Improving Butter Production Yield in a Dairy Company: A Lean Six Sigma Agile Approach

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Master's Dissertation

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Master's in Mechanical Engineering

2024-06-27

Abstract

The dairy market has a significant impact on the global economy, and the dairy sector in Portugal makes a notable contribution to the national economy through the production of dairy-derived foods such as butter, cheese, yoghurt, and ice cream. The aim of the present thesis was to reduce the Specific Cream Consumption (SCC), which is the amount of cream needed per kilogram of butter produced. To achieve this objective, three methodologies were essentially applied in an integrated manner: Lean, Six Sigma, and Agile. This hybrid Lean Six Sigma Agile (LSSA) approach involved identifying and improving key production parameters to enhance process yield. By integrating Lean's waste reduction, Six Sigma's data-driven decision-making, and Agile's flexibility, the project improved process performance, reduced variability, and maintained high-quality standards in butter production.

Initially, the entire production process was analysed to identify variables, improvement opportunities, and process constraints at each stage. Then, a statistical analysis was carried out using *Minitab* software, with historical data provided by Company X, which included some variables from 2023 and early 2024, to identify the variables with the greatest impact on the SCC, and it was concluded that these variables were Moisture and Crystallisation Time.

Thus, knowing that Crystallisation Time was a difficult variable to change due to the Push model followed by the company, the next step was to study the Moisture variable, which represents the amount of water present in the butter, expressed as a percentage. To this end, brainstorming sessions with the operators and statistical tests were carried out over a week, revealing which variables had the greatest impact on Moisture. From this study, a One Point Lesson (OPL) was created to standardise Moisture regulation, resulting in higher Moisture levels and a reduction in SCC. Furthermore, weekly and monthly meetings were held for each team leader to present the implemented actions each week. *Gemba Walks* were conducted to observe and monitor Moisture levels in the field. *Daily Kaizen* was also implemented, consisting of brief meetings that allow team members to share information, discuss complaints, and propose potential solutions. As the project progressed, the company also began to monitor more process variables.

This thesis demonstrated that LSSA methodologies effectively reduced SCC, improved production processes and maintained product quality. Although the main objective of reducing the SCC has been achieved, the target values set before the start of the project have not been reached yet. Possibly, the increase in Moisture through process variables meant that other process parameters also changed, such as the amount of buttermilk generated in the cream's churning stage, which was not monitored by the company. Nevertheless, the integration of these methodologies presented significant process improvements, highlighting the relationship between Lean's efficiency, Six Sigma's precision, and Agile's adaptability to achieve project objectives and improve the overall yield of the butter production process.

Resumo

Melhoria do Rendimento de Produção de Manteiga numa Empresa de Lacticínios: Uma Abordagem *Lean Six Sigma Agile*

O mercado de lacticínios tem um impacto significativo na economia global, e o setor de lacticínios em Portugal contribui de forma notável para a economia nacional através da produção de alimentos derivados do leite, como manteiga, queijo, iogurte e gelado. O objetivo da presente tese foi reduzir o Consumo Específico de Nata (*SCC*), que é a quantidade de nata necessária por kilograma manteiga produzido. Para atingir este objetivo, foram aplicadas essencialmente três metodologias de forma integrada: *Lean, Six Sigma* e *Agile*. Esta abordagem híbrida (*LSSA*) envolveu a identificação e melhoria dos parâmetros chave de produção para melhorar o rendimento do processo. Integrando a redução de desperdício do *Lean*, a tomada de decisões baseada em dados do *Six Sigma* e a flexibilidade do *Agile*, o projeto melhorou o desempenho do processo, reduziu a variabilidade e manteve altos padrões de qualidade na produção de manteiga.

Inicialmente, todo o processo de produção foi analisado para identificar variáveis, oportunidades de melhoria e restrições do processo em cada etapa. De seguida, realizou-se uma análise estatística usando o programa *Minitab*, com dados históricos fornecidos pela Empresa X, que incluíam algumas variáveis de 2023 e início de 2024, para identificar as variáveis com maior impacto no SCC, concluindo-se que essas variáveis eram a Humidade e o Tempo de Cristalização.

Assim, sabendo que o Tempo de Cristalização era uma variável difícil de alterar devido ao modelo de *Push* seguido pela empresa, o próximo passo foi estudar a variável Humidade, que representa a quantidade de água presente na manteiga, expressa em percentagem. Para tal, foram realizadas sessões de *brainstorming* com os operadores e testes estatísticos ao longo de uma semana, que revelaram quais as variáveis com maior impacto na Humidade. Através deste estudo, foi criada uma *One Point Lesson* (*OPL*) para normalizar a regulação da Humidade, resultando em níveis de Humidade superiores e redução do *SCC*. Além disso, foram realizadas reuniões semanais e mensais para cada líder de equipa apresentar as ações implementadas em cada semana. *Gemba Walks* foram realizados para observar e monitorizar os níveis de Humidade no terreno. *Kaizen Diário* também foi implementado, consistindo em reuniões breves que permitem aos membros da equipa partilhar informações, discutir reclamações e propor potenciais soluções. À medida que o projeto avançava, a empresa também começou a monitorizar mais variáveis do processo.

A tese demonstrou que as metodologias LSSA reduziram o *SCC* de forma eficaz, melhoraram os processos de produção e mantiveram a qualidade do produto. Embora o objetivo principal de reduzir o *SCC* tenha sido alcançado, os valores alvo definidos antes do início do projeto não foram ainda totalmente atingidos. Possivelmente, o aumento da Humidade através das variáveis do processo significou que outros parâmetros do processo também alteraram, como a quantidade de leitelho gerada na etapa de batedura da nata, que não era monitorizada pela empresa. No entanto, a integração destas metodologias apresentou melhorias significativas no processo, destacando-se a relação entre a eficiência do *Lean*, a precisão do *Six Sigma* e a flexibilidade do *Agile* para atingir os objetivos do projeto e melhorar o rendimento global do processo de produção de manteiga.

Acknowledgments

Five years. Half a decade marked by challenges and triumphs, late nights and early mornings, doubts and discoveries that have profoundly shaped the journey to this thesis. I express my deepest gratitude to those who have consistently inspired, challenged, and supported me through this pivotal chapter of my life.

To my family, whose love and patience carried me through. To my parents, Isabel Duarte and Paulo Vassalo, both engineers, who provided not only roots but also wings to pursue the best education possible. Also to my brother Henrique, for the support, brotherhood and care. I am deeply thankful to each of you for turning my academic journey into a beautiful chapter of our shared story.

To Raquel Jesus, thank you for the constant support and all the knowledge transmitted. Your ability to demonstrate both personal and professional competencies has been truly inspiring.

To Professor José Barros Basto, for all the help, availability and guidance that was crucial in elevating my work to its greatest potential.

To *Kaizen Institute* for welcoming me from day one. These months were marked by my first real professional experience, which not only enhanced my engineering skills but also fostered significant personal growth. A special mention to my team leader Fátima Carneiro for her outstanding professional competence and all the support.

To FEUP, for these incredible five years that have provided me with extensive knowledge, numerous skills, and, most importantly, friendships and memories that will forever hold a special place in my heart.

To my friends from Porto and Viseu, for all the moments, laughs, and memories created over these years. It was a collaborative journey that culminated in the writing of this thesis. Your support and understanding have been invaluable. A special mention to my partner, Teresa Viana, for all the kindness and affection. Your disruptive ideas have significantly elevated the quality of this work. It's a true pleasure to share life's moments with you!

I am deeply grateful. Thank you all from the bottom of my heart!

"Progress is impossible without the ability to admit mistakes."

Masaaki Imai

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Acronyms and Symbols

5S	Sort, Set in order, Shine, Standardize, Sustain
6S	Adds 'Safety' to the traditional 5S principles
CAGR	Compound Annual Growth Rate
CI/CD	Continuous Integration/Continuous Delivery
Cpk	Process Capability Index
CSR	Corporate social responsibility
CtQ	Critical to Quality
DMAIC	Define, Measure, Analyze, Improve, Control
DMADV	Define, Measure, Analyze, Design, Verify
DMIS	Dairy Management Information Systems
DOE	Design of Experiments
DPMO	Defects Per Million Opportunities
FMEA	Failure Modes and Effects Analysis
GQCDM	Growth, Quality, Cost, Delivery, and Motivation
HACCP	Hazard Analysis and Critical Control Points
ISGLSAMS	Integrated Sustainable Green Lean Six Sigma Agile Manufacturing System
JIT	Just-In-Time
Kaizen	Continuous Improvement
KPIs	Key Performance Indicators
LM	Lean methodology
LSS	Lean Six Sigma
LSS 4.0	LSS with Industry 4.0
LSSA	Lean Six Sigma Agile
OEE	Overall Equipment Effectiveness
OPL	One Point Lesson
QI	Quality Improvement
SCC	Specific Cream Consumption
SIPOC	Suppliers, Inputs, Process, Outputs, Customers
SMED	Single Minute Exchange of Dies
SPC	Statistical Process Control
SS	Six Sigma methodology
TQM	Total Quality Management
VoC	Voice of the Costumer
VSM	Value Stream Mapping
XP	Extreme Programming

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Chapter 1

Introduction

The current dissertation was carried out at *Kaizen Institute* (*KAIZEN*, https://kaizen.com/pt/, Matosinhos, Portugal) for a period of five months (February to June). *Kaizen Institute* is a global firm that trains and implements Continuous Improvement and Lean Management in different organisations worldwide.

This dissertation was developed within a Project established between *Kaizen Institute* and a Portuguese food products company specialising in dairy and its derivatives. The client company offers yoghurt, cheese, butter, and cream products. This thesis focuses on the production process of butter since it is a product with a significant opportunity for improvement. The butter is a dairy product derived from cream, the fat of milk (Cheng et al., 2023).

Due to confidentiality reasons, the actual name of the company and project title cannot be disclosed. Within this dissertation, the client company is designated as Company X.

The main goal of project is to create a continuous improvement culture for Company X's butter production sector, enhance productivity and quality strategies, and increase market competitiveness by improving the yield of the butter process. To achieve this goal, the butter production section implements the hybrid Lean Six Sigma Agile (LSSA) methodology, which combines the principles of Lean, Six Sigma, and Agile methodologies.

This chapter provides contextualisation, motivation, and an overview of the company's profiles, research questions, objectives, and methodology.

1.1 Contextualization of the Project and Motivation

The dairy sector in Portugal has a significant impact on the national economy. The primary activity of the dairy industry is mainly the production of foods derived from milk, ranging from pasteurised milk to butter, cheeses, yoghurt, and ice cream (Gösta Bylund, 1995). The major Portuguese processing dairy company was founded by associating with northern Portugal's three largest milk cooperatives. In the food industry, milk and dairy products constitute 12% of overall sales, ranking as the third most crucial sub-sector in sales volume (Marramaque and Cardoso,

2021). The Portuguese dairy sector is a source of employment, generating more than 11,500 direct jobs in dairy farms and the processing industry (Marramaque and Cardoso, 2021).

In 2021, Portuguese dairy companies produced around 696.000 tonnes of drinking milk, 115.000 tonnes of yoghurt, 65.000 tonnes of cheese, 30.000 tonnes of butter, and 22.000 tonnes of cream (Statista, 2023). The sector comprises more than 459 companies, ranging from small traditional dairies to large companies that continually invest in new technologies, equipment, packaging, and environmental practices. These investments are necessary to improve productivity and quality strategies, adapting to the continuously increasing market competition. Companies must maximise production performance by ensuring a suitable operations strategy to meet customer demands.

Manufacturing management's improvement initiatives have been implemented in dairy companies to achieve this. Lean (L), Six Sigma (SS), Agile, and hybrid Lean Sigma Six (LSS) methodologies are some examples of these initiatives. Lean enhances process performance by eliminating waste and errors and improving speed, flow, and cost. Six Sigma improves process capability by analysing and solving problems, ensuring consistent quality and meeting customer requirements. Agile methodology, an iterative approach to software development and project management, emphasises flexibility, collaboration, and responsiveness to change. These methodologies, especially the hybrid LSS methodology, have increasingly been implemented (Widiwati et al., 2024; Azalan et al., 2022; Costa et al., 2021; Hariyani and Mishra, 2022; Hariyani et al., 2023) in the food manufacturing industry to enhance process capability, maximise value, improve customer satisfaction, reduce production costs, ensure high-quality outcomes, and serve as a robust operational excellence methodology.

This study proposes a hybrid LSSA methodology to maximise butter production using the same amount of cream, increase yield, and reduce Specific Cream Consumption (SCC). SCC measures the litres of cream required per kilogram of butter, which had not been previously monitored by Company X, motivating this initiative. With no reference to SCC value in existing literature, its reduction can be achieved by studying production variables or minimising waste. This project focuses on reducing SCC through production variables.

Enhancing butter production processes is crucial to meeting global standards of efficiency and sustainability (IMARC, 2023). Applying the LSSA methodology in butter production can serve as a benchmark for Company X, demonstrating the potential for significant improvements in production yield, process efficiency, and environmental sustainability (Villanova University, 2023). A rigorous statistical analysis was performed using Company X's historical data, applying standardised methodologies of this specific industry. This strategic approach aims to increase production yield, expand the company's market share, and solidify its competitive standing within the dairy industry. The adopted approach is the Define, Measure, Analyze, Improve, and Control (DMAIC) method and its tools are used to assess the impact of waste on the butter production process. This study examines how the DMAIC approach can help Company X reduce waste and provides detailed suggestions on implementing DMAIC tools, enabling Company X to evaluate its current processes and seek out opportunities for improvement.

1.2 Company Profiles

1.2.1 *Kaizen Institute*

Kaizen Institute, a global consulting firm dedicated to advancing continuous improvement methodologies, was founded in 1985 by the Japanese leader Masaaki Imai. Masaaki Imai played a crucial role in popularising this approach internationally, notably through his influential book, "KAIZEN: The Key to Japan's Competitive Success". Presently, *Kaizen Institute* operates in more than 45 sectors across more than 60 countries, as illustrated in Figure 1.1, which depicts the global reach of the *Kaizen Institute*.

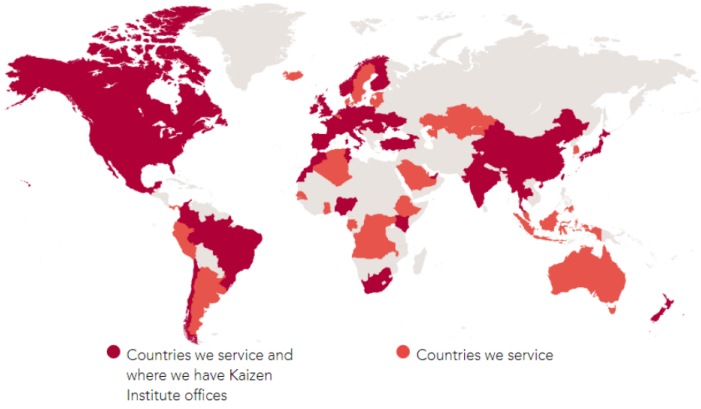


Figure 1.1: Presence of *Kaizen Institute* Worldwide (Kaizen Institute, 2024)

1.2.2 Portuguese Dairy Company

Company X, one of Portugal's largest agri-food companies, specialises in dairy products such as yoghurt, cheese, butter, and milk. With over 5.000 employees, it operates multiple manufacturing units, logistics platforms, and commercial delegations in Portugal (including the islands) and Spain. A manufacturing unit in Portugal has an installed capacity of 13.500 tonnes per year for butter production.

Company X exports to Europe, Asia, and Africa. Its quality policy is designed to ensure its products' high quality, maximum freshness, and safety while reducing environmental impact and avoiding unnecessary waste. Company X strictly complies with all European and National Quality, Food Safety, and environmental regulations, promoting continuous improvement, sustainability, and a food safety culture. The company holds certifications like ISO 9001 for Quality Management Systems and EN ISO 22000 for Food Safety Management Systems. These certifications demonstrate the company's commitment to quality, safety, environmental responsibility, ethical production, and meeting diverse consumer dietary needs.

In a partnership with *Kaizen Institute*, Company X has performed several projects in different units (e.g., the cheese production unit), fostering a culture of continuous improvement to achieve operational excellence. Continuous improvement is accomplished by standardising the monitoring and analysis of processes and the quality and food safety objectives.

1.3 Project Description

The production of butter represents a significant part of this company's overall production activities. Known for its quality butter made in large quantities, Company X is proud of its market presence. It aims always to achieve better quality. Therefore, focusing on growth and making things better all the time is essential for keeping up high productivity and customer satisfaction (Pazmiño-Arias et al., 2023).

Company X's strategy follows a Push model, where the cream is pushed into the process, prioritising machine occupancy over process performance. Consequently, one of the project's key focuses is to shift away from this paradigm and eliminate the practice of merely pushing the cream. In November of 2023, a comprehensive diagnostic analysis was conducted to scan the flow of materials and information from the reception of milk to its transformation into finished products within the company's warehouse. This evaluation revealed multiple opportunities for improvement in daily operational tasks and the need to define a new strategy to improve the company's flows, productivity, quality, motivation, and overall service.

This project focuses on enhancing butter production yield, which means reducing the SCC and decreasing variability. Inefficiencies in stages like Churning, Packaging and the intermediate handling of the product, though seemingly minor, can significantly impact overall profitability. Additionally, efforts will be undertaken to ensure the traceability of each butter unit, increase the automation of specific tasks, and eliminate wastage during the packaging phase. These measures are crucial in maintaining high standards of quality and efficiency in butter production.

For project success, key stakeholders, from shop floor operators to top management, must actively participate. Regular communication, workshops, and feedback sessions will keep stakeholders informed and engaged. The project aims to make butter production more efficient and sustainable by smartly using resources and improving every process step, adhering to continuous improvement principles.

1.4 Objectives and Research Questions

The primary goal of this project is to apply Lean Six Sigma Agile methodologies to reduce the SCC. Beyond this key objective, the project seeks to enhance efficiency across the value chain, from cream reception to final product storage, improve productivity, and elevate the company's overall service quality, ensuring the butter meets the organoleptic characteristics demanded by customers.

Alongside the main goal, the project also focuses on other equally important objectives, which include improving resource utilisation such as equipment and labour to enhance efficiency, standardising tasks to improve their flow, and increasing manufacturing yield by reducing raw material waste. Company X always aim to improve the quality of organoleptic characteristics by reducing their variability, ensuring better process control, and creating dashboards to monitor the waste in the process.

From the previous objectives, the following research questions were derived:

- *How can Lean Six Sigma Agile methodologies be applied to reduce the Specific Cream Consumption in butter production?*
- *What are the main process variables directly impacting butter's Specific Cream Consumption?*
- *How can the standardisation of tasks impact the process yield and reduce the process variability?*

1.5 Methodology

This project's approach was methodical, focusing on effectively organising the work and planning tasks. It was structured taking into account the DMAIC phases: Define, Measure, Analyze, Improve, and Control. This structure was followed from start to finish. A detailed schedule outlining the tasks undertaken during the project's timeline is provided in Appendix A.

The project's initiation under the Define phase focuses on identifying critical areas in butter production that require improvement. This phase involves mapping out the entire butter production process from cream reception to final packaging. The key to this phase was the factory floor observation, which aimed to identify inefficiencies and align project goals with organisational objectives.

In the Measure phase, a detailed data collection plan is developed to quantify the butter production process's current performance. This involves gathering baseline data on SCC, production efficiency, and quality metrics.

During the Analyze phase, the collected data is rigorously examined to identify the root causes of inefficiencies and waste within the butter production process. This analysis was heavily based on statistical evaluation, primarily guided by Lean Six Sigma methodology. Techniques such as root cause analysis and fishbone diagrams uncover patterns and correlations affecting yield and quality. This phase aims to pinpoint specific variables and process steps that contribute to high SCC and variability.

The Improve phase implements targeted interventions to address identified issues, improve process parameters like Churning and Malaxing Speeds, refine production workflows, and introduce best practices. Pilot tests validate these changes, ensuring they lead to reduced SCC and enhanced yield.

Finally, in the Control phase, measures are put in place to sustain the improvements achieved. Monitoring systems, such as dashboards and control charts, are established to continuously track process performance and maintain improvements over time.

The Agile methodology considers the DMAIC cycle as a flexible framework rather than a rigid sequence. This allows for iterative cycles, enabling the project team to refine stages based on new insights and data. As the project progresses, this iterative process supports continuous improvement, adaptability, and responsiveness to changes and challenges in butter production.

The project used statistical tools, notably Minitab, to evaluate intervention outcomes, ensuring data-driven decisions. Adhering to the DMAIC framework provided a structured approach to enhancing butter production efficiency, supported by a commitment to quality and operational excellence.

1.6 Project Structure

The thesis is organised into six main chapters and four appendices. Chapter 1 provides the context and motivation for the project, including profiles of *Kaizen Institute* and a Portuguese Dairy Company, as well as the project's description, objectives, research questions, methodology, and overall structure. Chapter 2 gives an overview of the global butter market and production and reviews relevant literature on the application of Lean, Six Sigma, Agile, and hybrid approaches in the food and dairy sectors. Chapter 3 characterises the current situation, detailing the project's scope, metrics, and critical quality factors and provides a detailed mapping and description of the production process. Chapter 4 presents an analysis of the production process, identifying improvement opportunities and causes of variability. It includes an examination of measured variables, their impacts, correlations, and multiple regression analysis, with specific factors like Moisture and Crystallisation Time explored in detail. Chapter 5 discusses the proposed solutions and actions implemented to address the identified problems. It covers standardisation of Moisture regulation, process monitoring, and streamlining of work processes and presents the main results of these actions. Chapter 6 summarises the main findings and discusses potential future research directions and work based on the project outcomes.

The annexes include the project schedule (Appendix A), butter production data (Appendix B), a comparative analysis of Lean, Six Sigma, Agile, and hybrid methodologies (Appendix C) and Scopus results on these methodologies in food and dairy sectors (Appendix D).

Chapter 2

Literature Review

2.1 Butter: Global and Production Market

2.1.1 Global Butter Market

The butter market has seen significant growth in production and consumption, driven by retail, food service, and food processing. According to (Research, 2023), the butter market is projected to grow at a Compound Annual Growth Rate (CAGR) of 4.8% from 2023 to 2030. This growth is attributed to changing consumer preferences, increased use in the food industry, and new culinary trends.

According to Statista (2023), the revenue from the global butter market is expected to reach US $49.91 billion in 2024, with an annual growth rate of 6.15% until 2028. The butter market was valued at US $46.8 billion in 2023 and is expected to rise to US $67.6 billion by 2033.

Europe and Asia (Figure 2.1) have long been at the forefront of the global butter market, driven by a rich culinary tradition, high consumer demand for quality dairy products, and a diverse range of butter varieties catering to evolving tastes and preferences Statista (2023).

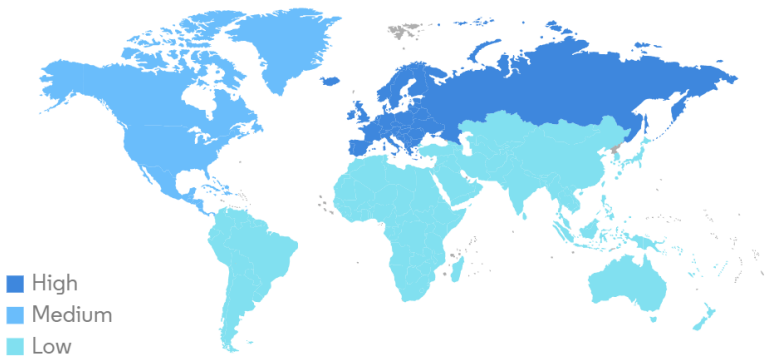


Figure 2.1: Butter Market Map (Mordor Intelligence, 2024)

2.1.2 Butter Production Market

Butter production has significantly improved due to technological progress, growing consumer preference for healthier choices, and sustainability concerns (FHA FNB, 2024). Major producers include the United States, Germany, France, and New Zealand.

According to Statista (2023), the butter production volume in the European Union (EU) is forecasted to consistently rise from 2023 to 2032, adding a total of 69.9 thousand tonnes (+3.05%). By 2032, the production volume is expected to have risen for the tenth year in a row, reaching 2.4 billion tonnes. Germany and France are the largest producers of butter in the EU (2.2).

In Portugal, butter production represents 2% of the total EU production (Figure 2.2). In 2021, Portugal produced nearly 31.000 tonnes of butter, marking a 3.6% reduction from the previous year. The decline persisted into 2022, with production falling to 27.000 tonnes. However, 2023 saw an increase to almost 29.000 tonnes. In 2024, butter production increased by 0.4%, totaling 11,440 tons from January to April (CLAL, 2024).

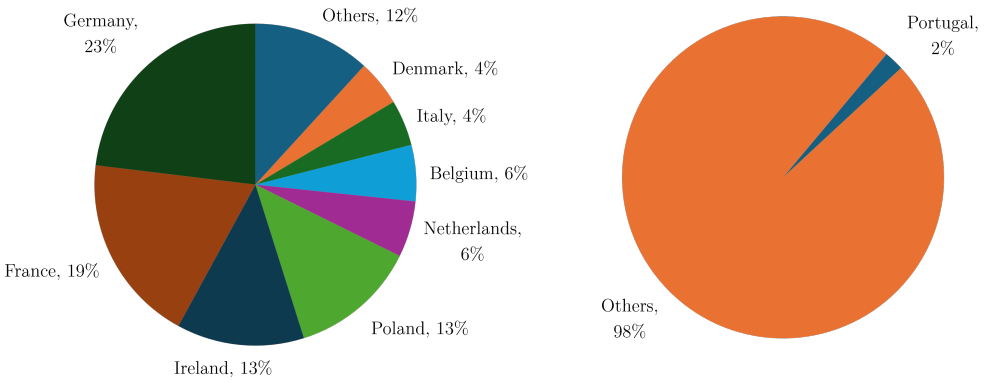


Figure 2.2: Distribution of butter production in Europe (a) and Portugal (b) (CLAL, 2024)

Portugal's butter industry is valued at €2.1 billion and is ranked 13th in Europe in 2024 (out of 27 EU countries). Appendix B provides more information.

2.2 Quality Improvement Methodologies in Food and Dairy Sectors

The Quality improvement (QI) methodologies have been implemented (Nicolay et al., 2012; Hoefsmit et al., 2022) in various industries, services and sectors to enhance efficiency, reduce waste and improve quality. Three main QI methodologies are Lean, Six Sigma and Agile. The challenges of integrating these QI methodologies into existing systems and the need for tailored approaches to achieve continuous improvement and maximise organisational performance are well documented. Currently, there is a growing trend to apply hybrid methodologies (e.g. Lean Six Sigma), which combine the principles and tools of the different applied methodologies.

Appendix C provides a comparison of Lean, Six Sigma, Agile and Lean Six Sigma (LSS) methodologies. Briefly, Lean focuses on eliminating waste and optimising flow by employing tools like Value Stream Mapping (VSM), 5S (Sort, Set in order, Shine, Standardize, Sustain) and *Kaizen* (continuous Improvement). VSM visualises the flow to eliminate waste, 5S organises the workspace for efficiency, and *Kaizen* drives continuous improvement through incremental changes. Six Sigma aims at reducing defects and process variation through a data-driven approach using techniques such as DMAIC (Define, Measure, Analyze, Improve, Control), DMADV (Define, Measure, Analyze, Design, Verify), and FMEA (Failure Modes and Effects Analysis). DMAIC optimises the existing processes to enhance performance and quality, while DMADV designs new processes or products to meet specific customer requirements, ensuring quality from the start. FMEA is used to identify and mitigate potential failures in both existing and new processes. Agile is an iterative and incremental approach that prioritises flexibility, collaboration and customer satisfaction, implementing practices like *Scrum* and *Kanban*. Its critical values encompass individuals and interactions, working software development, customer collaborations and responding to change.

Nowadays, companies and organisations have been implementing hybrid methodologies, particularly LSS methodology, instead of individual methodologies (e.g., Lean). These hybrid methodologies integrate Lean's waste reduction, Agile's flexibility, and Six Sigma's data-driven decision-making, using tools from different methodologies. They are particularly beneficial for leading a rapid response to market changes and maintaining high quality standards.

Several studies have shown that LSS methodology is successfully applied across various sectors such as healthcare (McDermott et al., 2022), public services (Juliani and de Oliveira, 2021; Francescatto et al., 2023), higher education (Davidson et al., 2020) and manufacturing (Kumar et al., 2023). The success of LSS is not entirely based on the application of appropriate tools but also on overcoming critical success factors such as leadership involvement, project management, organisational infrastructure, and training. The organisational culture and communication with leaders are examples of the challenges that can hinder the successful implementation of these methodologies.

The integration of LSS with Industry 4.0 (LSS 4.0) also represents a significant evolution (Macias-Aguayo et al., 2022; Maia et al., 2024; Citybabu and Yamini, 2023), combining customisation, automation, and digitalisation to enhance operations, and sustainable development. Despite its potential, LSS 4.0 is still emerging, with researchers striving to identify key components and develop a conceptual framework for its application in digital transformation contexts.

The integration of the Lean, Six Sigma, and Agile manufacturing methodologies combined with sustainable and green practices have been recently explored (Hariyani et al., 2023, 2024), demonstrating significant improvements in economic, environmental, and social performance. This hybrid approach effectively addresses sustainability challenges while enhancing overall organisational performance. The application in the food industry (Costa et al., 2018), especially in dairy processing (Nader, 2022), remains under-explored, presenting opportunities for further research and implementation.

2.2.1 Methodology for Literature Review

The Scopus database was utilised to identify and analyse academic documents on the application of Lean, Six Sigma, Agile and Hybrid methodologies in butter processing within the food industry, particularly the dairy industry. Three main previous research questions were defined to guide this literature review (Figure 2.3):

- *How are Lean, Six Sigma, and Agile methodologies applied in butter processing within the food industry?*
- *What benefits and challenges are associated with these butter processing methodologies within the food industry?*
- *Are there specific case studies or successful implementations of these butter-processing methodologies within the food industry?*

The Scopus search covered the period from the earliest available year to June 2024. This comprehensive search included titles, keywords, and abstracts to ensure thorough coverage of relevant literature. An advanced search using Boolean operators (OR, AND, AND NOT) was conducted.

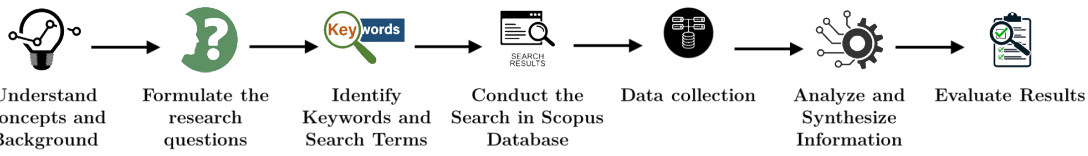


Figure 2.3: Methodology for Literature Review

The initial advanced search encompassed terms directly related to butter processing, such as "butter processing", "butter production", and "butter industry," combined with methodologies like "Lean manufacturing", "Six Sigma", and "Agile." However, no documents were found within this specific scope, which is the main focus of this thesis. Figure 2.4 presents the two steps followed for the Scopus database search.



Figure 2.4: Case Studies of Scopus Database Search

To ensure comprehensive coverage of relevant literature, the search was expanded to broader categories such as the "food industry" and "dairy industry." Subsequent searches utilised terms including "food industry," "food manufacturing industry," "dairy industry," and "dairy manufacturing," combined with terms such as "Lean," "Six Sigma," "Agile," "Lean Manufacturing," "Lean Production," "Lean Management," "Lean Supply Chain," "Lean Tools," "Agile Manufacturing Systems," "Lean Six Sigma," "Six Sigma Approaches," "Six Sigma Methodology," "Agile Supply Chains," "Continuous Improvement," "DMAIC," and "Value Stream Mapping." In conducting the Scopus search for the application of individual methodologies (Lean, Six Sigma, or Agile) within the food or dairy sectors, the search string "AND NOT Lean Six Sigma" was used to exclude papers discussing hybrid methodologies.

Appendix D presents an advanced search results from Scopus for various case studies (Figure 2.4) within this thesis, respectively.

2.2.2 Lean

Lean methodology (LM), derived from the Toyota Production System (Womack et al., 1990), focuses on minimising waste while maximising productivity. The goal is to create more value for customers with fewer resources. LM application in the food industry (Case 1, Appendix D) is well-documented, with a total of 73 documents (e.g. 45 articles, Table D.1) found. Studies from the literature have demonstrated that the food sector benefits significantly from LM. Significant improvements in operational efficiency, waste reduction, and overall quality have been reported. These studies highlight the effectiveness of LM tools in achieving these outcomes. For instance, De Steur et al. (2016) examined the application of VSM in reducing food losses and wastes within supply chains, reporting that VSM can effectively enhance performance by reducing lead time and other inefficiencies. VSM is compatible with other lean tools like Just-In-Time (JIT), *Kaizen* and 5S, which support continuous improvement.

Implementing Lean Manufacturing in the food sector has led to notable productivity, quality, and sustainability improvements. For instance, in a frozen food manufacturing company, the LM application optimised the production line layout, enhancing productivity and reducing bottlenecks (Bučko et al., 2024). Similarly, a Peruvian egg product company observed a significant reduction in product deterioration and demand forecast errors through a lean inventory management model that utilised machine learning and the 5S methodology (Carbajal-Vásquez et al., 2023). Naranjo et al. (2023) found that Lean Supply Chain (LSC) management improved supplier responsiveness and cooperation, although it faced challenges in conceptual clarity. Budianto et al. (2023) demonstrated that quality systems played a crucial role in improving operational performance with lean manufacturing in the food industry, showing that proper integration is crucial despite initial resistance. Additionally, Mohib et al. (2023) established that identifying critical success factors for lean implementation in Morocco's food industry provided valuable guidance yet underscored the need for management commitment and training. Garcia-Garcia et al. (2022) highlighted that implementing the Single Minute Exchange of Dies (SMED) methodology in a ready-meal manufacturer

reduced changeover time and increased overall equipment efficiency despite the complexity of implementation being a challenge.

Studies have shown that effective Lean Manufacturing in the food industry yields substantial benefits but requires overcoming challenges. Akanmu and Nordin (2022) reported that sustainability and competitive positioning in the food and beverage industry have been enhanced despite financial constraints and capacity issues. Pyvovarov et al. (2021) reported that a new technology for fat removal in wheat germ improved food quality and shelf life, though it required specialised equipment and faced initial resistance. Kazancoglu et al. (2021) found that Lean and sustainable operations reduced food waste and improved sustainability in Turkey's poultry industry, although integration complexity and resistance to change were significant hurdles. Lean-green integration improved water management and sustainability in the agri-food industry but required high initial investment and continuous monitoring (Viles et al., 2021). A Model-Driven Decision Support System using Lean and Industry 4.0 tools enhanced overall equipment effectiveness but faced challenges in integrating these tools (Rahman et al., 2020). Cuggia-Jiménez et al. (2020) found that while lean manufacturing in the food industry reduces product defects and operational costs, its implementation in Small and Medium Entreprises (SMEs) is limited due to high resistance to change.

Integrating safety and hygiene standards with Lean practices is crucial for high product quality and operational excellence. Combining lean tools with Statistical Process Control (SPC), Hazard Analysis and Critical Control Points (HACCP) reduces product returns and improves food safety (Cabrera et al., 2020; Domínguez et al., 2021). Simulation and real-time monitoring enhance Overall Equipment Effectiveness (OEE), reducing downtime and improving decision-making. Domínguez et al. (2021) found that integrating Lean 6S methodologies with HACCP significantly enhances operational efficiency and product safety, fostering continuous improvement, waste reduction, and sustainable practices through management commitment and proper training.

Compared to the broader food industry, LM application in dairy processing is less documented (Case 2, Appendix D), with a total of 24 documents indicating a growing interest but a need for more focused research. In the dairy industry, LM tools enhance operational performance and product quality. They offer dairy a systematic approach to optimising their processes like milk collection, churning, packaging, and distribution, reducing waste and improving efficiency. Tools such as VSM and 5S help identify and eliminate inefficiencies throughout operations. Analysing each step in the value stream allows producers to prioritise impactful improvements. Standardising processes and reducing variability ensures consistent quality and safety across product lines, improving OEE, reducing lead times, and minimising waste.

For instance, Alnounou et al. (2023) reported a 12.8% improvement in OEE and system performance at a Saudi milk factory using OEE, VSM, and SMED. Kumar and Shankar (2022) used VSM to streamline dairy operations in India, reducing lead time by 34.79% and increasing efficiency, although they faced challenges with integration complexity and initial resistance to change. Wesana et al. (2019) identified food loss hotspots in Uganda's dairy value chain using VSM, improving food security through targeted reduction strategies. Ramakrishnan et al. (2019) showed

productivity and competitiveness improvements in Indian SMEs with lean techniques like *Kaizen* and 5S, requiring sustained training and support. Bonamigo et al. (2024) found integrating Lean with Industry 4.0 significantly enhanced operational performance and milk quality in the Brazilian dairy ecosystem using cluster analysis and the Mann-Whitney test.

LM encourages continuous improvement, innovation, and problem-solving by encouraging employee involvement.

2.2.3 Six Sigma

Six Sigma (SS) methodology, introduced by Bill Smith at Motorola in 1980 and later adopted by Jack Welch at General Electric in 1995 (Snee, 2010), is a comprehensive set of techniques and tools for process improvement. It focuses on improving quality by reducing defects and process variation through a structured, data-driven approach.

A Scopus search found 22 documents (Case 3, Appendix D) on SS methodology in the food industry. These studies show that SS methodology enhances quality control and operational efficiency by reducing defects and improving processes. However, successful implementation often faces challenges such as resistance to change, data collection, training, and resource allocation.

For instance, Gilligan et al. (2023) applied SS methodology in an Irish meat processing plant to improve process yields, utilising DMAIC, statistical analysis, and key performance indicators (KPIs) to reduce process variation and improve yields. This led to eliminating over-trimming, improved process capabilities, increased revenue, and reduced meat wastage despite challenges such as initial resistance to change and the need for detailed data collection. Garcia-Garcia et al. (2022) conducted a case study on applying Lean and Six Sigma to optimise changeover processes in a ready-meal manufacturer. By implementing tools like SMED and DMAIC, they achieved a 30% reduction in changeover time, increased OEE to over 70%, and reduced labour costs by 10%. However, they faced challenges such as the complexity of implementing SMED and the need for continuous monitoring and employee training. Partalidou et al. (2020) examined the impact of Corporate Social Responsibility (CSR) performance on financial performance in the food industry, using Total Quality Management (TQM), Lean methodology, and SS methodology. They found that these methodologies improved economic performance, enhanced sustainability, and increased transparency, though the complexity of implementation and the need for continuous improvement were significant challenges. Vanany et al. (2021) proposed a Halal Six Sigma framework to reduce Halal food defects in the chicken meat industry. Using DMAIC, SIPOC tools, and Pareto diagrams, they significantly reduced Halal defects and lowered defect costs, improving compliance with Halal requirements. The main challenges included the need for a specific Halal assurance system, extensive employee training, and continuous monitoring. Scott et al. (2009) surveyed structured continuous improvement programs in the Canadian food sector, highlighting the use and benefits of SS. They reported reductions in process variability, increased profitability, reduced waste and rework, and improved quality performance. Challenges included the need for capital investment, resource allocation, organisational commitment, extensive training, and management involvement.

Only 12 documents were found on SS application in dairy processing (Case 4, Appendix D), indicating its adoption is still developing. SS tools like SPC and FMEA can ensure consistent quality and safety, and the DMAIC approach helps identify and address inefficiencies. Implementing SS in dairy production improves product quality, operational efficiency, and sustainability but requires overcoming challenges like complexity, training needs, data accuracy, and continuous monitoring. Integrating SS with Lean principles further optimises processes and enhances productivity.

Hakimi et al. (2018) applied the DMAIC methodology to improve the quality of plain yoghurt production by optimising factors affecting yoghurt acidity. They used tools such as Design of Experiments (DOE) and SIPOC diagrams to improve product quality, enhance customer satisfaction, and reduce process variability. However, the challenges included initial implementation complexity, the need for continuous training, and ensuring data collection accuracy. Kumar and Shankar (2022) demonstrated the application of Six Sigma and VSM in dairy firms, optimising operations and reducing waste. Their approach resulted in reduced waste, improved OEE, and enhanced sustainability. The challenges faced included the complexity of integrating Six Sigma with existing processes and the need for comprehensive training and management commitment.

The adoption of SS-based Dairy Management Information Systems (DMIS) has facilitated precision agriculture, supporting best practices that reduce product defects, optimise product mix, improve quality, and increase operational efficiencies. Berger and Hovav (2013) focused on implementing the AfiMilk DMIS to support best practices in dairy farming and enhance precision agriculture. They used Six Sigma principles to reduce product defects, achieve an optimal product mix, improve operational efficiencies, and reduce labour costs. The main challenges were the limited adoption of Information Technology (IT) in agriculture, initial implementation costs, and the need for business knowledge.

2.2.4 Agile

A total of 25 documents (Case 5, Appendix D) were found on Agile methodology in the food industry. Still, none specifically addressed its application in dairy processing (Case 6, Appendix D), indicating a significant gap in the literature and an area for potential research.

Studies have demonstrated that applying Agile methodology in the food industry offers significant benefits and presents various challenges. Agile tools, including Scrum and Kanban, enhance flexibility, responsiveness, and productivity in the food sector by managing supply chain variability and improving team collaboration. These tools streamline processes, enable swift product introductions based on feedback, and address challenges like seasonality and raw material fluctuations. Despite cultural resistance and training needs, Agile practices significantly enhance performance, decision-making, and operational excellence.

Mesaros et al. (2022) explored the Scrum framework in the food processing industry, highlighting improved flexibility, collaboration, customer satisfaction, and the ability to adapt quickly to market changes. De Steur et al. (2016) identified VSM as a crucial tool for reducing food losses and waste, improving visibility and efficiency in the complex and perishable agri-food supply

chains. Asl et al. (2023) reviewed green, resilient, agile, cold, and lean supply chains, showing that these integrated paradigms enhance flexibility, sustainability, and resilience but introduce high complexity and potential implementation costs. Putri and Dona (2019) applied lean manufacturing to redesign the production floor layout of the Indonesian home-food industry, achieving a 40% reduction in displacement and enhanced production efficiency. However, continuous monitoring, adaptation, and detailed data collection were required. Cabrera et al. (2020) improved product quality in a Peruvian food SME by implementing lean manufacturing, SPC and HACCP, resulting in an 89.2% reduction in product returns and a 35.6% increase in cash flow, despite the need for thorough training and complexity in managing multiple quality control systems. Dora et al. (2016) found that management commitment, culture, training, and resources were critical for successful lean implementation in food-processing SMEs. However, resistance to change, financial constraints, and employee scepticism posed significant barriers. Tanco et al. (2013) applied lean techniques to nougat production in the seasonal food industry, significantly reducing lead time and improving work cycle efficiency, though substantial employee training was necessary.

2.2.5 Hybrid Methodologies

Lean Six Sigma (LSS) methodologies are increasingly applied in the food industry, with 25 documents (Case 7, Appendix D) showing significant improvements in process control and waste reduction. However, only seven documents (Case 8, Appendix D) focus on dairy processing, highlighting an emerging interest and need for more research. Studies demonstrate LSS benefits in operational efficiency, environmental sustainability, and financial performance despite challenges like high implementation costs, complex statistical techniques, and the need for continuous training and cultural adaptation.

Costa et al. (2021) developed and validated LSS measurement scales for the food industry, identifying performance and competitiveness improvements through Lean tools and Six Sigma metrics. Implementation was affected by industry-specific factors like compulsory cleaning and heterogeneous operations. Costa et al. (2020) found that LSS practices significantly enhance performance, financial gains, product quality, and customer satisfaction despite challenges such as low familiarity with LSS, high training costs, and issues like seasonality and perishability. Utama and Abirfatin (2023) proposed a Sustainable LSS framework integrating economic, environmental, and social indicators to enhance sustainability and production efficiency in the Agro-Food Industry despite the complexity and high implementation costs. Besseris (2014) applied LSS to optimise quality, leanness, and safety in cocoa cream filling, improving product quality, process efficiency, and safety despite complex experiments and specialised statistical requirements. Shokri et al. (2016) identified key human factors for LSS readiness in manufacturing SMEs, such as personal competence, strategic vision, and organisational culture, with challenges including limited LSS understanding, resistance to change, and significant training investment needs. Omoush (2020) found that LSS significantly reduced defects and overproduction, improving product quality in Jordanian food companies despite challenges with employee readiness and high implementation costs.

Azalanzazllay et al. (2022) identified 28 LSS pre-implementation readiness factors for the food industry, emphasising management support, organisational culture, and strategic planning. Costa et al. (2018) found that LSS methodologies enhance operational efficiency and sustainability despite barriers like resistance to change and extensive training needs. Strong management commitment and a skilled workforce are crucial for success, with further research suggested on best practices and adoption strategies.

Applying LSS in the dairy sector shows clear benefits, with studies demonstrating quality, efficiency, and operational performance improvements. Trubetskaya et al. (2023) used a hybrid DMAIC/TAM model to optimise annual maintenance shutdowns, reducing overhaul duration by 36% and adding 8.9 million euros in value. This approach improved planning, employee engagement, and material delivery despite requiring extensive manual work and facing potential resistance. Powell et al. (2017) applied LSS in a Norwegian dairy producer, reducing milk waste from 2% to 1% and promoting environmental sustainability. LSS has improved efficiency, financial returns, and product quality. Tools like VSM and DMAIC reduced food losses and enhanced nutrient retention. Critical success factors were management commitment and broad involvement, while challenges included complex measurement systems and raw material variability. Effective tools included the hybrid DMAIC/TAM model, VSM/DMAIC model, and ISO 50001 integration. Trubetskaya et al. (2023) integrated LSS with ISO 50001 in an Irish dairy plant, reducing the CO_2 footprint by 50% and annual energy costs by 35%, despite high initial investment. Satolo et al. (2023) used LSS tools to improve milking efficiency in small-scale dairy farms, leading to financial gains and increased knowledge despite initial resistance and economic constraints.

Only nine documents (Case 9, Appendix D) on Lean Six Sigma Agile (LSSA) exist, but none relate specifically to the food or dairy sectors. This methodology integrates Lean's waste reduction, Six Sigma's data-driven decision-making, and Agile's flexibility, helping dairy producers quickly introduce new products while maintaining high quality and safety standards.

Recent studies (Hariyani and Mishra, 2022; Hariyani et al., 2023, 2024) show that combining Lean, Six Sigma, Agile, and sustainable and green practices improves economic, environmental, and social performance.

Chapter 3

Problem Description

This chapter analyzes the problem in alignment with the Define phase of DMAIC, providing a detailed description of Company X's butter production process.

3.1 Characterization of Company's Current State

3.1.1 Scope

Until now, Company X has not monitored process yield, making the Specific Cream Consumption (SCC) a new concept for them. Their primary focus was on maximising cream pushing and maintaining continuous machine operation without considering the impact of process variables on overall yield.

SCC is a crucial metric in butter production, representing the litres of cream needed per kilogram of butter. Reducing the SCC can be approached in two ways: by studying and modifying the variables involved in the production process or by minimising waste during the Packaging phase. This project focuses on reducing SCC through production process variables. By adjusting these variables, the aim was to lower the SCC, which in turn increases the yield of the process. Despite the absence of reference SCC values in existing literature, the company identified an opportunity for improvement in this area.

A critical factor contributing to this inefficiency is the variability in the production process. This variability can be attributed to various factors, including differences in cream origin, such as variations in fat content, freshness, and regional sourcing. Additionally, inconsistencies in operational processes and variable skill levels among operators contribute to significant deviations from ideal production parameters, thereby increasing the SCC.

To systematically improve operational performance and organisational effectiveness, Company X has adopted the GQCDM framework, focusing on five key dimensions: Growth, Quality, Cost, Delivery, and Motivation. Table 3.1 provides a detailed breakdown of the objectives associated with each dimension.

Table 3.1: Specific objectives of the GQCDM Framework

Dimension	Objective
G (Growth)	Increase production volume and revenue
Q (Quality)	Decrease customer complaints
C (Cost)	Improve yield from cream to butter and minimize waste
D (Delivery)	Improve internal service levels
M (Motivation)	Enhance work environment

Company X produces various types of butter products to meet its clients' diverse requirements. These different product lines, known as references, often include yeast as an additive, though not all contain salt. The production frequency of each reference varies based on customer demands, with some being produced more frequently than others. Each reference represents a specific formulation tailored to satisfy the unique needs of the company's diverse client base.

The production method, whether continuous or batch, depends on the specific butter references being made. Table 3.2 shows the specifics of each of the references produced by Company X. There are three types of Type A references (A1, A2, A3), each differing in the percentage of salt present in the butter. References A and B are produced using continuous production, while Reference C is produced using batch production, which is considered more traditional due to its less frequent production.

Table 3.2: References Specifications

Reference	Additives	Type of Production	Frequency
A1	Salt and Yeast	Continuous	Every day
A2	Salt and Yeast	Continuous	Every day
A3	Salt and Yeast	Continuous	Every day
B	Yeast	Continuous	Every 2 days
C	Parsley and Garlic	Batch	Every 2 weeks

3.1.2 Metrics

The Specific Cream Consumption (SCC) serves as a pivotal metric for assessing butter production efficiency at Company X. Defined as the ratio of the volume of cream used (litres) to the weight of butter produced (kilograms), SCC can be calculated through equation 3.1.

$$\textbf{SCC} = \frac{\text{Quantity of cream consumed (L)}}{\text{Quantity of butter produced (kg)}} \tag{3.1}$$

A lower SCC indicates better production yield and resource utilisation. Tracking SCC identifies inefficiencies, supports waste reduction, and contributes to production sustainability and cost-efficiency goals.

3.1.3 Critical to Quality

Beyond the factors previously mentioned, ensuring high-quality butter with minimal defects is crucial for Company X. As detailed in Table 3.2, Company X produces five butter references (A1, A2, A3, B and C), each of them adapted to the specific needs of various clients. Figure 3.1 presents the specifications for each reference. The three critical quality factors identified, Butter Fat, Moisture, and Salt Percentage, must be meticulously controlled to align with the Voice of the Customer (VoC) and translate these needs into Critical to Quality (CtQ) attributes, ensuring that each batch satisfies both global retailers and direct consumers.

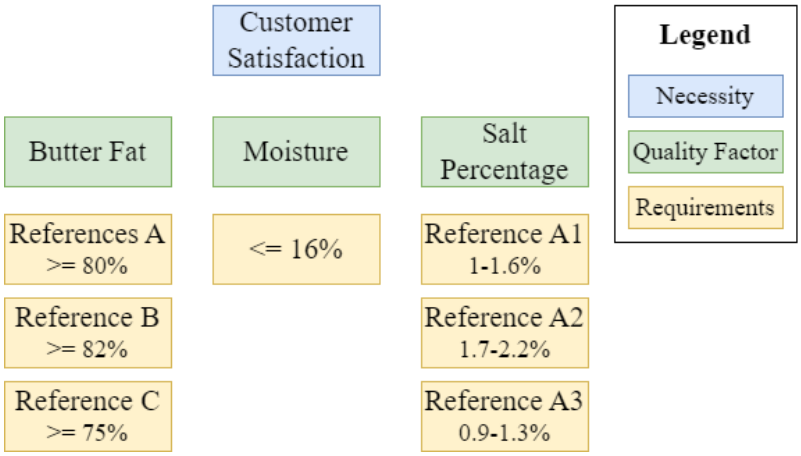


Figure 3.1: Critical to Quality Diagram

3.2 Problem Definition

The main objective of this project is to reduce the Specific Cream Consumption (SCC), as illustrated in Table 3.3, which shows a base and a target value for each reference.

To define the Base Value for each reference, the sum of litres of cream consumed in 2023 was divided by the sum of kilograms of butter produced in 2023. To determine the Target Value, given the high variability and seasonality of SCC values, the 4-month rolling average was calculated for each month. The target value for each reference was then set as the lowest of these monthly averages for 2023.

Achieving this goal means producing the same amount of butter while consuming less cream. Additionally, the project aims to reduce variability, stabilise the production process, and minimise waste.

Table 3.3: Base and Target Value for each Reference

	SCC				
References	**A1**	**A2**	**A3**	**B**	**C**
Base Value	2.24	2.27	2.23	2.34	2.45
Target Value	2.08	2.10	2.08	2.21	2.32

3.3 Production Process

Regarding the butter production process, Figure 3.2 illustrates the global sequential stages, from raw cream to the final packaged product. The process begins with the reception of raw cream, which is then moved to the cream treatment phase, where it is pasteurised and crystallised to ensure safety and quality. Next, the crystallised cream undergoes butter processing, where it is churned and malaxed into a butter base. The butter is then sent to the Packaging stage, where it is prepared for distribution and placed into butter silos, ensuring it maintains its quality and freshness. Finally, the packaged butter is ready for the expedition, ending the production process line.

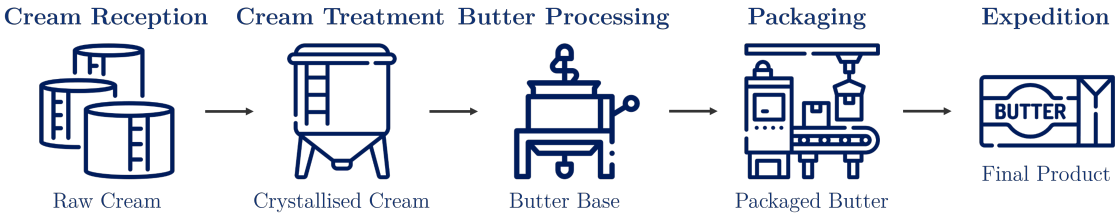


Figure 3.2: Global Stages for Butter Process

In addition to understanding the production stages of butter, it is essential to acknowledge the varying origins of the raw cream used in the process. Specifically, the cream used in Company X's butter production can be categorised into three distinct origins, each contributing unique characteristics to the final product:

- Cream X: Generated in-house using milk from the company's geographical region and represents the smallest quantity among the three cream origins;
- Cream Y: Sourced from a different, nearby region, this cream is delivered in the largest quantities. Its abundant supply is essential for maintaining consistent production levels and meeting high demand;
- Cream Z: Sourced from the furthest region, this cream travels the longest distance to the facility.

These variations in the source material not only influence the physical and chemical properties of the cream but also affect the efficiency and adjustments needed in the production process. The factor most influenced by sourcing cream from different origins is the cream fat content. Understanding these differences is crucial for improving production parameters and ensuring a high-quality end product that meets consumer expectations.

3.3.1 Process Flowchart

Once the cream is received, the process consists of three major phases: cream processing, butter production, and Packaging, before being exported to the end customer. Figure 3.3 provides the flowchart of the production process of Company X.

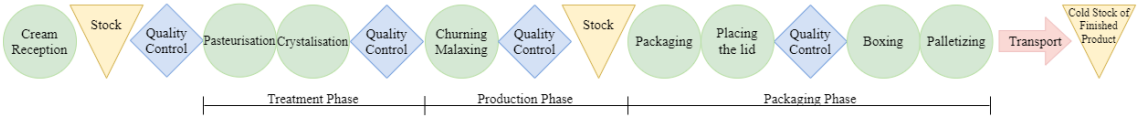


Figure 3.3: Flowchart of the Production Process

Several quality control operations are performed throughout these phases to ensure the product meets high standards. However, the numerous quality control checks present a substantial opportunity for improvement according to Lean principles. By reducing the number of these operations, the process could become more efficient and streamlined, minimizing waste and enhancing overall productivity without compromising butter quality.

3.3.2 Operation Detailing

For a clearer understanding of the butter production process, Figure 3.4 presents an illustrative diagram of the process. Each step of the butter production is described in detail, with reference to the corresponding numbers shown in this figure.

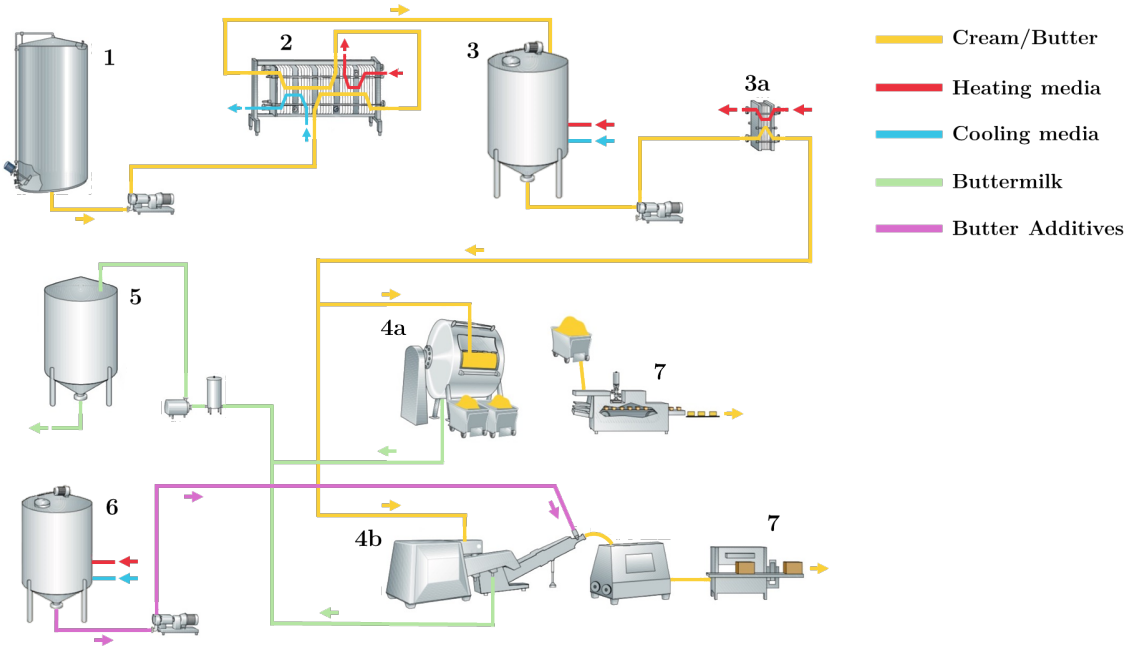


Figure 3.4: Illustrative Diagram of Butter Process

1. Cream Reception

   Regarding the cream generated internally, Cream X, the butter production begins with the arrival of milk, which undergoes pre-heating and pasteurisation. This process separates the milk into skimmed milk and Cream X. The skimmed milk is immediately packaged for sale, while Cream X advances to the next stage of butter production. Additionally, Cream Y and Z, sourced externally, are transported in specially conditioned trucks to prevent degradation. This ensures all creams meet the highest quality standards for butter production, contributing to a consistent and efficient process.

2. Cream Pasteurisation

   Pasteurisation involves heating cream to a high temperature, typically 93 °C or higher, usually without holding time. This intense heat treatment effectively kills pathogenic bacteria, other microorganisms, and enzymes that could impact the cream's quality. The Pasteurisation Temperature and Time are controlled and fixed values, ensuring consistency and safety. However, the heat should not be so intense that it causes defects, such as a cooked flavour, which can negatively affect the cream's quality and taste. Figure 3.5 presents the factory machine for pasteurisation.



Figure 3.5: Pasteurisation

3. Crystallisation

   In the Crystallisation of cream, the fat globules, initially in liquid form after pasteurisation, are crystallised at temperatures around 10 °C. This process occurs in crystallisation tanks (Figure 3.6) where the Crystallisation Time is not actively controlled. Gradual cooling allows different cream fat content to crystallise at their respective temperatures, producing softer butter and minimal solid fat. Agitation during this stage ensures uniform crystal formation, enhancing the butter's texture and quality. Following crystallisation, the cream undergoes a temperature treatment (3a), allowing control over the temperature at which it enters the Churning stage.



Figure 3.6: Crystalisation

4. Churning/Malaxing

   Churning and Malaxing are crucial operations where the treated cream is transformed into butter. Company X utilises two production methods: batch production, which is more manual, and continuous production, which is more automated. Figure 3.7 presents the factory machines for this process stage. Batch production is reserved for specific references, such as reference C, and is produced only biweekly. Churning involves continuous agitation of the cream, leading to the separation of butter from buttermilk. This process allows control over various variables, including Churning Speed and cream Flow Rate, significantly affecting the final product's parameters. A detailed analysis of these variables is presented in Chapter 4. Following Churning, Malaxing occurs, where an auger machine beats the cream at a slower speed than the Churning Speed. This step further refines the butter, ensuring the desired texture and consistency and finalising its preparation before Packaging and distribution.



a)



b)

Figure 3.7: Churning and Malaxing for Continuos (a) and Batch (b) Production

The Churning and Malaxing machine transforms cream into butter in a series of steps, as shown in Figure 3.8. First, the cream enters a Churning cylinder (1), agitated by beaters, separating butter grains from buttermilk. The butter is washed and conveyed forward in the separation section (2). The butter then passes through squeeze-drying (3) and gets to the Malaxing stage (4). The stage (5) consists of four small sections, each separated by a perforated plate. In section (6), salt and yeast are added, as will be explained in the butter additive preparation section, before the butter is discharged for a butter silo which stores the butter for later Packaging.

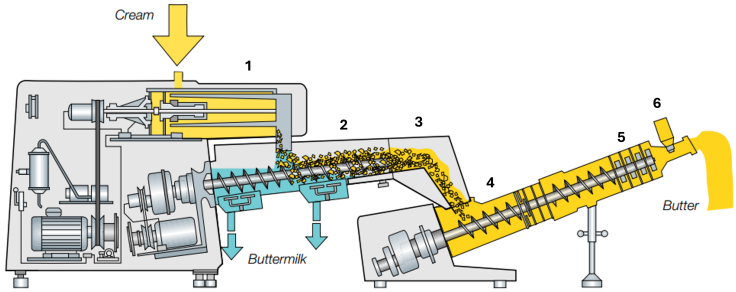


Figure 3.8: Churning and Malaxing Continuous Production Illustrative Diagram

5. Buttermilk collection

Buttermilk is the liquid that results from churned cream and is a byproduct of the butter-making process. During Churning, the buttermilk separates from the butterfat just before Malaxing begins. Several variables influence this separation, including Churning Speed, cream Temperature, and cream Flow Rate. Efficient separation is crucial for achieving high-quality butter. The buttermilk is removed using a filter to balance two key considerations: it must be narrow enough to prevent butter loss and wide enough to avoid clogging the machine. Currently, the lost butter in buttermilk production is not reintroduced in the production process. Instead, it is directed to the sewer system for disposal. Figure 3.9 presents the factory tank for the buttermilk collection.



Figure 3.9: Buttermilk Collection

6. Butter Additives Preparation

   During the butter production process, at the end of the Malaxing process, additives such as salt and yeast are injected to enhance the product's quality and meet the customer's requirements. Yeast is added to all types of references because it develops flavours and aromas that significantly improve the sensory quality of the butter. The preparation of yeast involves rehydrating active dry yeast in warm water to activate it before injection. On the other hand, salt is only added in references of type A. This involves creating an aqueous solution known as brine, consisting of salt and water.

7. Packaging

   In the butter Packaging process, there are four distinct lines, each operated by a dedicated machine (P1, P2, P3, P4). The butter is distributed to these lines based on the specific Packaging needs of each product reference. All machines automate the placement of butter into packages and the placement of lids and separators, eliminating the need for operators for these tasks. Figure 3.10 presents the Packaging machines of this stage.



a) b)

Figure 3.10: Packaging Machines for 250 g Packets (a) and 8 g Packets (b)

P1 machine, the most advanced of the four, handles the Packaging of 125 g and 250 g packets (Figure 3.10 (a)). It not only places butter into packages but also automatically folds cardboard boxes and places the packets into these boxes. The operators' role at P1 is limited to feeding cardboard into the machine and controlling (on the machine's screen) the amount of butter that goes into each package. P2, P3, and P4 machines output only butter packets. P2 and P3 are two identical machines that produce 8 g packets typically used in restaurants (Figure 3.10 (b)), while P4 output is packages of 25 kg for specific bakery services. For these machines, operators are necessary to place the butter packets into the folded cardboard boxes manually. Operators perform some quality checks throughout the shift, assessing the packets' Moisture, Salt, pH, and weight to ensure they meet customer specifications. It is important to note that all types of butter references (A, B or C) can be packaged in the 4 machines, depending on the requirements of each client.

Chapter 4

Statistical Analysis and Findings

4.1 Production Process Analysis

Regarding the production process analysis, the main improvement opportunities for each stage were identified, and a fishbone diagram was constructed based on the principal causes of the high variability.

4.1.1 Improvement Opportunities

Improvement opportunities focus on identifying areas within the production process that can be enhanced to increase efficiency, reduce waste, and improve overall yield. The main opportunities associated with each process stage are presented below.

Cream Reception

- Challenges in managing raw cream inventory due to fluctuating reception cream volumes, which are influenced by Company X's Push model.
- Difficulties maintaining robust product traceability throughout the reception and initial processing stages.
- Differences in the origin of cream, which influences its characteristics and determines the appropriate treatment methods.

Pasteurisation

- Lack of precise control and assurance over the cooling temperature, leading to potential variations in product quality.
- Difficulty in measuring the exact pasteurisation temperature along this stage.

Crystallisation

- The duration of the crystallisation stage lacks a standardised time value, currently serving only as a stock period for the cream.
- Need for defining and implementing optimal Crystallisation Times to enhance product consistency and quality.

Churning/Malaxing

- Unstable parameters during this stage attributed to the lack of standardisation in the preceding stages.
- The necessity for frequent sample testing, conducted every 30 minutes, to ensure process consistency and quality.
- Sample testing leads to significant butter and Packaging waste, highlighting a need for more efficient quality control methods.

Buttermilk Collection

- The imperfect filtration system allows small butter grains to pass through with the buttermilk, reducing the yield of the process.
- Opportunity to reintroduce the filtered buttermilk back into the process to maximise resource utilisation and improve efficiency.

Packaging

- Use precise automated weighing systems to ensure uniform package weight, reducing overfilling or underfilling.
- Train operators on best handling practices and optimise their working posture to reduce errors and improve ergonomic conditions.
- Create standardised procedures for Packaging, ensuring consistent positioning of butter packets in boxes for machines P2, P3 and P4.

It is important to note that the project's scope focuses primarily on the process variables, thereby temporarily putting opportunities for improvement related to waste in the Packaging stage on standby.

While there are opportunities for improvement at all stages of butter production, this project has prioritised specific areas. These priorities are based on the detailed statistical analysis presented later in this chapter, ensuring that efforts are focused precisely where they will have the most significant impact.

4.1.2 Variability Causes Analysis

High variability in butter production negatively impacts the entire process by causing inconsistencies in quality, reducing yield, and increasing waste. Figure 4.1 illustrates a fishbone diagram that categorises the main causes of this variability, enabling a systematic examination of issues related to equipment, methods, materials, manpower, environment, and measurement techniques.

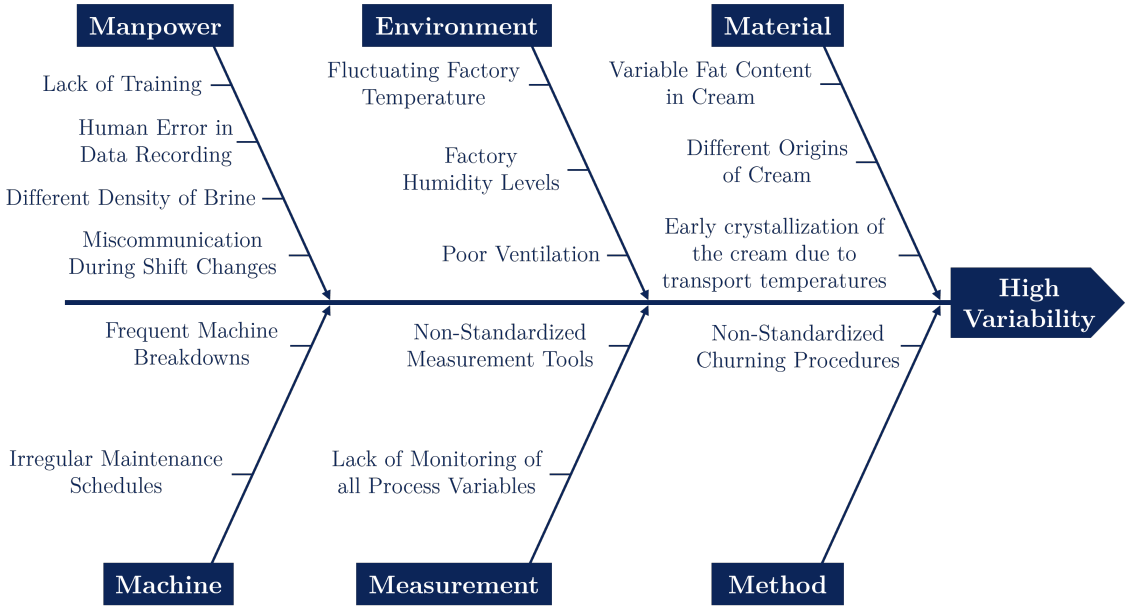


Figure 4.1: Fishbone Diagram for High Variablilty of Butter Production

For manpower, issues such as lack of training, human error in data recording, and miscommunication during shift changes are evident. Environmental factors include fluctuating factory temperatures, varying humidity levels, and poor ventilation, all of which impact the product. In terms of materials, variability in fat content and the origins of cream, along with early crystallisation due to transport temperatures, are significant concerns. Machine-related issues such as frequent breakdowns and irregular maintenance schedules further exacerbate variability. Measurement inconsistencies arise from non-standardised tools, while method-related variability is linked to non-standardised Churning procedures. Addressing these specific factors through targeted interventions will reduce variability and enhance overall production yield.

4.2 Variables Measured

This section presents the key variables measured throughout the butter production process. As already mentioned, the process yield can be improved in two ways: through the variables of the production process or by eliminating waste at the Packaging stage. Therefore, as the scope of this project is to improve yield through process variables, the measured variables shown in Table 4.1 are variables prior to Packaging.

Table 4.1 summarises the production process variables, each one characterised by its controllability and the availability of historical data. Controllability indicates whether the variable can be influenced or adjusted during the production process, while the availability of historical data reveals whether past records exist for the variable. Additionally, the last column provides the unit of measurement for each variable.

Table 4.1: Process Variables

Stage	**Variable**	**Controllable**		**Hist. Access**		**Unit**
		Yes	No	Yes	No	
Cream Reception	Origin		✓		✓	-
	Transport Temperature		✓		✓	ºC
Stock 1	Stock 1 Time	✓			✓	hour
	Stock 1 Temperature	✓		✓		ºC
	Cream Agitation	✓			✓	rpm
Quality Control 1	-	-	-	-	-	-
Pasteurization	Past. Temperature	✓		✓		ºC
	Past. Time	✓		✓		hour
Crystallization	Cryst. Temperature	✓		✓		ºC
	Cryst. Time	✓		✓		hour
Quality Control 2	-	-	-	-	-	-
Churning/Malaxing	Churning Speed	✓			✓	rpm
	Malaxing Speed	✓			✓	rpm
	Flow Rate	✓			✓	litre/hour
	Yeast Pump Speed	✓			✓	rpm
	Salt Pump Speed	✓			✓	rpm
	Churn. Temperature	✓			✓	ºC
Quality Control 3	-	-	-	-	-	-
Stock 2	Stock 2 Time		✓		✓	hour
	Stock 2 Temperature		✓		✓	ºC
Packaging	-	-	-	-	-	-
Quality Control 4	-	-	-	-	-	-

Quality control operations do not have specific variables assigned to them because they primarily involve meticulously measuring and assessing the outputs of various stages in the production process. Instead of being controlled parameters, these operations focus on thoroughly evaluating the product to ensure it meets predefined quality standards. Therefore, Table 4.2 outlines the parameters assessed during each quality control operation, its availability in historical data and the unit of measurement.

Table 4.2: Quality Control Parameters

Stage	Assessed Parameter	Hist. Access		Unit
		Yes	No	
Quality Control 1	Cream Fat Content	✓		%
	pH 1		✓	-
Quality Control 2	Fat Content 2		✓	%
	pH 2		✓	-
Quality Control 3	Churn. Moisture		✓	%
	Buttermilk Fat Content	✓		%
	Salt Content 3		✓	%
	pH 3		✓	-
Quality Control 4	Moisture	✓		%
	Salt Content		✓	%
	pH		✓	-

4.3 Variable Impact Analysis

To accurately analyse the impact of various production variables on butter process yield, historical data from Company X was essential. However, obtaining this data posed a significant challenge, as it is recorded according to individual Production Orders, complicating the data recovery process. Despite these difficulties, the company managed to provide data for several key variables.

This dataset covers data from January 2023 to the end of February 2024, with approximately 10 observations per week, totalling 603 observations. The company could only provide data for the Cream Fat Content, Stock 1 Temperature, Pasteurisation Temperature and Time, Crystallisation Temperature and Time, Buttermilk Fat Content, Moisture and SCC. Table 4.3 presents each variable's minimum, average, and maximum values.

Table 4.3: Variables Range

	Min.	Average	Max.	Unit
Cream Fat Content	37.44	39.43	41.08	%
Stock 1 Temperature	9.00	10.22	11.00	ºC
Past. Temperature	92.75	92.94	93.27	ºC
Past. Time	9.92	10.05	10.10	second
Cryst. Temperature	10.00	10.57	11.00	ºC
Cryst. Time	0.58	10.84	59.34	hour
Buttermilk Fat Content	43.23	50.60	58.18	%
Moisture	13.73	14.79	15.88	%
SCC	2.15	2.36	2.96	L/kg

It is important to note that temperature and pasteurisation time are almost constant variables, with the temperature set at 93 ºC and the time at 10 seconds and thus were not included in the analyses.

The analysis was conducted using *Minitab* software to determine which variables most impact SCC in butter production. It began by examining the correlation between the various process variables to identify any significant interrelationships. Then, the correlation between these variables and SCC was evaluated. Finally, a multiple regression analysis was conducted to determine the combined effects of the variables on the SCC.

4.3.1 Correlation between Variables

The first step of the analysis involved assessing the correlation between the process variables provided by the historical data. This was crucial in identifying significant interrelationships that could influence the subsequent analysis. The correlation matrix, created using data collected from January 2023 to February 2024, is presented in Table 4.4. This table shows the correlation coefficient (r) for each pair of variables.

The correlation coefficient (r) is a statistical measure that quantifies the strength and direction of the relationship between two variables. Its value can vary between -1 and 1, and the higher its module, the greater the correlation between the variables. A negative r indicates that as one variable increases, the other variable tends to decrease, and vice versa, demonstrating an inverse relationship between the two variables.

The *p-value* measures the probability that the observed results occurred by chance. A *p-value* of 0.05 indicates a 5% chance of the results being random. If the *p-value* is 0.05 or less, the results are considered statistically significant, suggesting they are unlikely to be due to chance.

Table 4.4: Correlation between Variables

	Cream Fat Cont.	**Stock 1 Temp.**	**Cryst. Temp.**	**Cryst. Time**	**Buttermilk Fat Cont.**	**Moisture**
Cream Fat Cont.	1.000	-	-	-	-	-
Stock 1 Temp.	0.037	1.000	-	-	-	-
Cryst. Temp.	0.036	0.079	1.000	-	-	-
Cryst. Time	-0.050	-0.019	-0.007	1.000	-	-
Buttermilk Fat Cont.	0.053	0.028	0.024	-0.061	1.000	-
Moisture	-0.032	-0.009	0.022	-0.014	-0.032	1.000

**p-value $\leq$ 0.05*

The matrix shows that all the correlation coefficients are relatively low, with the highest value being 0.079 between Stock 1 Temperature and Crystallisation Temperature. This indicates weak relationships among the variables. Furthermore, the *p-value* for all correlations is greater than 0.05, signifying that none of the correlations are statistically significant at the 95% confidence level. Therefore, it can be concluded that there are no strong linear relationships between the process variables, suggesting that each variable might independently contribute to the variability in the process.

4.3.2 Correlation with SCC

To further understand the impact of the process variables on the SCC, a correlation analysis was conducted between these variables and the SCC. Table 4.5 presents the correlation coefficients and the respective *p-values*, which provide insights into the strength and significance of these relationships.

Table 4.5: Variables Correlation with SCC

Variable	**Correlation Coef.**	***p-value***
Cream Fat Content	0.034	(.400)
Stock 1 Temperature	0.036	(.383)
Cryst. Temperature	0.029	(.469)
Cryst. Time	0.075	(.066)
Buttermilk Fat Content	-0.035	(.388)
Moisture	-0.116*	(.005)

*p-value ≤ 0.05

Table 4.5 shows that the variable Moisture has the greatest impact on SCC, as indicated by its correlation coefficient of -0.116 and a significant *p-value* of 0.005. This negative correlation suggests that higher Moisture levels are associated with lower SCC values, implying that Moisture plays a critical role in influencing the SCC. Additionally, the Crystallisation Time variable shows the second greatest impact on SCC with a correlation coefficient of 0.075, though its *p-value* is 0.066, which is above the 0.05 threshold for statistical significance. Despite this, the data suggests a trend where shorter Crystallisation Times are associated with lower SCC values. The other variables show weak and statistically insignificant correlations with SCC, indicating they have less impact on SCC based on the historical data analysed.

4.3.3 Multiple Regression Analysis

Having analysed the correlation between the variables and the correlation of the variables with the SCC, the next step was to perform a multiple regression analysis. As observed from the correlation analysis between variables, there is a weak correlation between them, allowing all the variables to be included in the multiple regression model. The results are presented in Table 4.6.

Multiple regression analysis is a statistical technique used to understand the relationship between one dependent variable and two or more independent variables. In this case, the dependent variable is the SCC and the other variables are independent. The R-squared (R^2) value indicates the proportion of the variance in the dependent variable that is predictable from the independent variables. A higher R^2 value signifies a better fit of the model. The F-test Estimate assesses the overall significance of the regression model, determining whether at least one of the independent variables significantly predicts the dependent variable. The corresponding *p-value* for the F-test indicates whether the observed F-test value is statistically significant.

Table 4.6: Multiple Regression with Historical Data

Variable	**Coefficient**	***p-value***
(Intercept)	2.595*	(.000)
Cream Fat Content	0.005	(.403)
Stock 1 Temperature	0.006	(.411)
Cryst. Temperature	0.007	(.467)
Cryst. Time	0.011	(.070)
Buttermilk Fat Content	-0.001	(.352)
Moisture	-0.023*	(.005)
R^2	2.35%	
F-test Estimate	2.38	
F-test *p-value*	(.028)	

**p-value* ≤ 0.05

From the multiple regression analysis presented in Table 4.6, the R^2 value is 2.35%, indicating that the model explains only a small portion of the variance in SCC. The F-test estimate is 2.38, with a *p-value* of 0.028, suggesting that the regression model is statistically significant at the 5% level.

Examining the regression coefficients and their *p-values*, Moisture has the most substantial impact on SCC, with a coefficient of -0.023 and a significant *p-value* of 0.005. This negative coefficient confirms that higher Moisture levels are associated with lower SCC values. Crystallisation Time also shows a notable effect with a coefficient of 0.011 and a *p-value* of 0.070, indicating a trend where shorter Crystallisation Times are associated with lower SCC values, though this effect is not statistically significant.

4.4 Exploratory Examination

4.4.1 Moisture

At the beginning of the project, there was already a slight suspicion that the butter's Moisture could significantly impact SCC. Moisture is expressed as a percentage, representing the proportion of water in the butter's total weight.

As illustrated in Figure 3.1 (Critical to Quality), the maximum legal Moisture content allowed is 16%. This means that up to 16% of each packet of butter can be composed of water, with the remaining 84% consisting of fat, proteins, and other solids. Theoretically, a higher Moisture content in the butter would result in a lower SCC because less cream would be required to produce the same quantity of butter. Essentially, with more water in the mixture, the amount of cream needed decreases, thereby making the overall production process more efficient in terms of cream usage.

Figure 4.2 provides descriptive Moisture statistics. The histogram (Figure 4.2 (a)), which includes a normal distribution curve, shows the frequency of different Moisture values among the 603 samples. The average of Moisture is 14.79%, with a standard deviation of 0.6174%, indicating the variability around this average.

A boxplot is a graphical representation of a dataset that shows its central tendency, spread, and potential outliers. The boxplot in Figure 4.2 (b) displays the distribution of Moisture values. The box represents the interquartile range (IQR), containing the middle 50% of the data. The line inside the box indicates the median Moisture level, approximately 14.7%.

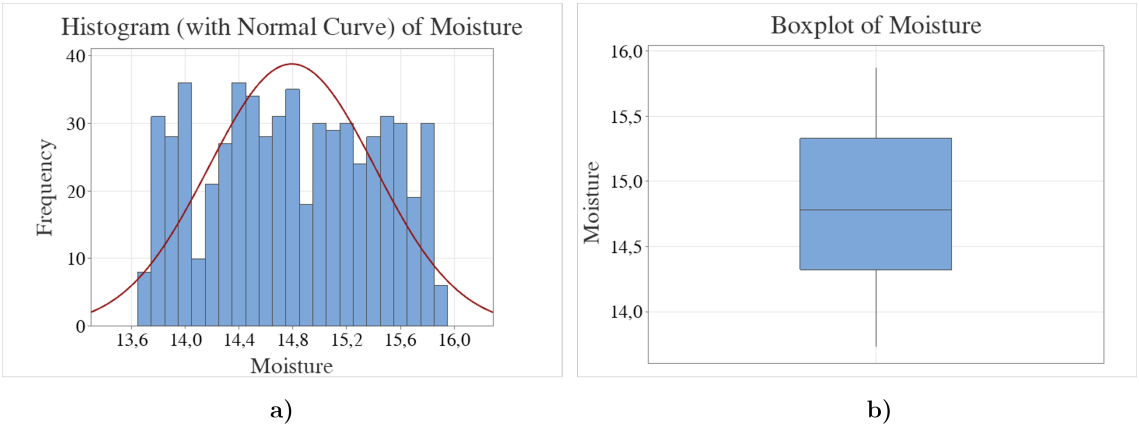


Figure 4.2: Moisture Descriptive Statistics: Histogram (a) and Boxplot (b)

Figure 4.3 illustrates a linear regression analysis between the SCC and Moisture. The regression equation is $SCC = 2.889 - 0.02270 * Moisture$, with a *p-value* of 0.005, indicating the statistical significance of the relationship, as previously observed. This equation indicates that for each one percentage unit increase in Moisture, the SCC decreases by 0.02270 units.

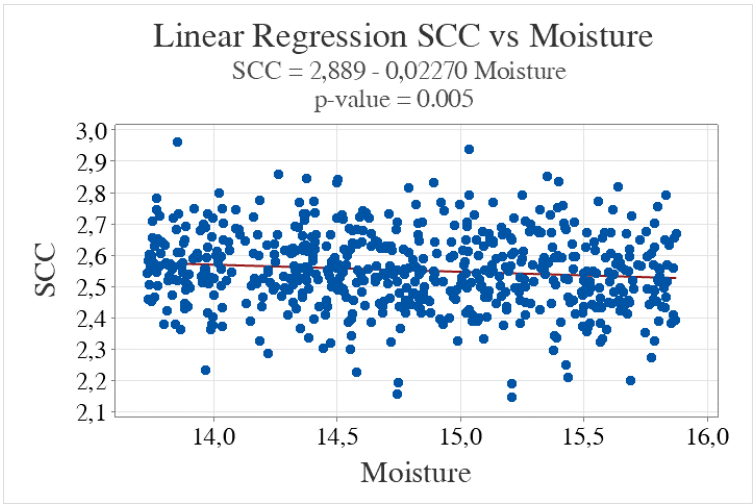


Figure 4.3: SCC vs Moisture Linear Regression

After analysing the historical data provided by the company through statistical analysis, the next step was to explore ways to increase the Moisture content of the butter directly on the shop floor. To achieve this, after exploring some literature on the subject, several brainstorming sessions were held with the operators to gain their insights on how to enhance Moisture levels. Initially, the operators were somewhat resistant to changing their daily work routines. However, as a relationship of trust developed, they became more receptive to collaborating on the project.

Through these collaborative sessions, operators identified the process parameters they believed most influenced the Moisture, prioritising them based on their field experience. Six critical variables were identified, shown in Table 4.7. To validate the operators' perceptions, experimental tests were conducted over a week in the production plant to assess the impact of these six variables on Moisture content. Due to the factory's need to maintain continuous production, these tests were challenging to execute, resulting in only 32 observations.

Despite the limited data, Table 4.7 presents the correlation results between Moisture and the other variables, including the correlation coefficients and their respective *p-values*. These results offer valuable insights into which process parameters are most strongly linked to Moisture, providing guidance to enhance butter production yield.

Table 4.7: Variables Correlation with Moisture

Variable	**Correlation Coef.**	***p-value***
Churning Speed	0.458*	0.017
Malaxing Speed	0.322*	0,015
Flow Rate	-0.315*	0,048
Yeast Pump Speed	0,149	0,066
Salt Pump Speed	0,085	0,054
Churning Temperature	0,007	0,931

*$p\text{-value} \leq 0.05$

As the operators suggested, all variables except the Churning Temperature significantly impact Moisture. As can be seen at Table 4.7, Churning Speed has the strongest positive correlation with a coefficient of 0.458 and a *p-value* of 0.017, indicating a statistically significant relationship, followed by Malaxing Speed and Flow Rate. Yeast and Salt Pump Speeds also have significant correlations. Churning Temperature, with a correlation coefficient of 0.007 and a *p-value* of 0.931, does not significantly affect Moisture, according to the observation data.

It is essential to be careful with the Yeast and Salt Pump Speeds due to strict requirements outlined in Chapter 3.1.3 (Critical to Quality), which limit each reference's yeast and salt values. As a butter additive, Yeast significantly influences the butter's pH level. The higher the Yeast Pump Speed, the lower the pH. Similarly, the Salt Pump Speed directly affects the butter's salt content. Therefore, variations in these variables with respect to Moisture must be rigorously analysed, as they also influence other critical parameters of the final product. Chapter 5 presents a One Point Lesson developed to standardise the operators' actions based on Moisture and pH levels.

4.4.2 Crystalisation Time

According to historical data, Crystallisation Time is the second most impactful variable affecting the SCC. It exhibits considerable variability, partly because the factory operates only five days a week, leaving cream in the crystallisation tanks over the weekend. Consequently, Crystallisation Times range from 0.58 hours to 59.34 hours. Figure 4.4 presentes descriptive statistics for the Crystallisation Time. The mean Crystallization Time is 10.84, with a standard deviation of 11.14, indicating significant variability around the average. The histogram in Figure 4.4 (a) shows the frequency distribution of Crystallisation Times, with most values clustered around the mean and a few values extending to higher times. The accompanying boxplot (Figure 4.4 (b)) provides a visual representation of the data's spread and central tendency.

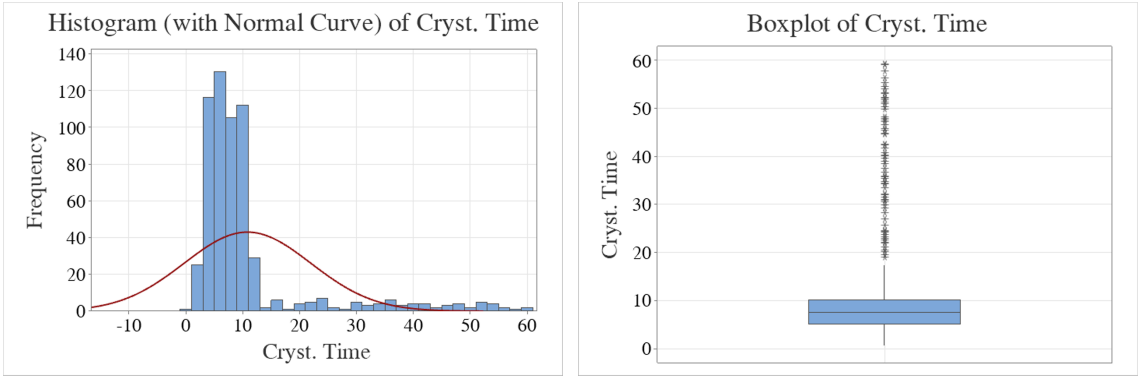


Figure 4.4: Crystallisation Time Descriptive Statistics: Histogram (a) and Boxplot (b)

Figure 4.5 illustrates the linear regression analysis between Crystallisation Time and SCC. The regression equation is $SCC = 2.544 + 0.000817 * Cryst.Time$, though its *p-value* is 0.066, which is above the 0.05 threshold for statistical significance.

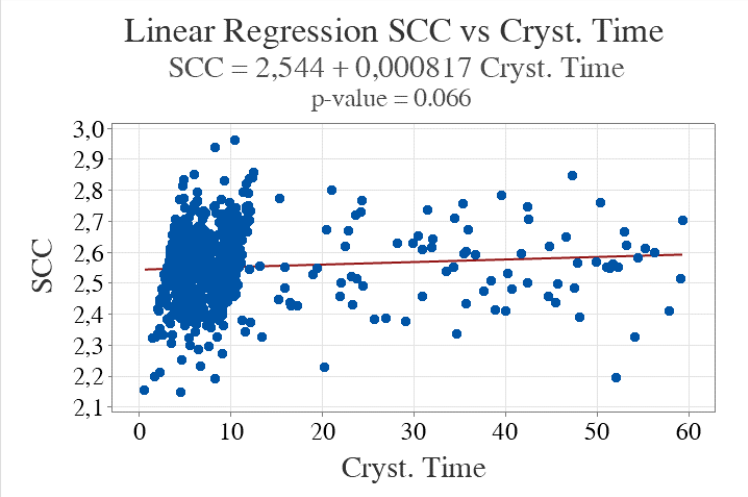


Figure 4.5: SCC vs Crystallisation Time Linear Regression

The Crystallisation Time extends beyond the project's primary focus on the butter production process. As shown in Table 4.3, the Crystallisation Temperature is around 10 ºC, with an average of 10.57 ºC. Notably, the temperature of the cream in stock tanks after receipt is, on average, 10.22 ºC. This raises the question:

– *Can the cream begin to crystallise before the designated crystallisation stage?*

No definitive answer existed, so this variable was put on hold, with a potential plan to analyse the cream microscopically to assess crystallisation levels at various stages before processing.

Additionally, the transportation temperature of the cream from origins Y and Z was considered. If this temperature is close to 10ºC, the journey time to Company X might also influence the SCC. Consequently, adjusting the Crystallisation Time variable would need to be integrated into the cream receipt planning process.

Chapter 5

Solution Proposal and Action Plan

5.1 Implemented Actions

Based on the statistical findings, several actions were implemented to achieve the project's goal. These actions included standardising Moisture control, monitoring additional process variable and streamlining work processes to enhance overall productivity and reduce waste.

5.1.1 Moisture Control Standardisation

As explained in Chapter 4, historical data analysis revealed that Moisture had the greatest impact on the SCC. To address this, the operators participated in a brainstorming session to identify which process variables most significantly affected Moisture levels. The operators' insights were then validated through experimental tests carried out on the shop floor.

Based on these findings, a One Point Lesson (OPL) was developed. This guide serves as a reference for operators, providing them with clear and concise instructions on the procedures to follow based on the butter's Moisture and pH level (Low, OK or High). This OPL was specifically designed for butter references without salt, as it was common knowledge among the operators that increasing the Salt Pump Speed would raise the salt levels in the butter. The OPL standardises the operators' tasks, ensuring consistency and precision in regulating butter Moisture. It includes step-by-step instructions and best practices to follow under various conditions to achieve higher Moisture values. This helps improve the SCC by guiding the operators on how to adjust process parameters effectively. Figure 5.1 illustrates this One Point Lesson, outlining the steps that operators should take under various conditions to achieve higher Moisture values and maintain optimal pH levels.

OPL CHURNING

Note

For each of the actions carried out, it is necessary to evaluate their impact (take a new sample) and consult the table again.

Decision-making

High Moisture and **High** pH **or** **High** Moisture and pH **OK**	- Reduce Churning Speed - Reduce Malaxing Speed - Reduce Flow Rate - Reduce Churning Temperature
High Moisture and **Low** pH	- Reduce Yeast Pump Speed
Moisture **OK** and **High** pH	- Increase Yeast Pump Speed
Moisture **OK** and **Low** pH	- Reduce Yeast Pump Speed
Low Moisture and **Low** pH **or** **Low** Moisture and pH **OK**	- Increase Churning Speed - Increase Malaxing Speed - Reduce Flow Rate - Increse Churning Temperature
Low Moisture and **High** pH	- Increase Yeast Pump Speed

Figure 5.1: OPL for Moisture and pH Regulation

To utilise the OPL correctly, operators must assess the Moisture and pH levels during the control step, which is performed every 30 minutes. In the left column of the OPL, operators identify the row that corresponds to the current butter parameters. In the right column, they find the specific action to be taken based on the identified parameters in the left column. For instance, if the butter exhibits low Moisture and high pH, the OPL instructs operators to increase the Yeast Pump Speed.

Initially, workers exhibited resistance to the OPL due to their prior focus on maximising cream throughput by operating at higher cream flow rates, which inherently hindered the achievement of higher Moisture values in the butter. The project necessitated a paradigm shift, requiring operators to prioritise achieving higher Moisture levels rather than simply increasing cream flow rates. This shift necessitated a substantial change in their daily operational practices and objectives. As a result, operators faced the challenge of adapting to new procedures and methodologies, emphasising these parameters over production volume.

5.1.2 Process Monitoring

One of the key actions implemented during this project was the establishment of more consistent process monitoring. Although the company had been tracking many of the process variables, there was a significant gap in accessing historical data before the project began. Without this access, it was difficult to draw reliable conclusions and make decisions about the production process. Table 5.1 illustrates the process variables that became available as the project progressed.

Table 5.1: Variables Current Access

Stage	**Variable**	**Hist. Access**		**Current Access**	
		Yes	No	Yes	No
Cream Reception	Origin		✓	✓	
	Transport Temperature		✓		✓
Stock 1	Stock 1 Time		✓	✓	
	Stock 1 Temperature	✓		✓	
	Cream Agitation		✓		✓
Quality Control 1	-	-	-	-	-
Pasteurization	Past. Temperature	✓		✓	
	Past. Time	✓		✓	
Crystallization	Cryst. Temperature	✓		✓	
	Cryst. Time	✓		✓	
Quality Control 2	-	-	-	-	-
Churning/Malaxing	Churning Speed		✓	✓	
	Malaxing Speed		✓	✓	
	Flow Rate		✓	✓	
	Yeast Pump Speed		✓	✓	
	Salt Pump Speed		✓	✓	
	Churn. Temperature		✓	✓	
Quality Control 3	-	-	-	-	-
Stock 2	Stock 2 Time		✓		✓
	Stock 2 Temperature		✓		✓
Packaging	-	-	-	-	-
Quality Control 4	-	-	-	-	-

In addition to accessing data on process and quality control variables, it became possible to differentiate the data by reference. This differentiation helped identify significant differences between various references.

Similar to the previous table, Table 5.2 below outlines the variables monitored during the various quality control stages, now accessible as the project progressed.

Table 5.2: Current Access Quality Varibles

Stage	Assessed Parameter	Hist. Access		Current Access	
		Yes	No	Yes	No
Quality Control 1	Cream Fat Content	✓		✓	
	pH 1		✓		✓
Quality Control 2	Fat Content 2		✓		✓
	pH 2		✓		✓
Quality Control 3	Churn. Moisture		✓	✓	
	Buttermilk Fat Content	✓		✓	
	Salt Content 3		✓	✓	
	pH 3		✓	✓	
Quality Control 4	Moisture	✓		✓	
	Salt Content		✓	✓	
	pH		✓	✓	

5.1.3 Work Process Streamlining

Key strategies implemented to streamline work processes include *Weekly Meetings* and *Steerings*, *Daily Kaizen*, and *Gemba Walks*, all aimed at enhancing communication and fostering continuous improvement within the production environment.

Weekly Meetings* and *Steerings

Weekly Meetings are held, during which each project leader presents the actions implemented during that week, the actions planned for the following week, and any constraints found. These meetings ensure that all team members are aligned and aware of the project's progress, fostering a collaborative environment where challenges can be addressed promptly. Additionally, monthly meetings, formally known as *Steerings* involve administrators and sponsors, providing a higher level of oversight and strategic direction.

Daily Kaizen

To ensure efficient shift transitions, communication, and Key Performance Indicators (KPIs) analysis, *Daily Kaizen* meetings were introduced in each production sector. These brief meetings enable team members to share information, discuss complaints, and propose potential solutions. Supported by a physical dashboard displaying KPIs, goals, and improvement opportunities, these sessions empower team members to autonomously apply Continuous Improvement principles. By respecting established work standards and fostering a mindset focused on improvement, *Daily Kaizen* meetings promote proactive problem-solving and ensure that all team members are aligned in their efforts to enhance productivity and efficiency.

Gemba Walks

Gemba Walks, a concept promoted by Toyota, involves going into the field to observe and interact with operators directly. These walks were conducted to monitor Moisture levels during shifts, ensure that operators comply with the OPL, and identify any constraints operators faced in managing Moisture. By engaging with operators on the ground, *Gemba Walks* fostered a closer relationship, making operators feel more involved and valued in the project. This direct interaction not only provided valuable insights for process improvements but also increased the operator's commitment to the project's success.

5.2 Main Results

As stated throughout this thesis, the main focus was to reduce the SCC in Company X's butter production process. To achieve this goal, using the software *Power BI*, a dashboard was built to monitor the weekly evolution of SCC from the project's inception. Figure 5.2 illustrates the SCC trends for the five references produced (A1, A2, A3, B, and C) over the 20 weeks of the project. In each graphic, the yellow line represents the Base Value, while the green line denotes the Target Value, as defined in subchapter 3.2.

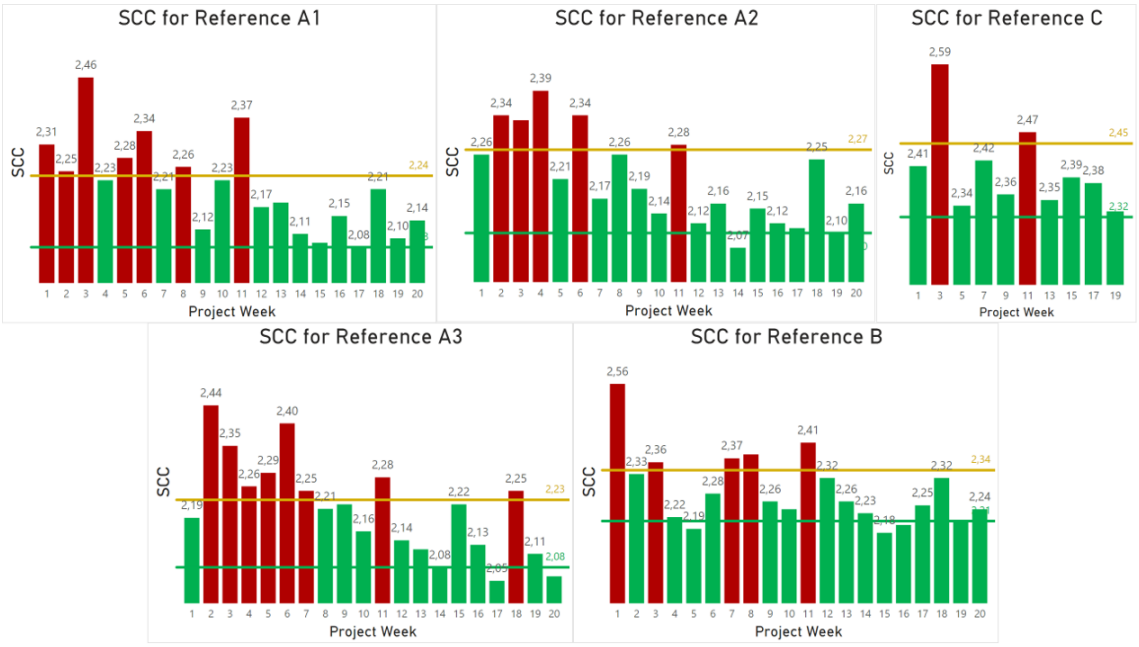


Figure 5.2: SCC Evolution during the Project

The objective of reducing the SCC was practically fulfilled. Notably, the implementation of the OPL aimed at increasing the butter's Moisture occurred in week 7. From that point onwards, a clear improvement in the SCC can be observed, although this improvement was accompanied by some variability.

A detailed examination of the dashboard reveals that there are specific weeks in which the SCC is clearly worse across all references, particularly in weeks 11 and 18. This decline can be explained by the excess cream received by the company during these weeks, highlighting a disadvantage of the company's Push model. When excess cream arrives, it must be utilised quickly to prevent degradation. Consequently, operators were instructed to work at a higher Flow Rate to use the cream. However, as discussed with the operators and presented in the OPL, increasing the Flow Rate leads to a decrease in Moisture, resulting in poorer SCC values during these weeks.

Table 5.3 presents the average Moisture and SCC values for each reference, comparing the periods before and after the implementation of the OPL. It provides the *p-values* of the statistical tests carried out on the Moisture and SCC averages before and after the implementation of the OPL. For the 'Before OPL' period, the first six weeks of the project were considered, while for the 'After OPL' period, the weeks from week 8 onwards were included.

Table 5.3: Average Moisture and SCC Before and After OPL Implementation

	Average Moisture (%)					**Average SCC** (L/kg)				
	A1	**A2**	**A3**	**B**	**C**	**A1**	**A2**	**A3**	**B**	**C**
Before OPL	14.54	14.69	14.67	14.34	14.43	2.31	2.31	2.32	2.33	2.45
After OPL	15.62	15.53	15.47	15.39	15.12	2.17	2.16	2.16	2.28	2.39
p-value	0.009	0.017	0.015	0.025	0.039	0.064	0.056	0.055	0.127	0.113

As can be seen in Table 5.3, the *p-values* of the statistical tests carried out on the Moisture and SCC averages before and after the implementation of the OPL reveal significant findings. For the average of Moisture, all references (A1, A2, A3, B, and C) show *p-values* less than 0.05, indicating that the increase in Moisture after the OPL implementation is statistically significant. In contrast, the *p-values* for average SCC are generally higher, suggesting that while there was an improvement in SCC after the OPL, the changes are not statistically significant for all references.

References A1, A2, and A3 (salted butter) exhibited the greatest difference in SCC. One explanation for this is that these references require the injection of brine. Since brine is a mixture of water and salt (detailed in subchapter 3.3.2), its injection into the butter promotes an increase in the Moisture content of the butter. On the other hand, reference B (unsalted butter) is only injected with yeast, which may explain why it does not have as significant an impact on the SCC. Reference C, which is produced differently from the other references (Batch Production) and only every two weeks, also did not show much improvement in SCC. This is due to the difficulty of regulating process variables in this type of production

5.2.1 Results Discussion

As the results presented indicate, there is a clear improvement in the SCC. However, it is evident that the Target defined in Table 3.3 has not yet been reached. This subchapter provides a brief discussion of the possible reasons for this.

After the analyses presented in Chapter 4, it became clear that Moisture was the variable with the greatest impact on the SCC. Following the implementation of the OPL, Moisture levels did indeed rise, indicating success in this aspect of the project.

Despite this success, the impact on the SCC was less significant than anticipated. The increase in Moisture was accomplished by modifying process variables such as the Churning Speed, Malaxing Speed, and cream Flow Rate. These adjustments may have led to variations in other process parameters, including some that were never monitored.

The truth is that when the cream goes into the Churning stage, it can only exit in one of two forms: either as butter or as buttermilk. Focusing on buttermilk, it is important to note that, as mentioned in subchapter 3.3.2, buttermilk does not re-enter the process but is instead expelled into the sewer.

This raises a critical question:

– *Could an increase in Moisture lead to a higher flow of buttermilk produced during the Churning process?*

This scenario could potentially offset the benefits gained from increased Moisture content in the butter, affecting the overall SCC.

This introduces a new process variable that has not been monitored until now: the amount of buttermilk generated during Churning. Buttermilk, the liquid that results from Churning the cream, could increase as butter Moisture increases. As buttermilk also consists of fine butter grains that pass through the tank filter, it is logical that increasing the buttermilk quantity makes the SCC worse. Therefore, any rise in buttermilk volume could negate the benefits of higher Moisture content in the butter, underscoring the need to monitor buttermilk production.

To address this situation, two solutions were considered:

– A large investment in a machine that would reincorporate the butter contained in buttermilk into the Churning process;

– A smaller investment in purchasing a flow meter that allows the measurement of buttermilk flow resulting from Churning in real-time.

In the short term, the company opted to invest in purchasing a flow meter. This flow meter will enable the execution of experimental tests to assess the impact of variables such as Churning or Malaxing Speed on the amount of buttermilk generated. By monitoring these variables in real-time, the company can gain valuable insights into the relationship between process parameters and buttermilk production, allowing for more precise adjustments to improve the SCC.

Chapter 6

Conclusions and Future Work

The dairy market is very vast and plays a significant role in the global economy, driven by diverse consumer preferences and a rich culinary tradition. In Portugal, the dairy sector has a notable impact on the national economy, with the primary activity being the production of foods derived from milk, such as pasteurised milk, butter, cheese, yoghurt, and ice cream.

This present thesis aimed to reduce the Specific Cream Consumption (SCC) by modifying variables inherent in the butter production process using Lean Six Sigma Agile methodologies. This systematic approach involved identifying and improving key production parameters to enhance the process yield. By integrating Lean's waste reduction, Six Sigma's data-driven decision-making, and Agile's flexibility, the project improved process performance, reduced variability, and maintained high-quality standards in butter production.

The proposed solution involved numerous interventions within the production process, providing a global improvement. After mapping the entire production process and identifying the main process variables, statistical analyses were conducted using Minitab Software to determine which variables had the greatest impact on the SCC. Based on these findings, specific actions were implemented to improve the overall yield of the process. For instance, the introduction of a One-Point Lesson (OPL) provided operators with clear and concise instructions on adjusting process parameters to achieve optimal Moisture levels.

Figure 6.1 shows the main methodologies used in this project, organised within the framework of the DMAIC (Define, Measure, Analyze, Improve, Control) methodology. The methodologies are categorised into three phases: Assessment, Improvement, and Monitoring, providing a structured approach to improving butter production yield in Company X.

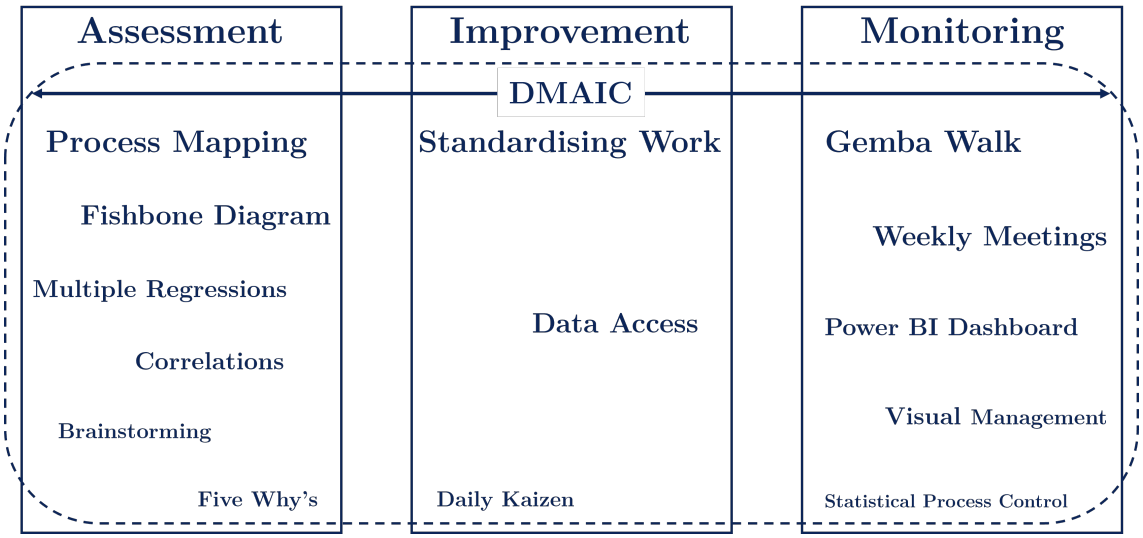


Figure 6.1: Tools and Methods

6.1 Main Conclusions

This subchapter presents the main conclusions drawn to answer the research questions in subchapter 1.4 of this thesis.

RQ1: How can Lean Six Sigma Agile methodologies be applied to reduce the Specific Cream Consumption in butter production?

The combination of Lean, Six Sigma, and Agile methodologies was effectively applied in this project, resulting in a significant reduction in the Specific Cream Consumption (SCC), the project's primary objective. By integrating these methodologies, the project successfully improved butter production processes, enhanced efficiency, and maintained high product quality. Each methodology brought its unique strengths, contributing to an effective approach to process improvement.

Lean methodology was applied by systematically mapping the entire production process to identify and eliminate inefficiencies. This involved creating detailed process flow maps to visualise each step and pinpoint areas for improvement. By conducting a thorough analysis, opportunities for enhancement were defined for each stage of the process. Additionally, a fishbone diagram was developed to understand the root causes of high variability in production. Lean principles focused on reducing waste, optimising workflow, and improving process flow, ultimately contributing to more efficient and consistent butter production.

Six Sigma methodology was the most extensively used throughout the project. The strength of the project was conducting statistical tests to determine which variables most influenced the SCC of the butter production process. These analyses, carried out using *Minitab* software, enabled the team to identify critical factors affecting SCC and implement targeted improvements. By using Six Sigma tools such as DMAIC (Define, Measure, Analyze, Improve, Control) and statistical

process control, the project achieved a data-driven approach to quality enhancement and variability reduction.

The Agile methodology was consistently present throughout the project. Its flexible nature allowed the DMAIC stages to be conducted in a non-linear order. For instance, after analysing the impact of variables on the SCC (Analyze stage), the team could return to the Measure stage to gather additional data on variables influencing Moisture. These iterative cycles enabled continuous improvement and adaptability, ensuring that the project could respond effectively to new insights and changing conditions within the production process.

In conclusion, the integration of Lean, Six Sigma, and Agile methodologies proved to be highly effective in reducing the SCC. Table 6.1 presents the SCC reduction values (in percentage) for each reference before and after the implementation of the OPL.

Table 6.1: SCC Reduction Values Before and After OPL Implementation

	References				
	A1	**A2**	**A3**	**B**	**C**
Before OPL (L/kg)	2.31	2.31	2.32	2.33	2.45
After OPL (L/kg)	2.17	2.16	2.16	2.28	2.39
SCC Reduction (%)	-6.06	-6.49	-6.90	-2.15	-2.45

RQ2: What are the main process variables directly impacting butter's Specific Cream Consumption?

After mapping the entire butter production process, it was necessary to collect all available historical data. With the collected data for a few variables, the first step was to check for correlations between the process variables using *Minitab* Software. No significant correlations were found between the variables. Subsequently, a multiple regression analysis was conducted with the SCC as the dependent variable, revealing that the model explains only a small portion of the variance in SCC.

Through the correlation and multiple regression analyses, it was concluded that, according to the historical data, the two variables with the greatest impact on SCC were the Moisture of the butter and the Crystallisation Time of the cream.

Regarding Moisture, it was observed that an increase in Moisture resulted in a reduction in SCC. This led to brainstorming sessions and a study of the variables that most significantly impact Moisture. As a result, an OPL was created to provide guidelines on regulating Moisture effectively.

For Crystallisation Time, although the *p-value* of its correlation with SCC was 0.066, it was identified as the second most impactful variable on SCC. A shorter Crystallisation Time is correlated with a lower SCC. Further investigation raised the question of whether the cream starts to crystallise before the crystallisation stage due to the temperature consistency of around 10ºC. This variable remains on stand-by as it interferes with the company's push planning model.

RQ3: How can the standardisation of tasks impact the process yield and reduce the process variability?

Standardisation played a fundamental role in the project, particularly by creating a One Point Lesson to regulate Moisture according to process variables. This approach ensured that all operators followed the same guidelines, leading to more consistent results.

Achieving consistent Moisture results required the development of the OPL. Initially, operators were resistant to changing their usual practices and did not prioritise Moisture control. However, through multiple brainstorming sessions, a consensus was reached on a standard method for regulating Moisture. This involvement increased operator engagement, allowing for the successful increase in Moisture and the reduction of SCC, the project's primary objective.

In conclusion, standardisation was crucial for achieving high moisture levels and reducing variability among operators. It ensures consistency and improves process yield.

6.2 Future Work Perspectives

Despite the good results achieved, actions still need to be taken in the short, medium, and long term to further improve butter production yield. As already mentioned, according to historical data, the two variables that had the greatest impact on SCC were Moisture and Crystallization Time. Regarding Moisture, there isn't much more to do apart from ensuring that the OPL is consistently followed and monitoring Moisture levels to maintain the average reached in recent weeks. However, there are still future actions that can be taken concerning Crystallization Time.

Crystallization Time was a variable that was left on standby during the process. Future actions should focus on studying this variable in more detail. First, the composition, appearance, and level of crystallisation of the cream should be assessed microscopically, if possible. This evaluation would need to be carried out with several samples from different origins and with different Crystallisation Times. Additionally, it would be interesting to determine whether the cream starts to crystallise before the crystallisation stage using microscopic analysis. Following this, statistical tests should be conducted again to find the optimal Crystallisation Time for the cream. Although it has been concluded that shorter Crystallisation Times lead to lower SCC, it is necessary to verify the differences between various low Crystallisation Times to identify the most effective duration.

Another focus for future action is examining whether increased Moisture results in a greater flow of buttermilk generated during the Churning process. As explained in Chapter 5.2.1, to draw conclusions about this, the company decided to purchase a flow meter to measure the buttermilk flow in real-time during Churning. It would be beneficial to carry out experimental tests using the Design of Experiments (DOE) methodology, where some process variables are fixed while others are varied. This approach would allow for the assessment of the impact of variables such as Churning speed and cream flow rate on the amount of buttermilk generated.

Finally, it is important to continue monitoring all variables and conducting statistical tests concerning SCC. As future actions, maintaining ongoing monitoring of the evolution of SCC over the weeks will be crucial to ensure continuous improvement.

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Appendix A

Project Schedule

Phase	Description	Week																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
D	Problem Characterisation																				
D	AS-IS mapping																				
M	Cause identification																				
A	Prioritisation																				
A	Solution designing																				
A	Solution testing																				
I	Improvement implementation																				
C	Standardisation & training																				

Figure A.1: Project Cronogram

Appendix B

Butter Production Data

This appendix describes trends and provides data about European butter production, including in Portugal. These data are processed by CLAL (2024) based on Eurostat data. Table B.1 lists the butter production volume, in tonnes, of the EU member states (CLAL, 2024). Butter production increased by 0.4%, reaching 11.440 tonnes from January to April 2024 CLAL (2024). Figure B.1 presents the rolling year of butter production in Portugal from 2018 to 2024, illustrating long-term trends, cyclical fluctuations, and significant changes in butter production over the past six years. Notable declines occurred in late 2019 and early 2022, while peaks were observed at the end of 2020 and early 2023. The most recent data indicates an upward trend, stabilising around 32.000 tonnes as of early 2024.

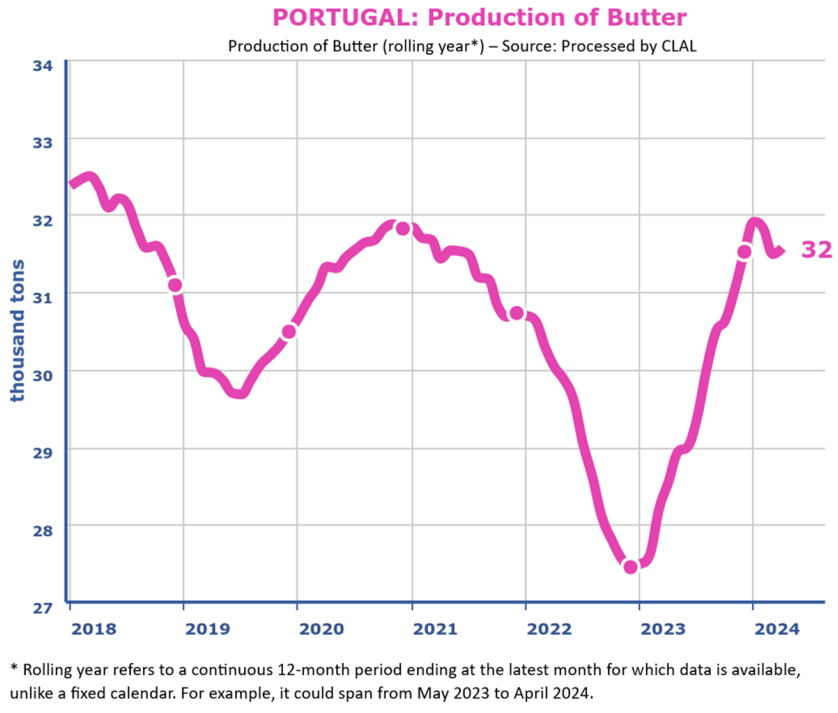


Figure B.1: Rolling Year Butter Production in Portugal CLAL (2024).

Table B.1: UE-27: Production of Butter (tonnes)

COUNTRY	2018	2019	2020	2021	2022	2023	2023	2024	Var %	Period
Austria	36,980	36,540	38,110	36,670	34,380	33,460	9,690	8,550	-11.80%	Jan - Mar '24
Belgium	64,240	111,960	122,590	109,650	107,830	119,810	30,120	31,980	6.20%	Jan - Mar '24
Bulgaria	1,110	1,060	1,030	1,040	1,190	1,060	480	350	-27.10%	Jan - Apr '24
Croatia	4,330	4,580	5,040	4,520	4,750	3,730	1,260	840	-33.30%	Jan - Mar '24
Czech Republic	23,810	26,170	26,950	25,780	25,330	24,470	7,910	8,660	9.50%	Jan - Apr '24
Denmark	74,000	74,700	72,700	81,500	85,100	95,900	31,300	25,600	-18.20%	Jan - Mar '24
Estonia	4,900	5,200	5,000	3,900	4,400	4,600	1,900	1,300	-31.60%	Jan - Apr '24
Finland	59,900	60,900	62,690	58,750	57,040	57,880	20,660	20,540	-0.60%	Jan - Apr '24
France	420,280	414,230	413,100	407,620	408,630	403,580	114,160	108,890	-4.60%	Jan - Mar '24
Germany	484,041	497,104	506,436	471,057	472,574	480,466	133,316	133,316 (e)	0.00%	Jan - Mar '24
Greece	1,110	1,200	1,450	1,660	2,160	2,360	610	530	-13.10%	Jan - Mar '24
Hungary	9,370	8,630	9,200	9,230	9,280	8,450	2,990	4,320	44.50%	Jan - Apr '24
Ireland	237,840	251,070	264,720	275,600	269,190	273,150	44,360	38,910	-12.30%	Jan - Mar '24
Italy	95,580	96,200	94,010	98,470	100,510	98,510	25,770	26,400	2.40%	Jan - Mar '24
Latvia	3,220	3,280	3,370	3,100	2,580	3,620	1,340	1,060	-20.90%	Jan - Apr '24
Lithuania	14,160	14,430	15,050	10,750	11,110	13,990	4,060	4,490	10.60%	Jan - Apr '24
Netherlands	153,800	136,400	133,500	137,700	138,300	125,500	33,400	31,600	-5.40%	Jan - Mar '24
Poland	221,760	224,610	243,300	231,410	243,070	264,450	93,930	90,620	-3.50%	Jan - Apr '24
Portugal	31,090	30,490	31,820	30,730	27,450	31,520	11,390	11,440	0.40%	Jan - Apr '24
Romania	10,880	10,670	12,170	11,190	10,480	10,970	2,420	2,830	16.90%	Jan - Mar '24
Slovakia	9,470	9,900	11,050	10,610	10,330	9,180	3,000	3,220	7.30%	Jan - Apr '24
Slovenia	2,620	2,560	2,620	2,470	2,260	2,250	700	700	0.00%	Jan - Apr '24
Spain	49,300	45,679	43,500	34,070	25,470	19,850	6,490	4,860	-25.10%	Jan - Mar '24
Sweden	16,380	17,170	17,510	17,950	20,060	22,480	6,180	6,090	-1.50%	Jan - Mar '24
TOTAL EU-27	2,030,171	2,084,733	2,136,916	2,075,427	2,073,474	2,111,236	551,096	530,756	-3.70%	Jan - Mar '24

Appendix C

Comparative Analysis of Lean, Six Sigma, and Agile and Lean Six-Sigma Methodologies

Table C.1: Comparison of Lean, Six Sigma, Agile, and Hybrid methodologies

	Lean	**Six Sigma**	**Agile**	**Hybrid methodology**
Primary Focus	- Eliminating waste and optimizing flow	- Reducing defects and process variation	- Flexibility, Collaboration and customer satisfaction	- Integrating Lean and Agile principles with Six Sigma for improved efficiency and adaptability
Key Principles	- Define value from the customer's perspective - Identify steps in the value stream and eliminate waste - Produce only what is needed by the customer - Strive for continuous improvement	- Identify the problem and project goals - Collect data and determine performance - Identify root causes of defects - Maintain improvements and ensure consistent performance	- Value people and communication over tools - Prioritize working solutions over documentation - Be flexible and adapt to changing requirements	- Combine Lean's waste reduction and Agile's flexibility - Focus on iterative improvements while maintaining quality - Prioritize customer needs and feedback - Respond to changes in the market and customer requirements quickly
Tools & Techniques	- VSM - 5S - Kaizen - JIT - Kanban	- DMAIC - DMADV - SIPOC - FMEA - SPC	- Scrum - Kanban - XP - User Stories - Sprints - Daily Stand-ups	- VSM - DMAIC for process improvement - Scrum or Kanban for project management - Statistical analysis tools - CI/CD for software development

Table C.2: Comparison of Lean, Six Sigma, Agile, and Hybrid methodologies (Cont.)

	Lean	**Six Sigma**	**Agile**	**Hybrid methodology**
Benefits	- Increased efficiency and productivity - Reduced waste and costs - Faster delivery times - Improved customer satisfaction - Enhanced quality of products/services	- Higher quality and fewer defects - Reduced variation in processes - Improved decision-making based on data - Increased customer satisfaction - Enhanced profitability	- Faster time to market - Greater flexibility and adaptability - Improved team collaboration - Enhanced customer engagement and satisfaction - Better alignment with customer needs	- Improved efficiency and quality through Lean principles - Enhanced adaptability and responsiveness to change with Agile methods - Data-driven decision making and process improvement from Six Sigma - Higher customer satisfaction and stakeholder value through integration of methodologies
Implementation Approach	- Focuses on long-term cultural change - Emphasizes employee involvement and empowerment - Uses a top-down approach for continuous improvement	- Relies on statistical analysis and data-driven decisions - Often requires specialized training (e.g., Green Belt, Black Belt) - Uses project-based approach with clear phases	- Iterative and incremental development - Emphasizes continuous delivery of small, workable pieces - Requires strong customer and stakeholder engagement	- Holistic approach to process improvement and project management - Combines elements of Lean, Six Sigma, and Agile based on project needs and objectives - Adaptable and flexible implementation strategy
Success Metrics	- Lead Time - Cycle Time - Waste Reduction - Customer Satisfaction	- DPMO - Sigma Level - Cpk - Cost Savings	- Velocity - Burn-down/Burn-up - Charts - Customer Satisfaction	- Balanced Scorecard approach considering efficiency, quality, customer satisfaction, and financial metrics - Project-specific metrics aligned with organisational goals and objectives - Continuous monitoring and improvement based on feedback and data analysis - Team Productivity

Appendix D

Advanced search results within Scopus database for the different case studies

Table D.1: Overview of Document Types by Case Study

Cases Studies	**Documents found**						
	Articles	**Conf. Papers**	**Review Papers**	**Conf. Review Paper**	**Books**	**Book Chapters**	**Total**
Case 1. Application of Lean Methodology in the Food Industry	45	19	3	-	2	2	73
Case 2. Application of Lean Methodology in Dairy Processing	11	7	-	1	1	4	24
Case 3. Application of Six Sigma Methodology in the Food Industry.	9	12	-		-	1	22
Case 4. Application of Six Sigma Methodology in Dairy Processing	5	6	-	-	-	1	12
Case 5. Application of Agile Methodology in the Food Industry	11	11	2	-	1	-	25
Case 6. Application of Agile Methodology on dairy processing	-	-	-	-	-	-	0
Case 7. Application of Lean-Six Sigma Methodology in the Food Industry	14	8	1	2	-	-	25
Case 8. Application of Lean-Six Sigma Methodology in Dairy Processing	5	1	-	1	-	-	7
Case 9. Application of integrated Lean Six Sigma Agile methodology	6	-	2	-	1	-	9