industry, aiming to optimize inventory accuracy, reduce picking errors, and enhance OTIF performance, thereby improving overall operational efficiency.

Design / Methodology / Approach: This applied and descriptive research adopts an action research strategy, with researchers actively participating in the project's execution. Lean Six Sigma principles and the DMAIC framework were systematically applied to inventory, picking, and supply processes. Statistical validation was conducted using the Z-test for two proportions to confirm the effectiveness of the improvements implemented.

Limitations of the investigation: The study focuses on a case analysis in a dairy processing environment; however, the structured methodology adopted allows replication in industries characterized by operational complexity, perishability, or high inventory turnover.

Practical implications: The study offers valuable insights for logistics, procurement, and operations professionals. The implemented methodologies led to a 36.63% reduction in inventory discrepancies, resulting in cost savings of R$124,540.56. Additionally, significant improvements were achieved in controlling picking errors and enhancing OTIF performance, underscoring the critical role of structured continuous improvement methodologies in inventory management.

Originality / Value: This research addresses a gap in applied studies on inventory management in the dairy sector, demonstrating the successful application of Lean Six Sigma and DMAIC to achieve substantial operational improvements. The study presents a replicable model for other industries seeking to optimize inventory control, minimize operational errors, and elevate supply chain performance.

Keywords: DMAIC; Quality tools; Inventory management; OTIF (On Time In Full).

1 INTRODUCTION

Inventory management plays a critical role in production sectors, particularly within the dairy industry, where the efficient use of inputs and waste minimization are essential for economic and operational sustainability. Given the finite nature of natural resources used in food production, there is increasing pressure for management practices that not only optimize costs but also ensure product quality and availability (Panigrahi, Singh and Muduli, 2024). Demand fluctuations often lead to variations in consumption patterns, resulting in significant operational losses. Mantravadi and Srai (2022) emphasize that maintaining inventory levels aligned with dynamic demand is critical to mitigate these risks.

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Inefficient inventory management can result in severe consequences, including lost sales, customer dissatisfaction, and production interruptions (Beveridge, Angelis and Mihajlov, 2024). The Brazilian dairy sector exemplifies this complexity: in 2023, it produced 35.4 billion liters of milk, generating R$80.3 billion in revenue (IBGE, 2024). With 98% of municipalities engaged in milk production, predominantly through small and medium-sized enterprises, ensuring accurate inventory control becomes vital (Mujuni Katunzi, 2011).

Inventory management accounts for nearly one-third of global logistics costs (Panigrahi, Singh and Muduli, 2024), making it a priority for research and operational excellence. Although some approaches treat inventory as waste, many organizations, particularly those located in remote regions with lead times exceeding 30 days, depend on it for operational resilience (Leite *et al.*, 2024).

Within this context, the implementation of Lean Six Sigma and the DMAIC framework emerges as a promising strategy for improving inventory processes. While Lean Six Sigma has been successfully applied in sectors such as industrial maintenance (Pophaley and Vyas, 2015; Barbosa, Peruchi and Junior, 2023) and automotive supply chains (Rehman *et al.*, 2018), its use in dairy operations remains underexplored. In parallel, methodologies like Total Quality Management (TQM) and Kaizen have demonstrated improvements in inventory optimization, but lack the structured statistical rigor embedded in DMAIC (Kaswan *et al.*, 2021; Rathi *et al.*, 2022).

Addressing this gap, the present study applies Lean Six Sigma's DMAIC framework in a dairy processing facility, combining it with action research to foster continuous improvement and operational sustainability. Moreover, it investigates how the integration of the OTIF (On Time In Full) indicator can enhance the responsiveness and efficiency of inventory management. The research thus contributes to expanding the theoretical and practical understanding of inventory control in industries with high perishability and operational complexity.

1.2 Theoretical framework

Lean Six Sigma (LSS) integrates the principles of lean manufacturing and Six Sigma to achieve process excellence through waste reduction and variability control. At its core, Six Sigma aims to enhance organizational efficiency by systematically eliminating root causes of non-conformities, guided by the structured DMAIC (Define, Measure, Analyze, Improve, Control) framework. Sagnak and Kazancoglu (2016) emphasize the critical role of detailed variability analysis in identifying improvement opportunities across operational processes.

The application of quality management tools such as process mapping, cause and effect diagrams, and root cause analysis strengthens the identification of systemic failures and supports targeted interventions. Kaswan *et al.* (2021) and Rathi *et al.* (2022) argue that the integration of these tools significantly enhances inventory accuracy, a fundamental element for ensuring customer satisfaction and reducing logistical costs.

Several empirical studies illustrate the effectiveness of Lean Six Sigma and the DMAIC methodology in diverse contexts. Pinto *et al.* (2017) demonstrated a 25% reduction in lead time and a 45.05% decrease in processing time by applying DMAIC in a manufacturing environment. Similarly, Antony *et al.* (2022) showcased the successful deployment of Lean Six Sigma in educational institutions, leading to notable improvements in organizational processes.

Braga *et al.* (2023) explored the application of DMAIC in optimizing the OTIF (On Time In Full) indicator, developing action plans that fostered new improvement cycles. Taheri *et al.* (2023) proposed a multi-objective optimization model for inventory management in dairies, which resulted in a significant reduction in inventory costs. Al-Aomar and Hussain (2019) further confirmed that DMAIC not only improves inventory accuracy but also mitigates operational disruptions arising from errors in separation and delivery.

In the context of inventory management, separation errors are recognized as a major source of non-conformities. Aguiar and Sampaio (2013) and Araujo *et al.* (2013) highlight that such failures undermine the reliability of supplier-customer relationships, affecting both operational performance and customer satisfaction. Pacheco, Marteletti, and Silveira (2020) stress the importance of efficiently managing separation processes to minimize logistical impacts and maintain organizational competitiveness.

Beyond internal accuracy, delivery performance metrics such as OTIF are critical indicators of supply chain effectiveness. Raaymann and Spinler (2023) argue that OTIF directly reflects a company's ability to fulfill customer requirements in a timely and complete manner. The integration of inventory management practices with OTIF monitoring enhances operational visibility and drives continuous improvements in customer service levels (Sato, Murata and Katayama, 2017).

Although alternative methodologies such as Total Quality Management (TQM) and Kaizen offer approaches to process improvement and inventory optimization, Lean Six Sigma's structured statistical foundation provides a more robust framework for measurable and sustainable gains

(Kaswan et al., 2021; Rathi et al., 2022). This distinction underscores the relevance of applying DMAIC in environments where variability control and data-driven decision-making are essential.

1.3 Potential for improvement in dairy inventory management with lean Six Sigma

The application of Lean Six Sigma (LSS) has demonstrated significant results in the optimization of logistical processes. Sharma and Shah (2015) highlighted layout reconfiguration to reduce the distance traveled during storage processes by 87%. Sharma and Shah (2016) observed improvements in the picking process, increasing operational efficiency, while Sangwa *et al.* (2023) reviewed organizational KPIs, resulting in enhanced efficiency. Khanzode, Sarma and Goswami (2023) optimized storage space utilization, achieving 99.94% occupancy and reducing waste by 67.06%. Dixit, Shah and Sonwaney (2020) present a case study in which the implementation of lean principles resulted in a 12% increase in customer service level (CSL) and a significant reduction in picking discrepancies, demonstrating the tangible benefits of the lean approach.

The DMAIC framework (Define, Measure, Analyze, Improve, Control) has driven advancements across various sectors. Bonetti *et al.* (2023) applied DMAIC in a cement factory, reducing the average wait time (AWT) from 4 hours to 40 minutes and stabilizing customer service time (ACST) at 2 hours and 45 minutes. Pinto *et al.* (2017) used Value Stream Mapping (VSM) alongside DMAIC to reduce Lead Time by 25% (from 15 hours to 11.25 hours) and processing time by 45% (from 6.66 hours to 3.66 hours), confirming the efficacy of these methodologies.

However, the literature on the application of Lean Six Sigma and DMAIC in inventory management within the dairy sector is limited. Although On Time In Full (OTIF) is a key performance indicator for logistics, its relationship with inventory accuracy and operational errors has not been sufficiently explored. This gap underscores the need for further studies on the application of Lean Six Sigma to improve inventory accuracy and OTIF performance, particularly in the dairy industry.

This research aims to address two main questions: How can Lean Six Sigma, through the DMAIC framework, improve inventory management in a dairy industry? And how can the integration of the OTIF concept contribute to reducing operational errors and optimizing inventory accuracy? The goal is to analyze the application of Lean Six Sigma and DMAIC in the inventory management of a dairy industry, seeking to optimize inventory accuracy and reduce picking errors, with a positive impact on OTIF and operational efficiency.

The justification for this study lies in the potential of Lean Six Sigma (LSS) application in the dairy industry, focusing on improving inventory accuracy, OTIF performance, and reducing operational errors. The study contributes to the literature by presenting a replicable continuous improvement model, combining both quantitative and qualitative approaches to measure the impact of LSS in a scarcely explored sector. The relevance of the study is in seeking more efficient inventory management practices and enhancing the dairy supply chain.

This article is structured to provide a detailed understanding of inventory management improvement through the DMAIC method. First, the theoretical framework will be presented, emphasizing the importance of metrics such as DMAIC, picking errors, and OTIF in performance evaluation. The applied methodology will be described, followed by an overview of the company studied. The phases of DMAIC will be detailed, with a focus on practical applications within the organization, and the conclusions will present the key findings and their implications for inventory management.

2 METHODOLOGICAL PROCEDURES

This study adopts an action research approach, combining investigation and intervention to foster improvements in inventory management practices. Action research enables participants to actively engage in identifying problems, implementing solutions, and reflecting on outcomes, thus facilitating organizational learning and systemic transformation (Tripp, 2005; Santos *et al.,* 2023).

Researchers, who were employees of the organization, acted as facilitators throughout the process. Their involvement encompassed problem diagnosis, data collection, root cause analysis, implementation of corrective actions, and evaluation of outcomes. This collaborative approach allowed a more precise understanding of operational dynamics and promoted the co-construction of tailored solutions (Thiollent, 2011).

The research is classified as applied, aiming to address real-world challenges in inventory management within a dairy processing environment. In terms of objectives, it is descriptive, seeking to characterize inventory management issues and document the interventions and outcomes achieved.

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to characterize inventory management issues and document the interventions and outcomes achieved (Doyle *et al.*, 2020). Observations were systematically recorded to ensure alignment with the original research questions (Bradshaw, Atkinson and Doody, 2017). The Lean Six Sigma DMAIC framework structured the project's development, guiding the definition of problems, data measurement, root cause analysis, implementation of improvements, and establishment of control mechanisms.

2.1 Company studied

The study was conducted in a dairy processing facility located in the semi-arid region of Paraíba (Brazilian Northeast), a strategic dairy production hub. The company ranks among the leading dairy suppliers in Northeast Brazil, manufacturing 112 dairy products for both retail and wholesale markets across five industrial plants, all operating under stringent quality control and traceability protocols compliant with regulatory requirements.

Inventory management proves critical, as supply chain disruptions directly induce equipment downtime and production losses. Operational workflows encompass inbound logistics, material handling, storage (with specific requirements such as dairy cultures maintained at -40°C to -60°C), and input distribution(Hertog *et al.*, 2014). This research employs Lean Six Sigma methodology to optimize inventory management systems, targeting operational efficiency and sustainable practices. Confidentiality was preserved through data anonymization. The study period spanned January 2023 to October 2024.

2.2 Metrics used in indicators

The primary function of inventory management is to understand inventory behavior and ensure that accuracy-related failures are avoided. To calculate accuracy, the following equation eq. 1 is used for stock accuracy.

$$Y = \frac{CT}{TI} \text{ x } 100 \tag{1}$$

Where CI, correct items and TI total items checked.

One of the tools for evaluating process stability was the X-bar-R chart. Control charts are powerful tools for statistical process control. These charts consist of the UCL (Upper Control Limit) and LCL (Lower Control Limit), which are used to monitor and detect process instability over time. When the process exceeds the limits, the point is referred to as an outlier and must be examined, understood, and resolved. A process that remains within the limits is considered compliant. Thus, control charts serve as a decision-support tool and for continuous improvement. In the measurement phase, the X-bar-R control chart is utilized to verify the variation in separation errors, aiming for process stabilization, as shown in eq. (2-4).

$$UCL = \bar{X} + \frac{3\hat{\sigma}}{\sqrt{n}} \tag{2}$$

$$LSC = \bar{X} - \frac{3\hat{\sigma}}{\sqrt{n}} \tag{3}$$

$$LM = \bar{X} \tag{4}$$

Where, UCL (Upper Control Limit); CL (Control Limit); LCL (Low Control Limit); $\bar{X}$ mean; $\hat{\sigma}$ standard deviation.

To measure the distribution process, an operation that directly impacts inventory management, the OTIF (On Time In Full) indicator was used. The purpose of the OTIF indicator is to monitor deliveries. In the case study, this indicator is applied to the supply of industrial plants. The calculation of OTIF is presented in Eq. 5.

$$OTIF = \frac{items\ delivered\ on\ time}{total\ items\ requested} x100 \quad or \quad OTIF = \frac{on\ time\ rate}{in\ full\ rate}\ x\ 100 \tag{5}$$

The logistics performance was assessed using the OTIF metric, which simultaneously evaluates delivery timeliness and completeness. As shown in Figure 1, this indicator encompasses four critical supply chain dimensions: timing, product specification, exact quantity, and correct destination.

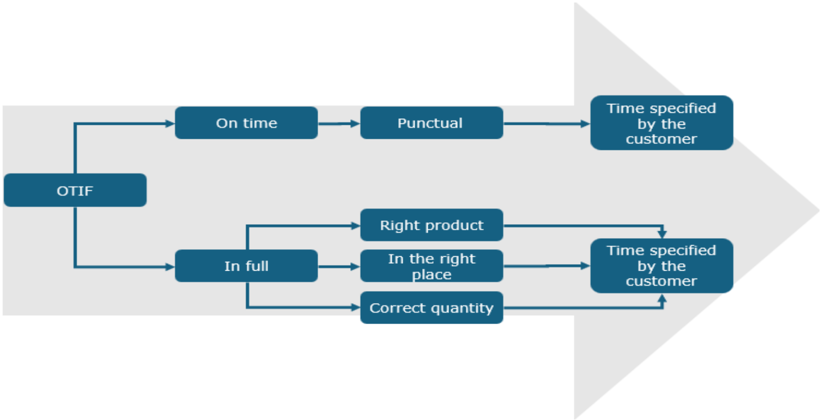


Figure 1 - Illustrates the representation and definition of OTIF terms

For the statistical validation of the improvement result in inventory between 2023 and 2024, the Z-test for Two Proportions was used to determine whether the observed difference between two proportions (percentages) is statistically significant. The following equations were used: Eq. 6 for Sample Proportions, Eq. 7 for Difference in Proportions, Eq. 8 for Standard Error of the Difference, and Eq. 9 for Z Statistic.

$$\hat{p}_1 = \frac{X_1}{n_1}, \hat{p}_2 = \frac{X_2}{n_2} \quad (6)$$

Where, $\hat{p}_1$ is the sample proportion of successes for sample 1, $\hat{p}_2$ is the proportion of successes for sample 2, X_1 and $X_2$are the number of observed successes in samples 1 and 2, and n_1 and n_2 are the sample sizes for 1 and 2.

$$\hat{p}_1 - \hat{p}_2 \quad (7)$$

Where, $\hat{p}_1 - \hat{p}_2$ is the raw difference between the two success proportions.

$$SE = \sqrt{\frac{\hat{p}_1(1-\hat{p}_1)}{n_1} + \frac{\hat{p}_2(1-\hat{p}_2)}{n_2}} \quad (8)$$

Where SE is the standard error of the difference between the two proportions, $\hat{p}_1(1-\hat{p}_1)$ is the estimated variance of proportion 1, $\hat{p}_2(1-\hat{p}_2)$ is the estimated variance of proportion 2, and $\frac{\hat{p}_1(1-\hat{p}_1)}{n_1}$ and $\frac{\hat{p}_2(1-\hat{p}_2)}{n_2}$ are the variances adjusted by the sample size.

$$Z = \frac{\hat{p}_1 - \hat{p}_2}{SE} \quad (9)$$

Where Z is the standardized value that indicates how many standard errors the observed difference is from 0, $\hat{p}_1 - \hat{p}_2$ is the actual observed difference, and the standard error (SE) is calculated in Eq. 8.

2.3 Application of the dmaic method

The DMAIC Method follows five distinct steps (Peruchi *et al.*, 2020). In the definition phase, the problems, scope, team, and goals are established. In the measurement phase, data is collected by specialists to understand the current state of the process. The analysis phase involves examining the data to identify the root causes of the problems. The improvement phase entails implementing the identified solutions, while the control phase develops assurances that ensure the sustainability of the improvements (Antony *et al.*, 2018; Rathi *et al.*, 2022). Figure 2 illustrates the tools applied in each phase of the DMAIC project and flow of application.

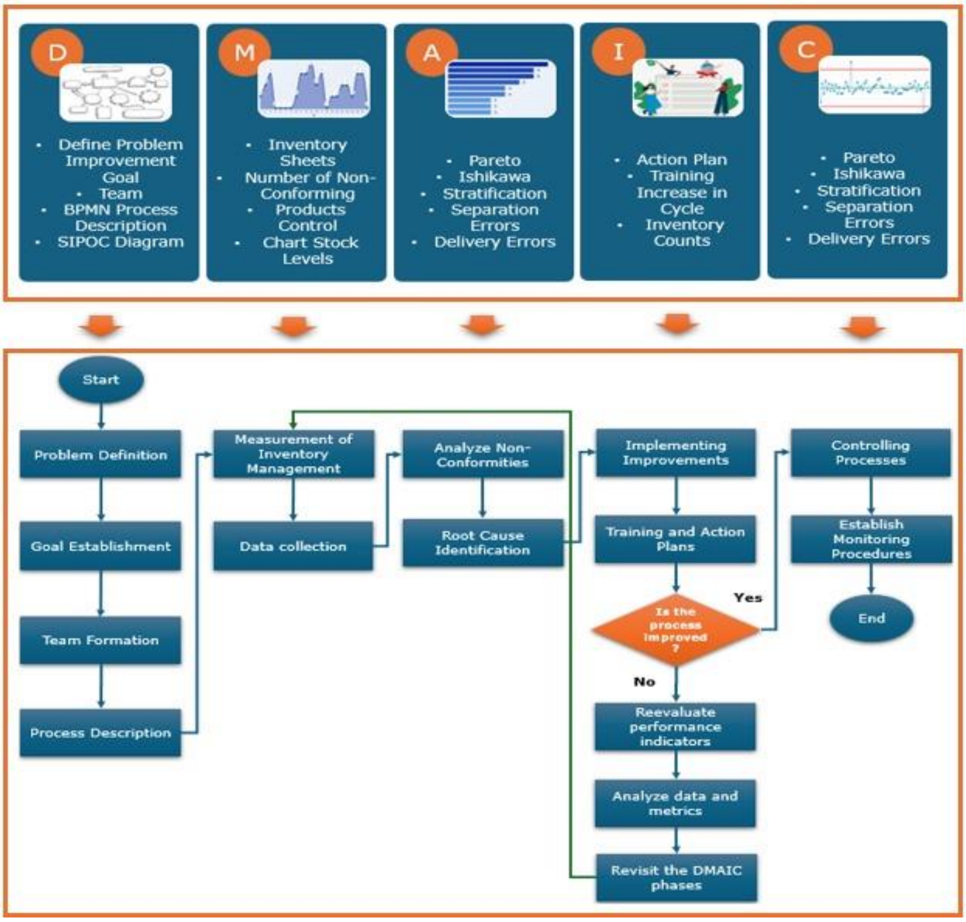


Figure 2 - Tools applied by phases in the DMAIC project and flow of application

2.4 Define phase: problem definition, scope, and team formation

Inventory management within the studied organization presented critical deficiencies, notably the absence of structured procedures for cycle counting. In January 2023, the inventory non-conformance rate reached 42.57%. Despite the goal of achieving 95% accuracy by December 2023, the target was not met, prompting the development of a Lean Six Sigma project. A multidisciplinary team from the supply chain department was assembled, applying the DMAIC framework to structure the improvement efforts (Kaswan *et al.*, 2023). To preserve confidentiality, company names and identifiable data were omitted. The study period spanned from January 2023 to October 2024.

During the problem definition phase, project objectives and scope were established (Kaswan *et al.*, 2023). The team included two Black Belts (a supply supervisor and an external specialist) and two Yellow Belts (warehouse assistants). The Black Belt coordinated the project activities, the external specialist validated the methodology, and the Yellow Belts supported operational implementation. A SIPOC diagram (Suppliers, Inputs, Process, Outputs, Customers) was developed to map the supply chain processes and interactions (Al-Aomar *et al.*, 2021), as shown in Figure 3. Although the SIPOC structure may appear simple, its development required multiple sessions, including on-site validations and meetings with suppliers and internal stakeholders, to ensure its accuracy and applicability to the operational reality.

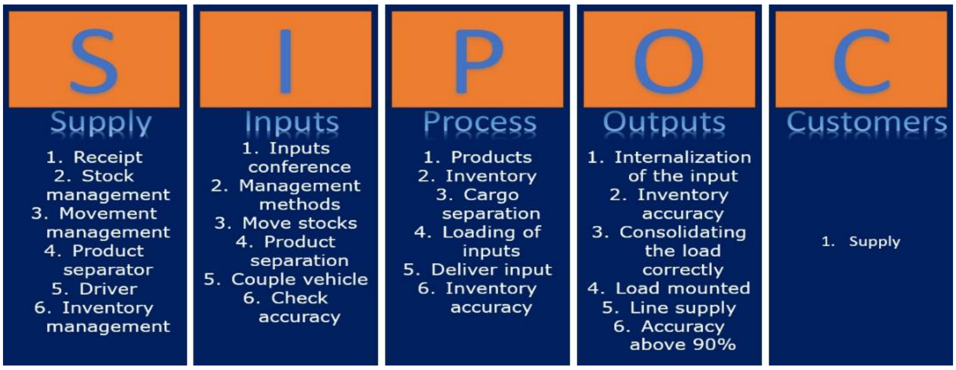


Figure 3 - SIPOC diagram of the inventory management process in the Supply Chain department

To better understand the operational dynamics, the inventory management, picking, and delivery sectors were mapped (Torvi, Nepal and Wang, 2023). The project's goal was to increase inventory accuracy from 80.30% (2023 baseline) to 90% by October 2024. The Critical to Quality (CTQ) parameter was defined as a 9.7% improvement in inventory accuracy.

Significant challenges were identified during process mapping, notably the lack of standardized procedures in picking and the frequent discrepancies between physical stock and system records. These inconsistencies not only impaired inventory accuracy but also complicated shelf-life management, increasing the risk of product expiration and input loss (Marchi, Galati and Zanoni, 2024).

Inventory accuracy was monitored using Equation (1), with data collected through Excel spreadsheets and analyzed in Power BI (Barros, Salvador and Francisco, 2020). Figures 4, 5, and 6 illustrate the mapped processes for inventory control, picking operations, and delivery management, respectively.

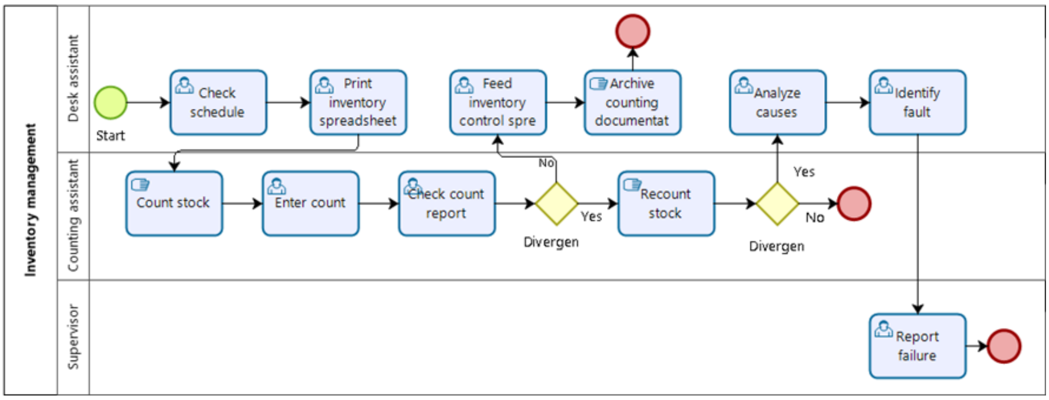


Figure 4 - Mapping of the Inventory Process

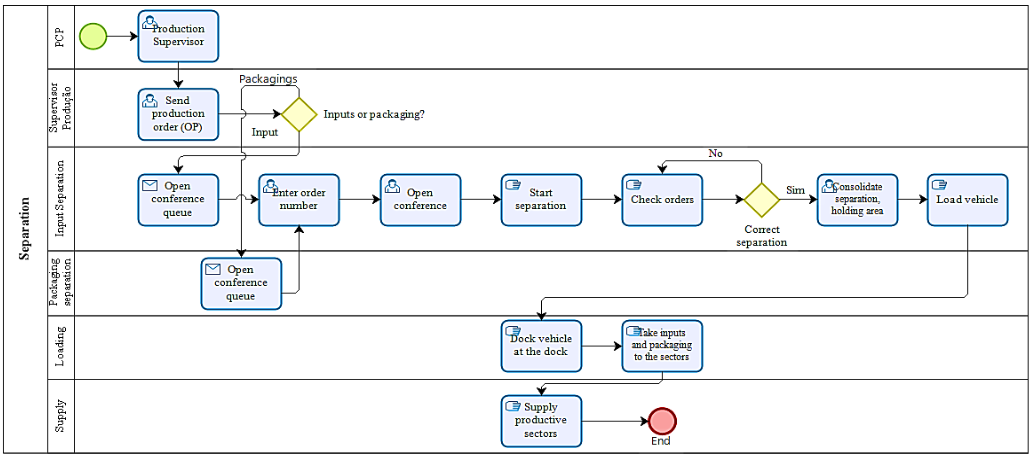


Figure 5- Mapping of the Separation Process

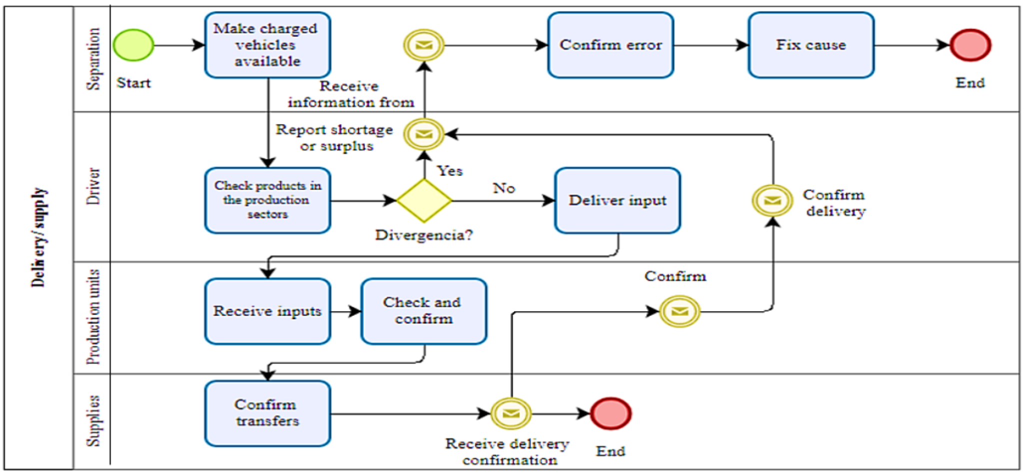


Figure 6 - Mapping of the Line Delivery/Supply Process

2.5 Measurement phase: inventory process assessment

In this phase, data from October to December 2023 were analyzed. Since there was no prior inventory history, the goals were established by management. However, by the end of 2023, the results did not meet expectations. Figure 7 illustrates the inventory results for the year 2023, highlighting the deficiencies in management and the need for interventions for improvement.

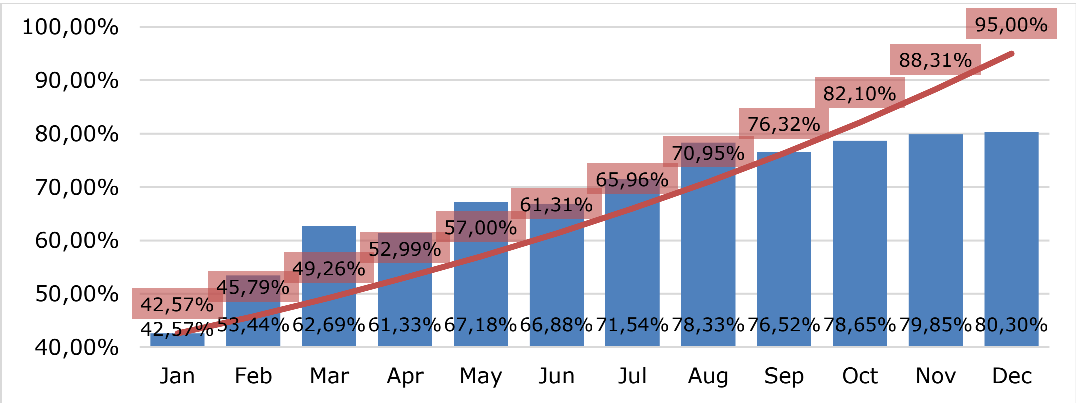


Figure 7 - Inventory management indicator results for 2023

The data were collected according to the inventory schedule, segmented by product groups. Figure 7 presents the inventory measurements for the year 2023. It is worth noting that prior to 2023, the company did not conduct monthly inventory counts. To ensure continuous process improvement, the company invested in standardizing processes and verticalizing inventory.

Furthermore, control charts were developed to verify the stability of the separation process, as it significantly influences inventory management outcomes. Figure 8 illustrates the X-bar and R control chart, which allows for the monitoring of process variability and compliance.

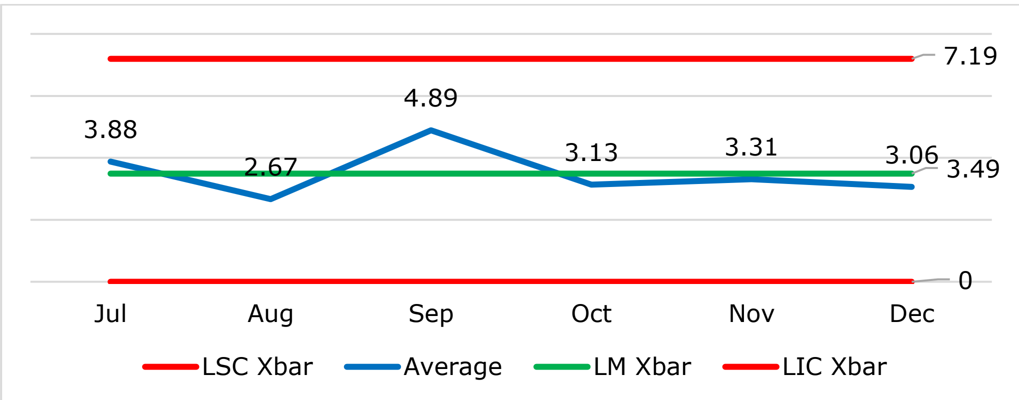


Figure 8 - X-bar Control Chart for separation errors

The control chart for separation errors (Figure 9) was implemented to monitor variability within the inventory management process. Separation errors, originating primarily during the picking phase, directly compromise inventory accuracy and reduce the reliability of stock information. A higher frequency of these errors correlates with greater deviations in inventory records, negatively affecting overall operational performance and decision-making reliability.

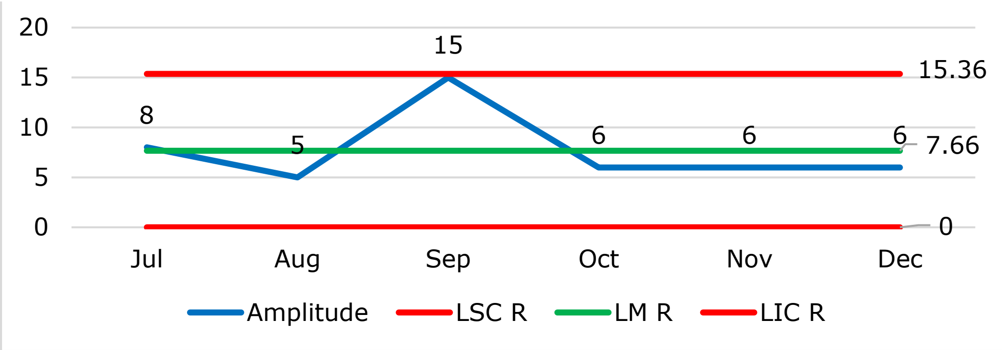


Figure 9 - Range-R control chart for separation errors

In the range (R) control chart, a significant increase in process variability was observed in September, coinciding with the temporary replacement of a trained separation operator by an untrained employee. This event contributed to the rise in separation errors. In subsequent months, no data points exceeded the established control limits, indicating improved process stability.

The range reflects the difference between the highest and lowest number of separation errors recorded over the months, directly impacting inventory accuracy. Additionally, delivery errors emerged as a secondary source of variation, first diagnosed in 2024, and were later identified as one of the root causes affecting stock accuracy. Figure 10 presents the monthly comparison between separation errors and systematic transfer errors throughout 2023.

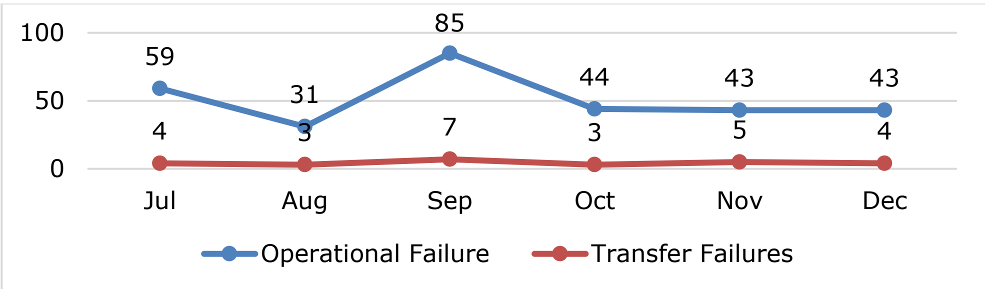


Figure 10 - Comparison between separation errors and systematic transfer errors

A monthly cyclic inventory was implemented throughout 2023. During the first nine months, challenges related to standardization and the consistent application of 5S practices were addressed using a see-and-act approach. From October onwards, processes became more stable, and the warehouse began systematically applying 5S principles. Nonetheless, some operational inconsistencies, not initially identified, delayed the full consolidation of improvements.

Although the organization does not utilize a dedicated Warehouse Management System (WMS), its existing ERP platform provides robust functionalities sufficient to support the project's inventory management demands, including order processing, systematic stock movements, inventory analysis, and adjustment controls.

The *labels* and *films* product groups, however, did not reach the targeted performance levels and were therefore evaluated separately. The assessment, based on the study by Barbosa et al. (2025) revealed significant irregularities related to suppliers' compliance with ISO 9001:2015 requirements. Key deficiencies were identified in operational control (Clause 8.1), nonconformity management (8.7), performance monitoring (9.1), corrective actions (10.2), and supplier control (8.4). Notably, large variations in roll and pallet weights were observed, without the implementation of effective corrective actions by suppliers.

As a corrective measure, a dedicated action plan was developed and formally communicated to the suppliers, highlighting the specific ISO 9001:2015 clauses requiring immediate compliance to resolve the identified discrepancies. Given that these issues originate externally, the improvement of the *labels* and *films* groups is currently considered an uncontrollable factor within the internal project scope. Table 1 presents the error distribution by product group, including percentages and cumulative totals for 2023.

Table 1 -Separation errors by groups

Movement errors by product group										
Group	**Skus**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**	**%**	**Accumu-lated**
Premium count	6	7	3	16	7	3	6	42	12.69	12.69
Cups	16	9	3	6	3	7	7	35	10.57	23.26
Cardboard box	17	4	3	7	6	2	6	28	8.46	31.72
Label	23	5	6	5	2	7	2	27	8.16	39.88
Cheese packaging	21	6	3	9	5	2	1	26	7.85	47.73
Caps	17	7		6	3	5	4	25	7.55	55.29
Condiments/stabilizers	23	5	2	6	2	4	3	22	6.65	61.93
Prepared	11	2	2	4	1	2	7	18	5.44	67.37
Yeasts	38	1	2	4	6	5		18	5.44	72.81
Films	17	5		3	2	2	2	14	4.23	77.04
Consumption	12	2	2	2	3	3	1	13	3.93	80.97
Stamps	9	3		6	1		1	11	3.32	84.29
Mix paper	6			1	2	5	2	10	3.02	87.31
Sweet/coconut milk label	6	1	2	3	3	1		10	3.02	90.33
Dye/flavory	11	2	3	2				7	2.11	92.45
Polystyrene	4			2		1	3	6	1.81	94.26
Film	5	2		2		1	1	6	1.81	96.07
Enzymes	3			4	1			5	1.51	97.58
Plastic bag	5					3	1	4	1.21	98.79
Cheese shapes/deener	6	1	1				2	4	1.21	100
Total	256	62	32	88	47	53	49	331		

Separation errors critically impact inventory management performance, making it essential to conduct a comprehensive analysis of all inventory results to identify failure patterns. The initial step involves reviewing systematic transactions to detect input errors, followed by verifying physical stock movements through direct monitoring of the picking process, supported by operational records. Although effective, this verification method is labor-intensive and can delay the inventory counting schedule.

The ERP system implemented in the case company, despite not being a dedicated WMS, provides robust inventory management functionalities, facilitating systematic stock movements, inventory analyses, and adjustment operations. This structure minimizes rework, prevents delays in counting activities, and contributes to reducing operational costs.

In March 2024, 230 deliveries were recorded, with an on-time delivery rate of 50.91% (124 deliveries) and an in-full delivery rate of 59.13% (136 deliveries). To better direct improvement efforts, OTIF performance was stratified by sector, enabling the identification of critical focus areas. Figure 11 presents the initial measurement of OTIF performance by sector.

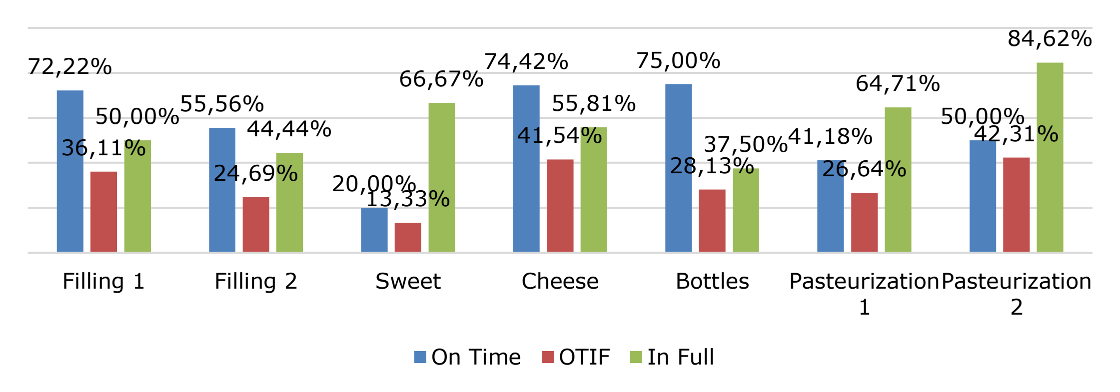


Figure 11 - OTIF stratified by supplied sector

The graph illustrates a significant decline in key performance indicators, particularly regarding punctuality (On-Time) and On-Time In Full (OTIF) delivery rates. The Filling 1 and Filling 2 production lines exhibited pronounced reductions, with OTIF rates of 36.11% and 24.69%, respectively, and punctuality rates falling to 72.22% and 55.56%. The Sweet line demonstrated critical inefficiencies, with only 13.33% of deliveries executed on time and an OTIF performance of 20%, indicating severe failures across both production and logistical processes.

While the Cheese (66.67%) and Bottles (75%) lines showed relatively greater stability in in-full deliveries, their performance remained below the levels required to ensure consistent customer satisfaction. The only positive outlier was the Pasteurization 2 line, which achieved an 84.62% OTIF rate, suggesting more effective operational control at that stage.

These findings underscore the urgent need for structured interventions aimed at optimizing supply chain and delivery processes, which can be effectively addressed through methodologies such as Lean Six Sigma. This diagnostic analysis provides a robust foundation for future high-impact research, exploring operational failures and proposing data-driven solutions to foster continuous process improvement.

2.6 Analyze phase: identification of root causes

During the analysis phase, the project team systematically identified the root causes of inventory discrepancies. Structured meetings with inventory controllers, picking operators, and supply staff were held to diagnose operational failures. Data were stratified by product groups using Pareto analysis, supported by detailed stratification spreadsheets (Ketan and Nassir, 2016; Al-Aomar *et al.*, 2021).

Errors were classified into three critical categories: delivery failures, raw material picking errors, and systematic transfer inaccuracies. This categorization enabled the prioritization of corrective actions, leading to a substantial reduction in inventory deviations. Figure 12 illustrates the stratification of inventory errors by product group.

Given that supply-related issues were a significant source of discrepancies, monitoring of the OTIF (On Time In Full) indicator was initiated, as described in Equation 5, to strengthen delivery control and sustain continuous improvement initiatives.

To guide improvement efforts in 2024, product groups were analyzed to identify the primary causes of inventory non-conformities. The main causes identified included separation errors, lack of process standardization, unscheduled inventories, and deliveries without verification by receiving personnel.

High-value items, such as whole and skim milk powder, polystyrene, and sugar, are stored in a dedicated facility separate from the main supply warehouse, covering 2,600 square meters and divided into five blocks by product type. Given that the supply process is centralized from a single inventory, enhanced operational attention was required.

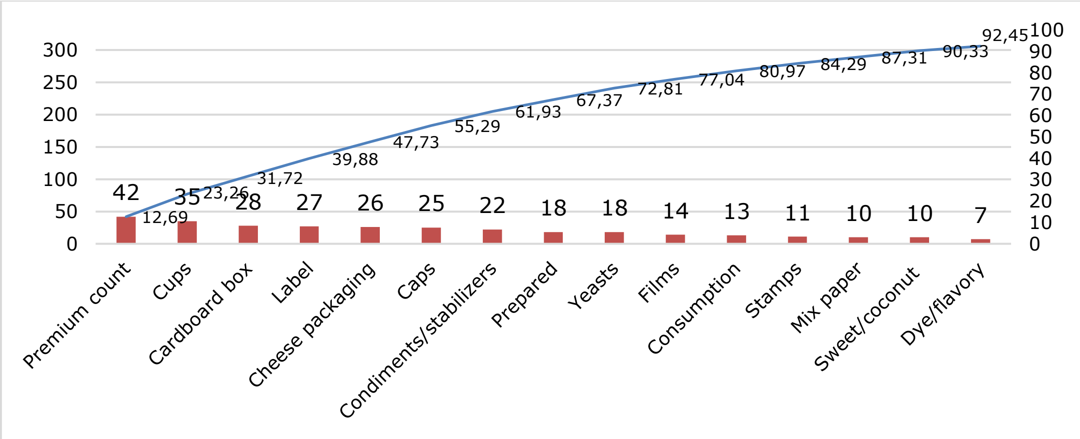


Figure 12 - Stratification of inventory groups of raw materials, Pareto Chart

Root causes were further mapped through structured brainstorming sessions involving supply, picking, and inventory management teams. Figure 13 presents the Ishikawa diagram developed to consolidate the identified root causes.

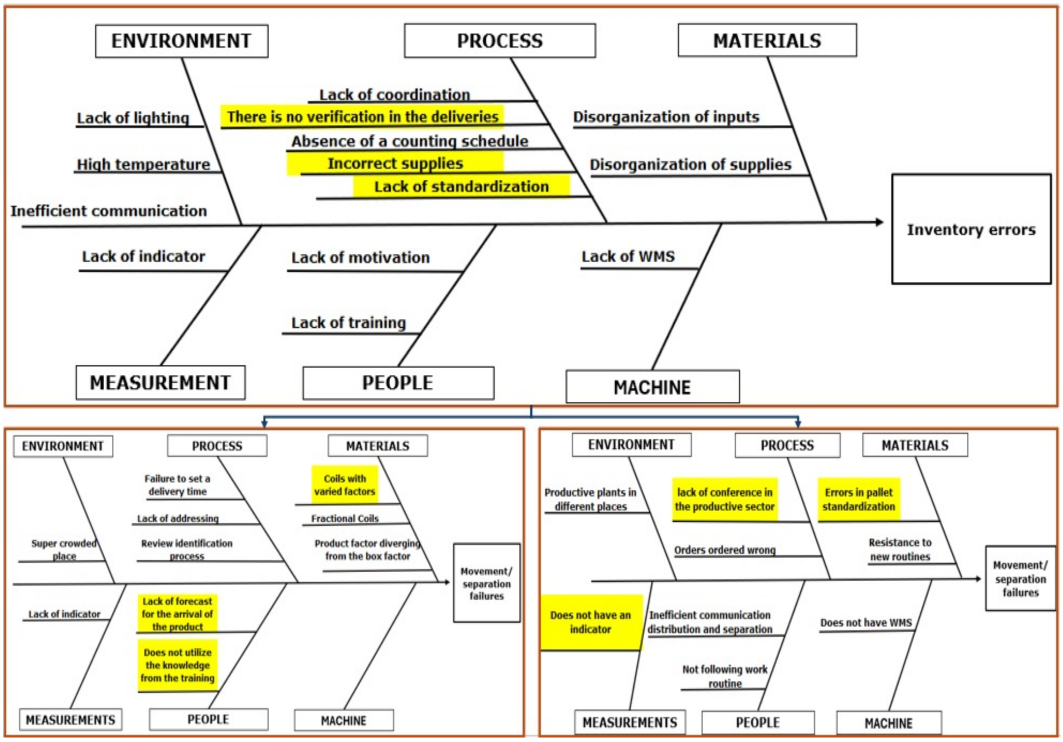


Figure 13 - Ishikawa diagrams illustrating root causes in inventory management, picking, and supply processes

After identifying the errors compromising inventory accuracy, targeted meetings were conducted with the inventory, picking, and supply teams to determine the primary causes. A Black Belt facilitated a structured session across departments to construct the Ishikawa diagram, mapping critical process failures and defining the areas requiring improvement to enhance the inventory accuracy indicator.

During this workshop, OTIF indicators for both distribution and separation errors were also established to strengthen performance monitoring. Figure 14 illustrates the sequential trend of separation errors recorded monthly.

Separation errors are closely related to the accuracy of the inventory process; when one of the operators makes an error during separation, the inventory count will reveal discrepancies in stock levels. Inventory management aims to understand stock behavior and resolve issues that lead to discrepancies in inventory levels.

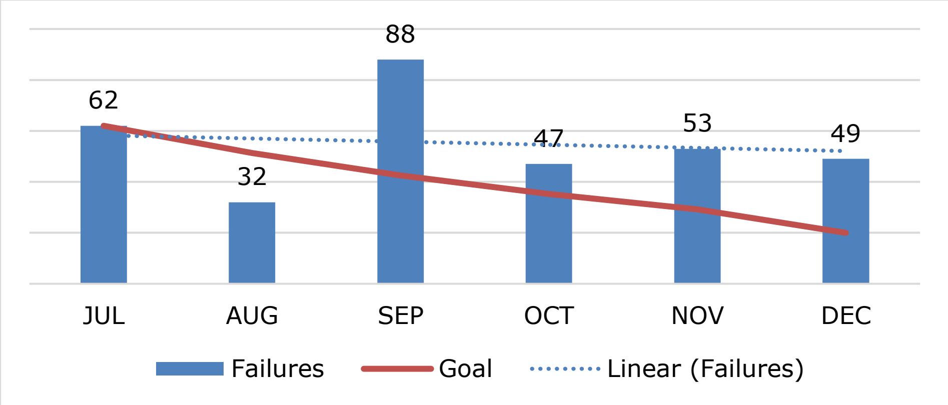


Figure 14 - Sequential graph of separation errors per month for the year 2023

2.7 Improve phase: implementation of corrective actions

Based on the root cause analysis, the project team implemented targeted corrective actions to reduce separation and supply errors, identified as the main sources of inventory discrepancies.

The measures included the creation of a delivery verification checklist, standardization of operational procedures (SOPs), validation of ordering and supply processes, and the implementation of a material arrival forecasting system. These actions aimed to standardize processes, reduce variability, and enhance operational reliability.

Continuous training sessions reinforced the correct application of the new standards. The OTIF indicator was formalized as a control tool, enabling real-time monitoring of supply chain performance and prompt response to deviations. Table 2 details the implemented action plan, listing causes, responsible parties, deadlines, and execution status.

Table 2 - Corrective Action plan for inventory management improvement

Identified Cause	Action to be Taken	Responsible	Deadline	Status	Additional Description
No verification in the delivery	Implement a delivery verification checklist	Supply Supervisor	30 days	Resolved	This action aims to ensure confirmation of all delivered items, minimizing receiving errors and increasing accuracy.
Incorrect supplies	Establish a validation process for orders and supplies	Purchasing Manager	45 days	Resolved	Order validation will help reduce the occurrence of incorrect supplies, ensuring that only the correct items are requested.
Lack of standardization	Create and implement an operations standard procedures manual	Supply Supervisor	60 days	Resolved	Standardization will ensure greater consistency in receiving operations, minimizing discrepancies.
Lack of forecast for the arrival of the product	Implement a system for forecasting product arrivals	Supply Analyst	30 days	Resolved	Accurate forecasting will facilitate product separation scheduling, avoiding delays.
Does not utilize training knowledge	Conduct refresher training sessions	Supply Supervisor	30 days	Resolved	Continuous training will ensure operators apply acquired knowledge, enhancing efficiency.
Coils with varied factors	Standardize separation instructions	Operations Manager	45 days	Resolved	Standardizing instructions will help minimize errors related to variable factors in product separation.

No performance indicator	Develop and implement performance indicators	Logistics Manager	30 days	Resolved	Implementing indicators will enable monitoring of efficiency in delivery and replenishment operations.
Lack of verification in the production area	Establish a verification protocol	Production Lead	45 days	Resolved	This protocol will ensure that all materials delivered to the production area are verified, increasing compliance.
Errors in pallet standardization	Create clear guidelines for standardizing pallets	Lean Six Sigma Project Team	30 days	Resolved	Standardizing pallets will help avoid errors during the delivery process, improving accuracy in replenishment.

The structured implementation of these actions strengthened inventory accuracy and prepared the operation for sustainable improvements during the control phase.

2.8 Controlling processes

During the control phase, weekly meetings were established to monitor the inventory accuracy indicator. These meetings reported the number of separation errors, system transfer errors, and delivery errors during supply replenishment.

Standard Operating Procedures (SOPs) were developed to reinforce process control. Employees responsible for inventory, distribution, and supply operations had their procedures reviewed, formalized, and were trained by the Black Belt project leader.

The X-bar and R control charts were employed to monitor variations in the separation process, identified as the primary cause of inventory inaccuracies. Figure 15 illustrates the evolution of separation error control between 2023 and 2024, highlighting the positive impact of the implemented corrective actions.

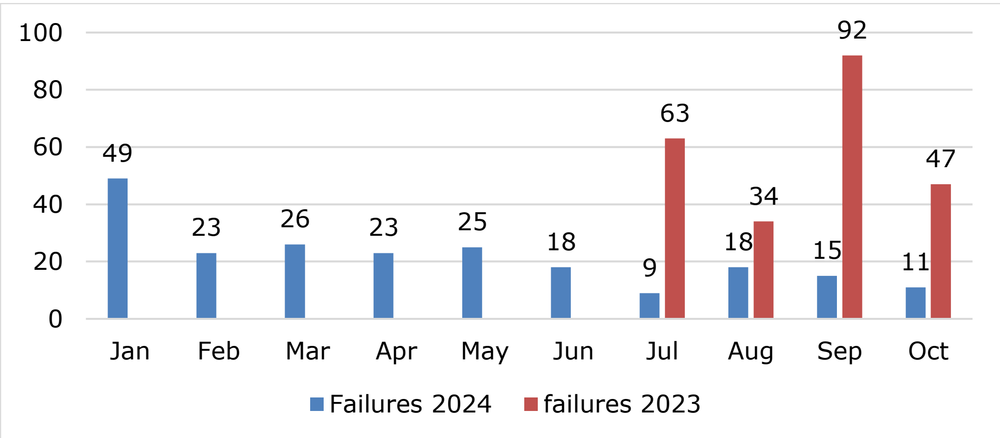


Figure 15 - Evolution of separation error control from 2023 to 2024

Separation errors significantly decreased in 2024 compared to 2023. In July, the reduction reached 85.72%, followed by 47.46% in August, 83.70% in September, and 76.60% in October. Key drivers of this improvement included the implementation of weekly performance meetings, the development of standardized operating procedures, the adoption of OTIF indicators for deliveries, and individualized feedback to employees responsible for inventory, picking, and supply processes. Figure 17 illustrates the evolution and stabilization of the separation process control over this period.

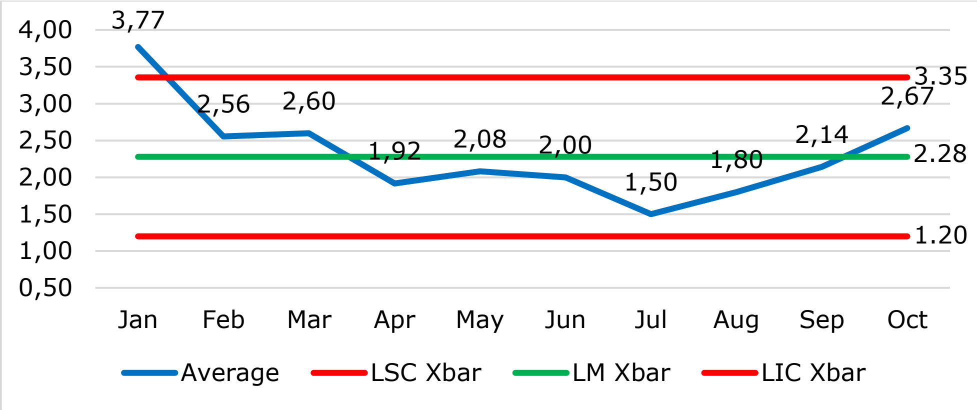


Figure 16 - X-bar-R control chart for separation errors by product group in 2024

The dispersion of separation errors by group indicates that the process is under statistical control. The variations are within the control limits, which have narrowed compared to the measurements of 2023. With a UCL of 3.35 and an LCL of 1.20, the average was 2.28, reflecting a reduction of 1.21 from the initial process average measured during the measurement phase (3.49). The tightening of the control limits demonstrates the effectiveness of the implemented action plan.

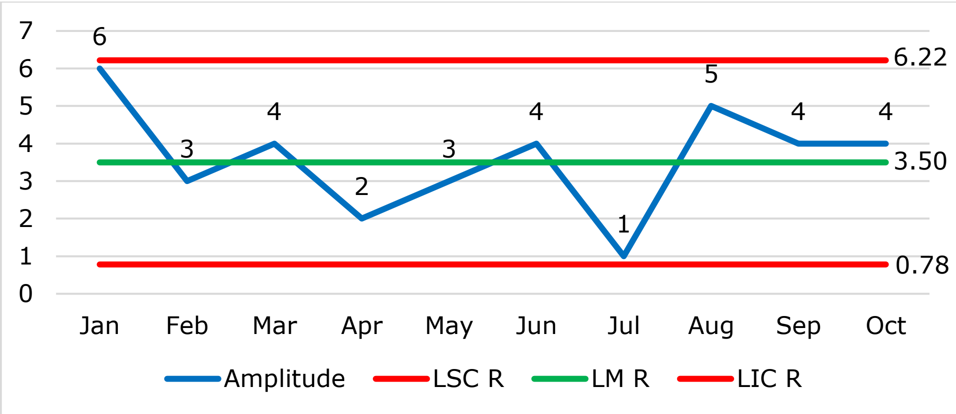


Figure 17 - Control chart of the range of the separation process for 2024

The range (R) control chart presented in Figure 17 demonstrates a 4.16-point reduction in process variation, indicating stabilized dispersion. In January, shortly after the implementation of corrective actions, the process amplitude peaked at 6, approaching the upper control limit. A subsequent increase in August was also observed; however, it remained within acceptable control limits, reflecting improved process stability. Table 3 summarizes the inventory accuracy results achieved between January 2023 and October 2024, reinforcing the positive impact of the implemented measures.

Table 3 - Inventory accuracy results from 2023 to 2024

Group	Items	Jan/2023*	Items	Dec/2023	Items	Jan/24	Items	Oct/2024
Cardboard Box	16	37.50%	17	58.82%	17	58.82%	17	85.24%
Consumption	6	35.00%	15	86.67%	13	86.77%	14	100.00%
Premium Count	6	100.00%	6	100.00%	7	100.00%	6	100.00%
Cups	15	20.00%	16	75.00%	16	75.00%	16	80.00%
Cheese Packaging	23	21.74%	20	85.00%	20	85.00%	21	100.00%
Yeast	39	38.72%	40	87.50%	35	87.50%	36	100.00%
Films	21	37.62%	20	40.00%	24	40.26%	24	33.33%
Forms/Cheese			7	71.40%	5	71.40%	6	100.00%
Mix Paper	6	46.94%	6	100.00%	6	100.00%	6	90.00%
Parmesan/Enzymes	3	56.67%	6	100.00%	3	100.00%	3	100.00%
Film	3		3	100.00%	2	100.00%	2	100.00%
Polystyrene	4	100.00%	4	100.00%	5	100.00%	5	100.00%

Prepared	13	36.85%	12	90.00%	12	98.60%	12	100.00%
Label	23	13.04%	23	42.17%	23	42.17%	23	50.87%
Sweet/Coconut Milk Label	6		6	66.37%	6	66.37%	6	77.67%
Road 7	23	49.57%	19	79.27%	21	79.27%	22	90.00%
Road 8	12	33.33%	13	82.31%	13	82.31%	14	94.00%
Plastic Bag	5	30.00%	5	100.00%	5	100.00%	7	100.00%
Stamps	9	40.78%	9	77.18%	9	77.18%	10	100.00%
Lids	16	25.00%	17	64.71%	18	64.71%	17	100.00%
	13,11	42.52%	80.32%	80.32%	13	80.77%	13.35	90.06%

According to Table 3, the average inventory accuracy in 2024 reached 90%, representing a substantial improvement over the previous year. This result indicates that the separation, supply, and inventory control processes operated with increased efficiency and reliability.

Most product groups met or exceeded the 90% target, reflecting process stabilization after the corrective actions implemented early in the year. However, labels, films, and cheese molds/release agents recorded lower accuracies, 60.87%, 33.33%, and 60%, respectively, highlighting persistent variability and the need for further improvement.

Conversely, products such as polystyrene, premium powdered milk, yeast, and cups achieved 100% accuracy, confirming the effectiveness of the interventions, particularly the enhanced separation control and the use of the OTIF (On Time In Full) indicator. Figure 18 illustrates the evolution of inventory accuracy between 2023 and 2024.

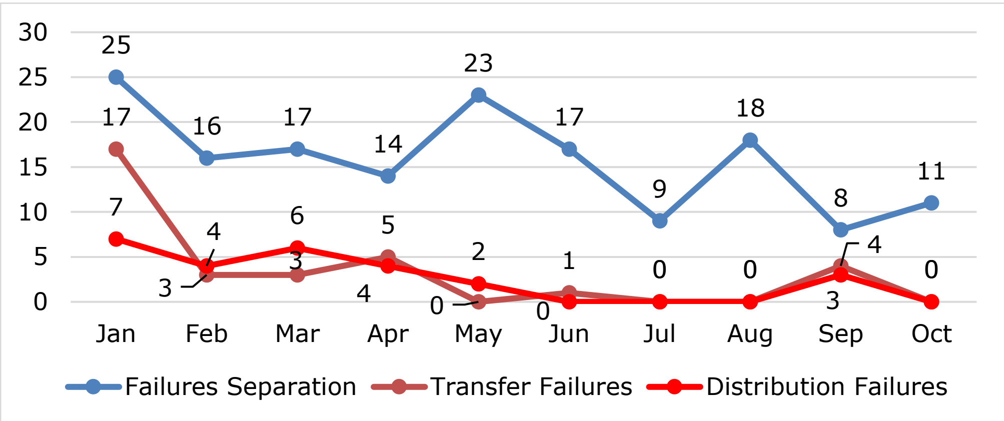


Figure 18 - Monitoring of delivery, transfer, and separation errors in 2024

In 2023, the priority activities focused on inventory management and separation (Figure 10). After further evaluation, the supply department was identified as a critical area for improvement and began receiving intensified monitoring.

The standardization of separation and delivery processes, pallet organization, and the implementation of the OTIF (On Time In Full) indicator led to a significant reduction in operational errors. Supply errors, which totaled seven occurrences in January, declined to an average of 2.11 between February and October 2024. Transfer errors decreased from an average of 4.33 (July to December 2023) to 0.75 in the same period of 2024. Separation errors fell sharply, from an average of 50.83 in 2023 to 15.80 in 2024, demonstrating substantial process improvements.

Following these interventions, there was a notable improvement in delivery performance. Filling 1 and Filling 2 lines achieved OTIF rates of 85.71% and 88.89%, respectively, both with 100% punctuality. The Sweet line, previously critical, improved to 79.78% OTIF and 94.74% punctuality. The Bottles line maintained excellent performance, achieving 100% across all evaluated indicators, reflecting robust process control.

Overall, the interventions significantly improved operational consistency and delivery efficiency. The findings reinforce that the structured application of continuous improvement and process control methodologies, such as Lean Six Sigma, was instrumental in elevating performance standards and ensuring sustained quality. Figure 19 summarizes the improvement trends observed across the supply and delivery performance indicators.

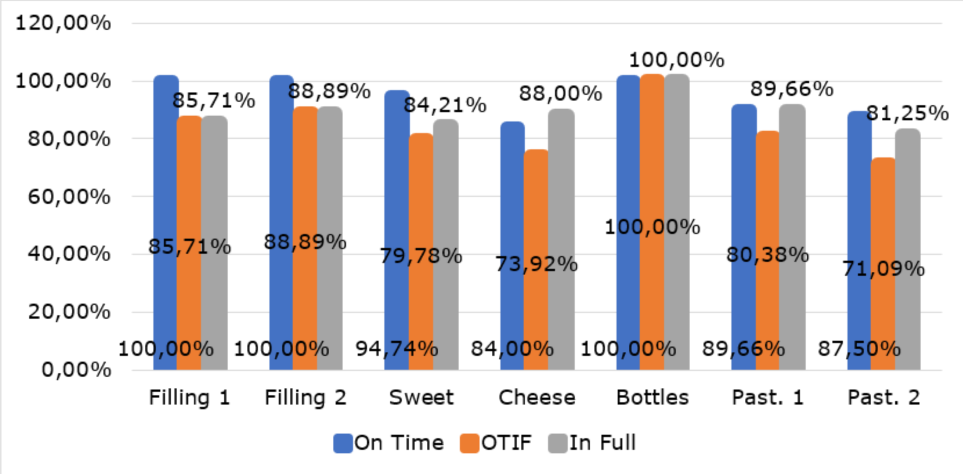
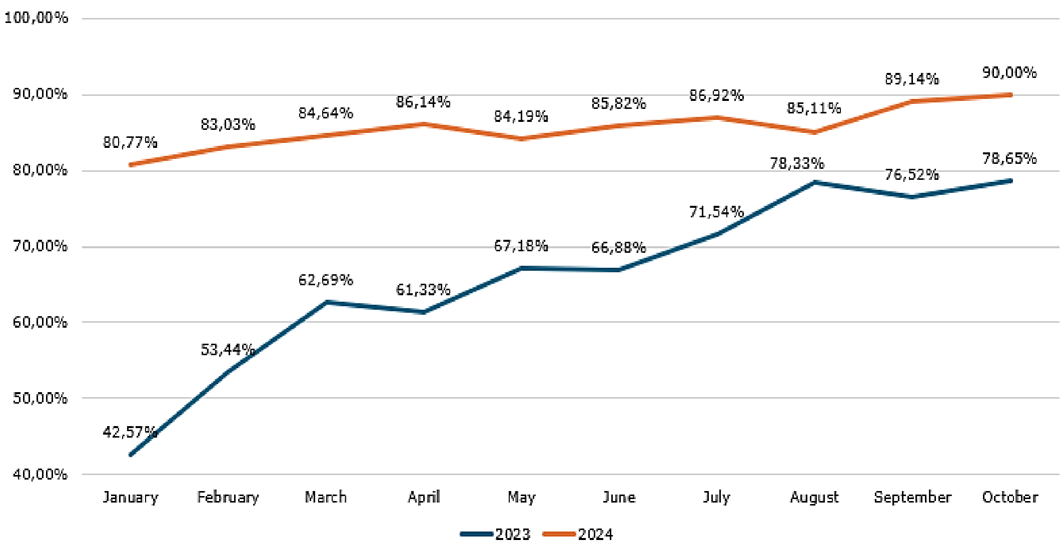


Figure 19 - OTIF from January to October 2024

The points related to on-time delivery quality were defined during meetings with production supervisors, where the delivery schedule was also established. Thus, the evaluation criteria were fully aligned between the supply and production departments. The actions taken to enhance delivery control significantly reduced supply errors, leading to improvements in inventory management. The Two-Sample Proportion Test confirmed the statistical significance of the improvements observed between 2023 and 2024. Figure 20 presents the evolution of inventory accuracy after the implemented interventions.



Data Summary						
Sample	Successes (X)	Total (N)	Sample Proportion (p)	P-Value	Hypotheses:	95% Confidence Interval
1	171	250	0.684	P-Value: P = 0.000 (rounded; effectively $P < 0.0001$), which is well below 0.05 → reject H_0	H_0 (null hypothesis): $p_1 - p_2 = 0$	It confirms that the true difference is negative → p_1 is significantly less than p_2
2	232	267	0.8689		H_1 (alternative hypothesis): $p_1 - p_2 < 0$ (one-tailed test to the left)	

Figure 20 - Evolution of inventory accuracy (2023–2024) with statistical validation through the Two-Sample Proportion Test

Throughout 2024, inventory accuracy consistently outperformed 2023 levels, demonstrating the effectiveness of the implemented improvement and control practices. From July onward, accuracy stabilized, whereas in 2023, stock accuracy fluctuated significantly in the second half due to separation and delivery errors, later mitigated through process enhancements. Figure 20 clearly illustrates the stabilization achieved through the inventory management improvements in 2024.

The statistical validation using the Two-Sample Proportion Test confirmed that the p-value was less than 0.05, leading to the rejection of the null hypothesis (H_0) and acceptance of the alternative hypothesis (H_1) that inventory accuracy in 2024 was significantly higher than in 2023. The project target was achieved, with accuracy increasing from 80.77% in January to 90% by October.

Following the DMAIC implementation, the company recorded a significant financial gain, reducing inventory overages and shortages by R$ 124,540.56, equivalent to a 36.63% decrease. Before the intervention, overages totaled R$ 165,456.87 and shortages R$ 49,968.99, summing R$ 339,966.42. After the improvements, the total was reduced to R$ 215,425.86, underscoring the effectiveness of the DMAIC project in optimizing inventory management and lowering operational costs.

3 CONCLUSIONS

The analysis of non-conformities in inventory management revealed critical factors negatively affecting inventory accuracy, highlighting the necessity of a systematic approach for identifying and correcting errors. The interventions implemented through the Lean Six Sigma project not only addressed immediate operational issues but also resulted in substantial financial gains, with inventory discrepancies reduced by R$ 124,540.56, corresponding to a 36.63% decrease in costs. These actions further established a foundation for continuous improvement, promoting a culture oriented toward operational efficiency, precision, and cost-effectiveness.

The project demonstrated that the stratification of errors, through tools such as Pareto analysis, was essential for prioritizing corrective actions. The identification of separation and delivery errors as the main causes of discrepancies enabled targeted interventions that significantly reduced failure rates. Additionally, the development and implementation of an operational procedures manual addressed the lack of standardization, minimized process variability, and reinforced quality consistency across operations. The adoption of the On Time In Full (OTIF) indicator also proved critical, ensuring that deliveries met timing and quantity requirements, enhancing supply reliability, and minimizing disruptions in production.

Continuous training initiatives strengthened operator competencies and fostered adherence to standardized procedures, while weekly meetings and the application of X-bar and R control charts provided systematic feedback on process performance. This structured monitoring enabled the early identification of deviations and the rapid execution of corrective actions, contributing to greater stability in operational routines.

The results achieved in 2024, with an average inventory accuracy of 90%, illustrate the effectiveness of the interventions. The sharp reduction in separation and transfer errors, along with the stabilization of processes observed from July 2024 onwards, confirms that improvements were sustainable rather than temporary. Nevertheless, residual variability in categories such as labels and films indicates areas requiring further refinement to reach excellence across all inventory components.

In conclusion, the improvements implemented not only optimized inventory management but also established a continuous learning environment that fosters resilience, innovation, and operational excellence. The experience gained during this project will be critical for sustaining advances and ensuring the organization is prepared to address future challenges in inventory management.

Future research could explore the application of emerging technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and advanced temporal analysis models to further enhance inventory optimization. The integration of these technologies can expand predictive capabilities, provide real-time operational visibility, and strengthen supply chain resilience, thereby extending the applicability of Lean Six Sigma and the DMAIC framework beyond the dairy industry into broader industrial contexts.

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