Journal of Industrial Intelligence
https://www.acadlore.com/journals/JII

Industrial Food Process Improvement by Waste Minimization in Pasta Packaging Using DMAIC Methodology

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Received: 02-13-2025 **Revised:** 03-16-2025 **Accepted:** 03-21-2025

Citation: S. Dabić-Miletić, "Industrial food process improvement by waste minimization in pasta packaging using DMAIC methodology," *J. Ind Intell.*, vol. 3, no. 1, pp. 20–30, 2025. https://doi.org/10.56578/jii030103.

Abstract: The food industry faces a growing challenge concerning improving operational efficiency and reducing waste to maintain competitiveness and meet sustainability purposes. This study explores the application of the Define–Measure–Analyze–Improve–Control (DMAIC) methodology as a critical part of the Lean Six Sigma (LSS) framework, as a structured, data-driven approach to identifying and eliminating raw material waste in the packaging phase of pasta production. The primary objective was to investigate the root causes of waste and implement targeted improvements to enhance industrial process performance in pasta packaging. Real production data from a pasta manufacturing facility were collected and analyzed, focusing on the packaging stage where significant losses had been observed. The DMAIC cycle guided the project through problem definition, data measurement, root cause analysis, process improvement, and long-term control strategies. The analysis identified key operational issues, including overfilling, equipment settings, and inadequate material handling. Equipment reconfiguration, staff training, and standardization of procedures were implemented, resulting in measurable reductions in raw material losses and improved packaging accuracy. An economic evaluation demonstrated that these improvements were effective from an operational standpoint and also generated a positive return on investment. The findings confirm that the DMAIC methodology provides a scalable and repeatable model for reducing waste and improving efficiency in food production environments. This research emphasizes the importance of structured problem-solving approaches in achieving ecologically and socially sustainable, as well as economically viable, process improvements in the food industry.

Keywords: Industrial optimization; Pasta packaging; Lean Six Sigma (LSS); Define–Measure–Analyze–Improve–Control (DMAIC); Waste reduction

1 Introduction

Modern manufacturing is continuously facing intense pressure to enhance operational efficiency, reduce the consumption of valuable resources, and eliminate all forms of waste to maintain competitiveness in an increasingly globalized and demanding market. This is especially dedicated to the food industry, where supply chains are tightly managed, product life is limited, and consumer expectations for quality, affordability, and sustainability are growing [1]. At the same time, companies across all industrial sectors are encountering mounting regulatory demands that enforce stricter compliance with environmental, safety, and quality standards. As a result, manufacturers are now expected not only to deliver products of consistently high quality but also to do so in a manner that is economically viable, environmentally responsible, and socially sustainable [1, 2].

Importantly, these challenges are not confined to the food industry alone. Significant operational and resource-related losses are prevalent across virtually every type of manufacturing, including textile production, electronics, automotive, metal processing, plastics, and the chemical sector [2]. These losses can take various forms, such as raw material waste, excess inventory, downtime, inefficient energy use, equipment malfunctions, defective products, rework, scrap, and non-value-adding activities. Often, these inefficiencies are symptoms of deeper systemic issues, such as inadequately planned workflows, lack of process standardization, insufficient training and supervision, and inadequate data-driven decision-making [3]. While individually these losses may seem minor or routine, their cumulative effect over time can result in substantial financial costs, reduced competitiveness, and diminished organizational sustainability.

In response to these challenges, there is an increasing need to adopt structured, methodical approaches that enable organizations to identify, analyze, and eliminate the root causes of waste and process variability. Among the most effective methodologies available for this purpose is Lean Six Sigma (LSS), a data-driven philosophy for quality improvement and process optimization. Within this framework, the DMAIC model consists of five phases: Define, Measure, Analyze, Improve, and Control, provides a systematic and repeatable structure for solving complex problems, enhancing process performance, and achieving lasting operational improvements [1, 3]. By integrating statistical analysis, cross-functional collaboration, and a focus on root cause elimination, the DMAIC approach enables manufacturing organizations to move beyond ordinary practice and pursue continuous, measurable, and sustainable improvements in quality and efficiency across diverse industrial environments.

One of the most critical challenges in modern food manufacturing is the effective management of waste generated within the logistics processes in the packaging phase. This stage of production bridges the transformation of finished goods into market-ready products and plays a pivotal role in ensuring product integrity, shelf-life stability, regulatory compliance, and consumer satisfaction [2]. However, it is also a frequent source of inefficiencies and material losses. Waste in packaging can arise from a range of causes, such as overfilling or underfilling packages, incorrect labeling, misalignment of sealing or cutting equipment, improper handling of packaging materials and delays in line changeovers or product transitions [1]. These issues are often compounded by poor integration between production and logistics systems, resulting in inventory mismatches, packaging material shortages or surpluses, and unplanned downtime. For example, inadequate settings of filling machines can lead to systematic overuse of product, directly reducing the amount of salable goods and inflating raw material costs. Similarly, damaged or rejected packaging due to handling errors or technical faults not only contributes to waste but can disrupt downstream distribution, increasing transportation inefficiencies and customer dissatisfaction [3, 4].

Despite the clear impact of these problems on cost and operational flow, packaging waste is rarely tracked with the same severity as production performance. Many companies rely on manual reporting, operate without standardized waste classification systems, and do not integrate packaging data into comprehensive performance monitoring frameworks. Consequently, interventions are often reactive and short-term, managing immediate symptoms without resolving the underlying process flaws. The need for waste reduction and process optimization is especially critical in countries like Indonesia, where wheat consumption for bakery products is projected to grow by about 2 kg per capita annually by 2030. With the bakery sector in Indonesia currently dominated by small-to-medium-sized enterprises (SMEs) accounting for two-thirds of the industry, rising demand will put additional pressure on packaging logistics and operational efficiency [1].

To overcome these limitations, companies need to adopt a proactive, but data-driven approach to waste management in packaging logistics. Implementing structured improvement methodologies such as LSS, and in particular the DMAIC framework, enables food manufacturing companies to systematically identify, measure, and address inefficiencies. Through detailed analysis of process variables, equipment performance, and human factors, it becomes possible to reduce food and packaging waste, stabilize industrial processes, and align packaging logistics more effectively with the demands of quality, efficiency, and sustainability as critical imperatives in the food industry [2].

To address these inefficiencies, this study applies the LSS methodology, a data-driven approach for process improvement that aims to reduce variability and eliminate the root causes of defects and waste. More specifically, the DMAIC is employed to investigate and solve a recurring problem in the pasta packaging process within a real-world production setting. The rationale for selecting the DMAIC methodology lies in several key advantages it offers [3, 5]:

- Structured Problem-Solving Framework: DMAIC provides a clear, step-by-step process that guides teams from identifying a problem to implementing sustainable improvements.

- Data-Driven Decision Making: The methodology emphasizes strict data collection and analysis, ensuring that decisions are based on objective evidence rather than assumptions.

- Determination of Primary Causes: Cause-and-effect diagrams, Pareto analysis, and statistical testing assist to DMAIC approach in uncovering the underlying reasons behind inefficiencies.

- Focus on Continuous Improvement: Instead of relying on one-off solutions, the DMAIC methodology fosters a continuous improvement culture focused on process control and sustained quality management.

- Interfunctional Cooperation: The approach encourages input from various branches included in food production, leading to solutions that are both technically sound, operationally feasible, and sustainable.

This study intends to analyze real production data from an industrial pasta manufacturing facility, focusing on the packaging stage, which has been identified as a critical point of raw material loss. The main objective is to investigate the causes of waste in this part of the process and to apply the DMAIC methodology as a structured and data-driven approach to improvement. The study seeks to reduce raw material waste, improve packaging accuracy, and enhance overall process pasta packaging efficiency. Planned actions include standardizing procedures, adjusting equipment settings, providing staff training, and strengthening monitoring practices. An economic evaluation will also be carried out to determine the cost-effectiveness and long-term sustainability of the implemented changes.

The structure of this paper is designed to provide a clear and systematic analysis of process improvement in pasta packaging through the application of the DMAIC methodology within the LSS framework. The Introduction outlines the background, objectives, and significance of the study. Section 2 explains the Lean Six Sigma methodology, focusing on its core principles, its structured and data-driven nature, and its applicability in industrial contexts, particularly in food manufacturing. Section 3 then defines the specific role of DMAIC within the broader LSS framework, detailing its five phases and emphasizing its effectiveness as a tool for process optimization. Section 4 provides an overview of the pasta manufacturing process, from raw material intake to the final packaging stage, setting the context for the study's focus on packaging-related inefficiencies. The core of the research is presented in Section 5, which details the practical application of the DMAIC methodology to reduce packaging waste. This includes examples such as minimizing overfilling of pasta bags and quantifying material losses through data analysis. Section 6 broadens the discussion by examining the practical implications of DMAIC implementation in the wider food industry, exploring its adaptability and potential for wider application. Finally, the Conclusion summarizes the main findings, evaluates the impact of the implemented improvements, and offers recommendations for future research and industrial adoption.

2 Lean Six Sigma Concepts in Industry

Lean thinking and the philosophy underlying the implementation of the Six Sigma concept, represent structured approaches to enhancing organizational performance. These methodologies support more effective strategic planning, thereby enabling improved competitiveness and positioning in the market. For an enterprise to achieve sustainable success, adherence to internationally recognized standards such as ISO 9001 (quality management), ISO 14001 (environmental management), and OHSAS 18001 (occupational health and safety management) is fundamental [3, 6]. The integration of these standards forms the basis for establishing an integrated management system, which in turn provides a foundation for the development of a LSS organization.

LSS organization consolidates the principles of both Lean and Six Sigma methodologies. Lean is a philosophy focused on the systematic elimination of waste, including all non-value-adding activities and process inefficiencies, thereby promoting streamlined and accelerated workflows. In contrast, Six Sigma emphasizes the reduction of process variation and the elimination of defects through the achievement of near-perfect outputs. Within the context of industrial application, the Lean Six Sigma concept is grounded in the following core principles [1, 3]:

-Satisfying customer requirements through timely and high-quality service delivery.

-Continuous improvement of business processes at all organizational levels.

-Ensuring comprehensive coordination and collaboration among all stakeholders to maximize collective benefit.

-Enabling informed and effective decision-making based on reliable data and measurable indicators.

The application of the LSS concept in manufacturing is supported by several key drivers identified across various academic and empirical studies, based on the experiences of companies that have adopted this methodology. The most frequently cited reasons for implementing LSS include improving product quality and production operations, increasing customer satisfaction, and enhancing market competitiveness. In addition to these primary motivations, other notable factors include cost reduction, error minimization in production, shorter process cycle times, increased process efficiency, and lower inventory levels [4, 6].

The successful implementation of the LSS concept within manufacturing environments is contingent upon a set of critical success factors [5]. Foremost among these is the professional training and education of personnel. Equally important are effective communication and the commitment of top management to the organization's strategic goals. Other relevant factors include organizational structure, project selection and prioritization, resource availability, performance measurement, employee selection, leadership, and an overall understanding of the significance of LSS. The relative importance of these factors can vary between companies and across countries. Furthermore, additional variables may influence implementation depending on the specific organizational context, operational practices, and external business environment [3, 6].

Despite the many advantages of implementing LSS, such as cost reduction, increased profitability, enhanced efficiency, accelerated process execution, and improved customer satisfaction, certain challenges may arise. These challenges are often associated with a lack of understanding regarding the core principles of the LSS concept, as well as insufficient knowledge of the tools and techniques involved in its application [6, 7]. The DMAIC methodology has proven to be a highly effective framework for the implementation of LSS in manufacturing processes. By employing a structured, step-by-step approach, DMAIC facilitates the integration of both Lean and Six Sigma principles, enabling detailed problem analysis and the identification of optimal solutions. This method ensures a systematic progression through problem definition, measurement, analysis, improvement, and control, thereby maximizing the benefits of LSS in industrial environments.

3 The Role of DMAIC Within the Lean Six Sigma Framework

The DMAIC methodology is a significant component of the LSS framework, which provides a systematic and data-driven approach to industrial process improvement. LSS, as a comprehensive quality management strategy, aims to minimize process variation and enhance performance by striving for near perfection, typically defined as no more than 3.4 defects per million opportunities. DMAIC is the primary methodology used to achieve this high level of operational excellence [2, 7]. Each phase of the DMAIC cycle plays a crucial role in identifying inefficiencies and transforming them into opportunities for measurable and sustainable improvement [1, 4] (Table 1):

Table 1. Phases and core components of the DMAIC framework

Phase	Description	Outcomes	Tools and Techniques
Defining	Problem description and defect identification defining existing performances defining goals training and education	Schedule of activities project goals graphics Sigma Metrics: An-Initial assessment	Brainstorming SIPOC model
Measurement	Gathering data about the current situation identification of possible causes of the problem	Data collection plan (standardization) Sigma metrics: An initial assessment cause prioritization (Pareto)	Pareto diagramcontrol charts process map
Analyzing	Data-driven root cause identification of relationships between variables	Brainstorming Ishikawa diagram FMEA data analysis	Logical analysis hypothesis testing Ishikawa diagram brainstorming
Improvement	Prioritization of causes through FMEA defining improved processes insurance of implemented actions	Corrective action plan process standardization	Brainstorming
Control	Measuring the effectiveness of project implementation making conclusions at the end of project implementation	Analysis and evaluation of the efficiency of the improved process monitoring plan for implemented corrective actions	Control charts descriptive statistics

Define: recognizing the problem, customer requirements, and project objectives; ensures alignment with business goals and sets a solid foundation for further analysis.

Measure: collecting relevant data to establish baselines and understand the current state of the process; accurate measurement is essential for quantifying problems and tracking improvements.

Analyze: employing statistical tools to identify root causes of process variation or defects; this phase moves the focus from symptoms to fundamental issues.

Improve: involving developing, testing, and implementing solutions aimed at eliminating the root causes of issues; it is a phase of experimentation, innovation, and change.

Control: focus is on sustaining improvements through standardization, monitoring, and continuous tracking; control plans and documentation are created to prevent disruptions that cause waste.

In industrial applications, such as food manufacturing, the DMAIC methodology offers a structured and disciplined approach to addressing specific operational challenges, including raw material waste, quality deviations, and production inefficiencies [5]. For instance, in a pasta packaging line where consistent overfilling results in excessive raw material consumption, DMAIC can be utilized to identify and rectify malfunctions within the filling system, thereby improving cost control and enhancing logistics processes' resilience [4, 6]. The integration of DMAIC within the broader LSS framework enables companies to resolve targeted issues while simultaneously fostering a culture of continuous improvement. This culture is driven by data, oriented toward measurable outcomes, and contributes significantly to long-term process optimization. As such, DMAIC represents a robust and effective methodology across both manufacturing and service industries, where operational performance and precision are essential for maintaining supply chain competitiveness [7].

4 Pasta Manufacturing: From Raw Material to Final Product

Pasta is a globally consumed staple food valued for its nutritional benefits, affordability, and versatility, with Italy leading both in production and consumption. While traditional high-quality pasta is made from durum wheat semolina, many producers worldwide use common wheat due to its lower cost, which can affect product quality. Despite its traditional production, the pasta industry has continually innovated to meet changing market demands, introducing products like wholegrain and gluten-free pasta [8]. These innovations require adjustments in processing, as changes in raw materials significantly influence the final product's texture, cooking methods, and general quality [9]. Understanding and managing these process variables is essential to maintaining high standards when using alternative ingredients.

Pasta production, as a component of the food industry, presents generators of unique technological and operational challenges that distinguish it from other food manufacturing processes. From raw material selection to final packaging, each stage must meet strict quality and consistency standards [10]. The production complexity involves ensuring food safety, preserving nutritional value, and maintaining the structural integrity and visual appeal of the product. Factors such as dough hydration, drying conditions, and environmental variables can significantly influence the market [4]. Some of the most critical challenges include minimizing production defects, reducing waste during packaging, and ensuring product uniformity, all of which have a direct impact on consumer perception and market competitiveness. This production consists of three main phases [8, 9]:

a. Processing - includes mixing raw materials (semolina flour, water, and possibly additives) and forming the dough, which is then shaped into the desired format (spaghetti, penne, etc.); the quality of the raw material, especially durum wheat semolina, can significantly influence the final appearance and integrity of the product.

b. Drying - one of the most critical stages; if not properly optimized (e.g., temperature, duration, and humidity), it can result in defects which often become apparent only during the packaging stage.

c. Packaging - often reveals previously hidden defects from earlier stages; breaks, fragments, or discoloration become noticeable to the end consumer; while these defects do not affect food safety, they significantly damage the perceived quality of the product.

The packaging phase has respective significance compared to other stages of pasta production because it represents the final point at which product quality can be visibly assessed before reaching the consumer. It is the stage where all upstream variations or defects, whether from processing or drying, become apparent and, if not properly controlled, can lead to immediate rejection by customers or retailers [8]. Moreover, packaging directly influences shelf appeal, brand perception, and regulatory compliance related to declared net weight and labeling accuracy, making it a critical control point for both quality assurance and consumer confidence.

The majority of losses that happen during the packaging phase in pasta production can be traced back to several underlying issues within earlier stages of the process. One of the main causes is mechanical damage that happens during internal transportation of the product within the facility. Inappropriate handling, excessive vibrations, or inadequate conveyor system configuration can lead to micro-fractures or visible breakage, which often go unnoticed until the final packaging stage [9, 10]. Another significant factor is the lack of thorough quality control following the drying phase. If defects such as uneven drying, cracks, or brittleness are not detected and addressed in time, they will inevitably compromise the product's appearance and durability during packaging and distribution. Additionally, the absence of advanced detection technologies in the early stages of production prevents the timely identification of structural flaws, which could otherwise be corrected before the product reaches the final stages. These difficulties result in elevated breakage rates, increased waste, and a higher frequency of product returns from distributors and shops. Furthermore, they contribute to negative consumer experiences, which manifest through complaints, dissatisfaction, and damage to the brand's reputation. In more extreme cases, poorly controlled packaging defects can even lead to contamination risks, especially if cracked pasta allows for external particles to enter, threatening food safety and exposing manufacturers to legal and financial liabilities [7, 8].

As part of the Improve phase within the DMAIC methodology, one of the implemented solutions involved a series of targeted corrective actions designed to address the root causes of variation identified in the packaging process. These actions included the precise recalibration of all weighing scales to ensure accurate and consistent measurements, the structure of automated sensors to regulate conveyor belt speed in real time, and the implementation of specialized training programs for packaging line operators to improve their technical skills and process awareness [3]. Concurrently, these measures contributed to achieving greater consistency in package weights, significantly reducing raw material waste, and enhancing overall industrial process resilience. As a result, both product quality and customer satisfaction were improved. The effectiveness of this solution is further demonstrated through a practical case study that illustrates its real-world application and measurable benefits.

5 Specificities of the DMAIC Methodology in Packaging Waste Reduction

In contemporary manufacturing and distribution systems, packaging waste has emerged as both a significant environmental challenge and a financial disservice. Companies striving to enhance sustainability and simplify processes are increasingly adopting structured problem-solving methodologies to address this issue [2]. One of the most prominent and effective frameworks is the DMAIC methodology, which is a core component of the LSS approach aimed at process improvement through the reduction of variation and elimination of waste [1, 3].

When applied specifically to packaging processes, DMAIC enables organizations to systematically investigate and address inefficiencies related to excessive or non-essential material use. The methodology facilitates a data-driven approach to identify the root causes of packaging waste, assess their impact on performance and cost, and implement targeted improvements [4, 6]. Through iterative refinement and continuous monitoring, DMAIC supports the development of more sustainable packaging practices while also contributing to cost savings and enhanced operational efficiency (Table 2). As such, it serves as a critical tool for companies committed to both environmental sustainability and competitive advantage.

Table 2. DMAIC framework implementation for minimizing packaging waste in pasta manufacturing

DMAIC Phase	Objective	Packaging Waste-Specifics
Defining	Clearly defining the problem, project goals, and expectations.	Characterizing packaging waste (e.g., excess material, misused or damaged packaging). Identifying key stakeholders (production, logistics, marketing). Setting measurable goals (e.g., reduce waste by 25% in 6 months).
Measuring	Quantify the current state and locate where waste occurs	Collect data on packaging material used vs. discarded (type, weight, volume). Training employees and documenting standard procedures. Identifying measurement points (e.g., damage rate, waste per batch).
Analyzing	Identifying root causes of waste generation.	Using tools like Pareto analysis, Fishbone diagrams, and 5 Whys. Evaluating whether the packaging design is irrational or inefficient. Analyzing process inefficiencies or damage during handling.
Improving	Developing and implementing waste-reduction solutions	Redesign packaging (smaller, recyclable, reusable). Introducing automation to minimize human error. Improving handling, warehouse, and transport procedures. Testing solutions through pilot programs.
Controlling	Supporting improvements and preventing regression	Implementing control mechanisms (e.g., regular waste tracking). Using dashboards and visual management tools. Training employees and documenting standard procedures.

5.1 Case Study: Minimizing Packaging Waste from Pasta Bag Overfilling

In a pasta production facility, a significant issue was identified during the packaging stage related to excessive raw packaging material usage due to overfilling. The standard weight for each package is 500 grams; however, frequent measurements revealed that many of the packages contained up to 530 grams of pasta. This 30-gram surplus per package may seem minor at first glance, but when scaled across thousands of units produced daily, it results in substantial raw material loss. Over time, this inefficiency leads to increased production costs, affects inventory management, and reduces the overall profitability of the company.

The core cause of this variation was traced to inconsistencies in the weighing and filling systems, as well as a lack of precise process control. As a result, the factory initiated a DMAIC approach to systematically identify the origins of waste, optimize the packaging process, and ensure product weight accuracy without compromising quality or compliance standards. The DMAIC method was specifically defined and tailored for this case to address the issue of raw material waste during pasta packaging. Each phase of the methodology was structured to systematically identify inefficiencies, reduce variation, and implement sustainable improvements. The steps were conducted as follows:

Defining (Define phase): Excessive pasta in packaging exceeds the standard 500 g weight, leading to raw material waste and increased production costs; project goals were established, and key stakeholders were identified.

Measurement (Measure phase): Data were collected from 5 packaging lines during one working week; by measuring, it was determined that the average weight per package is 512 g, with a standard deviation of 8 g, which significantly exceeds the allowed tolerance of ±5 g.

Analysis (Analyze phase): The analysis found that the main causes of weight variation are the following:

-Incorrectly setting scales on machines.

-Varying belt speed, which affected the amount of pasta distributed.

-Insufficient operator training on proper machine setup.

Improvement (Improve phase): the following measures were taken:

-Re-calibration of all scales.

-Installation of a sensor for automatic tape speed correction.

-Training was held for all packaging line operators.

After implementation, the average weight per package was reduced to 499 g, with a standard deviation of 3 g. Raw material waste was reduced by 27%, which led to savings of EUR 4,200 per month.

Control (Control phase): Weekly monitoring of package weight and monthly control of scale calibration were introduced, which achieved long-term stability of the process.

Figure 1 illustrates the distribution of pasta package weights before and after the implementation of process improvements. Before the intervention, the majority of packages exceeded the target weight of 500 grams, indicating a consistent trend of overfilling. This not only contributed to material waste but also increased production costs over time. In contrast, following the improvement measures, the weight distribution becomes more concentrated around the desired target, with a notable reduction in variability. This demonstrates enhanced process control and a more efficient use of packaging materials, ultimately supporting both quality consistency and sustainability goals.

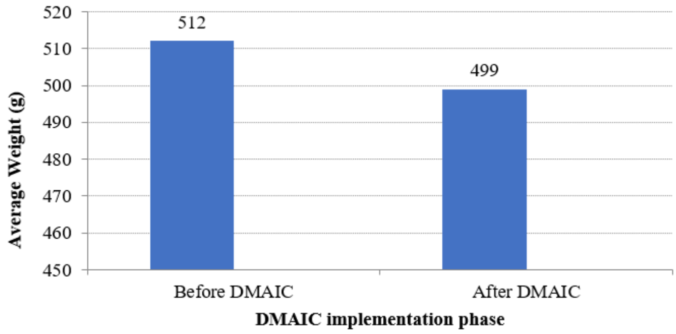

Figure 1. Weight distribution before and after DMAIC process

5.2 Case Study: Calculating

The average weight per package is calculated as the mean value of the weights of all the packages measured:

$$\text{Average Weight } = \frac{\sum_{i=1}^{n} xi}{n} \tag{1}$$

where,

- Xi is the weight of the $i-th$ package
- n is the number of packages in the sample

For example, if the average weight per package was measured as 512 g, it means that $\sum_{\mathrm{i}=1}^{\mathrm{n}} xi$ was 512 g per package on average.

The standard deviation is used to assess the variation in package weights and is calculated using the following formula:

$$\sigma = \sqrt{\frac{1}{\sqrt{n}} \sum_{i=1}^{n} (xi - \mu)} \tag{2}$$

Waste reduction is calculated as the percentage reduction of the weight exceeding the allowed tolerance. Before the improvement, the average package weight was 512 g, and after the improvement, it was 499 g.

where,

- σ is the standard deviation
- xi is the weight of the i-th package
- μ is the average weight of the packages
- n is the number of packages in the sample

In this case, the standard deviation was 8 g before improvements and was reduced to 3 g after improvements.

The waste reduction percentage is calculated as:

$$\text{Waste reduction}(\%) = \frac{\text{Recognized waste reduction}}{\text{Initial waste}} \times 100 \tag{3}$$

If we assume that the initial waste was 530 g (the maximum allowed weight) and it has now been reduced to 499 g:

$$\text{Waste reduction } = \frac{530 - 499}{530} \times 100 = 5.8\% \tag{4}$$

However, the example mentions that waste was reduced by 27%, which can be calculated based on the total reduction in weight and the reduction in variation of the packaging.

The cost savings from reduced waste can be calculated by determining the amount of raw material saved and its cost. If the 27% reduction resulted in savings of 4,200 EUR per month, this means that each kilogram of raw material that was previously wasted has a value that reflects this cost savings.

To calculate this, the following formula is used:

$$\text{Savings} = \text{Weight reduction (kg)} \times \text{Costs (per kg)} \tag{5}$$

Thus, in this case, all these formulas are connected to derive the exact values of waste reduction and calculate the savings.

This case study demonstrates the effective and practical application of the DMAIC methodology in reducing material waste and optimizing production processes within a pasta packaging facility. By systematically identifying and addressing the root causes of overfilling, such as improperly setting weighing scales, unpredictable conveyor belt speeds, and insufficient operator training, the organization was able to implement targeted corrective actions that significantly improved operational efficiency.

As a result of these interventions, the average package weight was successfully adjusted to fall within the acceptable tolerance range, and the variation in weight (as measured by standard deviation) was markedly reduced. This not only ensured compliance with regulatory weight standards but also enhanced product consistency and customer satisfaction. Notably, the process optimization led to a 27% reduction in raw material waste, translating into monthly cost savings of approximately 4,200 EUR.

A critical component of the project's success was the structured implementation of the Control phase, which introduced ongoing process monitoring, routine weight checks, and scheduled scale calibrations. These measures helped to preserve the achieved improvements and supported long-term process stability.

The primary benefits of this approach include measurable cost reductions, improved product quality, enhanced regulatory compliance, and a more sustainable use of resources. Additionally, by promoting a practice of continuous improvement and relying on data-driven decision-making, the company strengthened its overall process reliability and competitive position in the market. However, potential weaknesses include the significant initial investment of time and resources required for thorough data collection, staff training, and procedure reconfiguration. Resistance to change from personnel and the need for cross-functional collaboration can also pose obstacles during the initial phases of DMAIC projects, which considered socially unsustainable. Moreover, the sustainability of improvements depends heavily on the consistency of monitoring practices and the company's loyalty to defined targets over time.

6 Practical Use of DMAIC in the Food Industry

The food manufacturing industry plays a vital role in ensuring a stable supply of safe, high-quality food products to consumers worldwide. However, this industry frequently encounters serious operational challenges [10]. These include process variability, where the same process can produce different results each time, leading to inconsistent product quality. Additionally, the industry often struggles with excessive material waste, long production downtimes, high operational costs, and limited responsiveness to market demands [7, 8]. These issues not only affect profitability but can also impact food safety and customer satisfaction.

To address these problems, many companies have started turning to structured improvement methodologies such as LSS. One of the most widely used tools within LSS is the DMAIC framework. This step-by-step approach helps organizations identify the root causes of problems, implement targeted improvements, and sustain positive results over time [4].

Despite the proven success of LSS and the DMAIC methodology in industries such as automotive and electronics, the food industry has been relatively slow to embrace these approaches. Several factors may contribute to this uncertainty. First, the food industry tends to be more conservative and resistant to change, often relying on traditional practices that have been in place for decades. Second, it operates under strict regulatory frameworks related to food safety, quality standards, and hygiene, which can make process changes more complex and risk-averse. Finally, there is often a lack of awareness or understanding among food industry professionals about how LSS and DMAIC can be effectively applied to improve efficiency, reduce waste, and enhance product quality without compromising compliance. However, in recent years, a growing number of case studies have shown that applying DMAIC in food production environments can lead to substantial improvements [1]. These include more reasonable product consistency, reduced waste, improved efficiency, and lower production costs. As a result, there is increasing interest in adopting LSS as a practical tool to overcome the complex challenges of modern food manufacturing [5].

One clear example is from a gingerbread-producing company in Norway. The company had a problem with overfilling packages, which caused waste and extra expenses. Using DMAIC, they studied the situation in detail. They measured where the errors were happening and analyzed the reasons behind them. As a result, they upgraded their filling machines and made the process more consistent. This reduced weight differences by more than 30% and ensured the economic sustainability company [11]. In another case, a meat processing company in Ireland used

DMAIC to improve the way meat was cut. The cutting process was not consistent, which meant that some meat was being wasted. By analyzing this process using tools like laser guides, the company improved accuracy and reduced meat losses. This helped reduce waste, improve the quality of the product, and make customers more satisfied [12]. A baked goods company in Taiwan faced issues with product defects during the baking process. The products were sometimes changing shape or quality after baking. They used DMAIC to carefully study baking temperatures and timing. After finding the key problems, they made important changes to the process. In just six months, the number of defective products dropped by about 30% [13]. Another example is from a large beverage company that used both DMAIC and Industry 4.0 technologies (like sensors and data analytics). Management strived to improve the efficiency of their production machines. With more satisfactory data and analysis, they identified and reduced machine downtime. This raised their Overall Equipment Effectiveness (OEE) more than 5%, showing that combining DMAIC with modern digital tools can be significantly effective [14].

These real-world examples demonstrate how the DMAIC method can be effectively applied to solve practical problems in the food industry. Unlike some abstract improvement models, DMAIC offers a hands-on, structured approach that is directly applicable to daily operations on the production floor. From identifying inconsistencies in packaging and reducing waste to optimizing equipment performance and minimizing product defects, DMAIC provides a clear pathway for diagnosing problems, implementing targeted improvements, and maintaining control over results [11, 13].

One of the key strengths of DMAIC lies in its flexibility and adaptability to different contexts. Whether the challenge involves excessive use of raw materials, prolonged preparation sequence times between production runs, or frequent equipment failures, the five phases of DMAIC provide a structured and step-by-step approach to identifying root causes and implementing effective solutions. This structured approach not only helps companies understand the root causes of inefficiencies but also allows them to test solutions on a small scale before making broader changes [15]. This minimizes risk and creates confidence among employees and management alike. Moreover, DMAIC encourages data-driven decision-making, which is especially important in the food industry where even small variations can affect product quality, shelf life, or regulatory compliance. By relying on measurable indicators rather than assumptions, companies can make knowledgeable selections that lead to sustainable improvements at all supply chain levels [14, 16].

7 Conclusions

LSS and its core DMAIC methodology have become essential tools for enhancing operational performance across various industries. In the food manufacturing sector, where consistency, quality, and waste reduction are critical, these structured, data-driven approaches offer substantial practical benefits. One of the key advantages is the ability to systematically reduce raw material losses without compromising product quality or safety standards, which is particularly valuable in massive production environments. By focusing on root cause analysis and continuous improvement, LSS enables companies to streamline processes, increase output, and achieve significant cost savings, all while maintaining compliance with strict regulatory requirements. The application of these principles in food processing not only enhances production efficiency but also supports long-term sustainability and competitiveness in a tightly regulated market.

In this study, real production data were collected and analyzed from a pasta manufacturing facility, with a particular focus on the packaging stage as a critical point in the process where notable raw material losses had been consistently observed. The primary objective of this research was to investigate the underlying causes of waste in this phase of production and to evaluate the effectiveness of structured process improvement interventions based on the DMAIC methodology. The study aimed to not only reduce raw material waste but also to improve overall process efficiency and ensure long-term sustainability in industrial practices. Through detailed analysis, several operational inefficiencies were uncovered. The most significant examples are overfilling during packaging, inaccuracies resulting from poorly calibrated equipment, and deficiencies in material handling procedures. These issues, although individually small, cumulatively cause substantial raw material loss and variability in product quality. To address these concerns, a series of targeted improvement measures was developed and implemented. These included process standardization, resetting of packaging devices, staff retraining, and enhanced monitoring protocols. These activities led to a measurable reduction in raw material losses, improved packaging precision, and a more stable and predictable production output. Furthermore, a comprehensive economic analysis was conducted to assess the financial implications of the implemented improvements. The findings confirmed that the waste reduction not only had a positive environmental impact but also translated into significant cost savings. The improvements produced a favorable return on investment, validating the financial viability of the changes made. Altogether, the results of the study underscore the practical effectiveness of the DMAIC methodology as a structured, but data-driven approach to solving complex operational problems. The methodology proved to be not only an effective tool for waste reduction but also a repeatable and scalable model for driving continuous improvement in industrial food production environments.

As part of a structured improvement initiative, the company applied the DMAIC methodology to tackle inconsistencies in the packaging phase. During the Measure phase, data were collected from five packaging lines over one workweek. The measurement revealed that the average package weight was 512 grams, with a standard deviation of 8 grams, significantly exceeding the allowed tolerance of ±5 grams. In the Analyze phase, the root causes of weight variation were identified as improperly calibrated scales on the machines, inconsistent conveyor belt speeds affecting dosage, and insufficient operator training on proper machine adjustments.

The findings of this study highlight the tangible benefits of applying the DMAIC methodology within the food manufacturing sector, particularly in addressing waste and inefficiencies in critical production stages such as packaging. By leveraging real production data and following a structured problem-solving framework, the company was able to achieve measurable improvements in process control, product consistency, and cost efficiency. These results are especially relevant for SMEs, which often operate with limited resources and tighter margins. For such companies, even modest reductions in raw material waste or process variability can lead to significant financial and functional improvements. The structured nature of DMAIC makes it a practical and scalable solution for SMEs seeking to implement continuous improvement initiatives without requiring major capital investments. As this case demonstrates, when properly applied, LSS principles can support food industry SMEs to improve competitiveness, enhance quality, and move toward more sustainable and resilient company procedures.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there is no conflict of interest in the study.

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