

Improving Cheese Production Capacity in a Dairy Company: A Lean Six Sigma Approach for Enhanced Efficiency and Performance

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Abstract

The evergrowing competitiveness and increasing consumption levels witnessed in the food industry increasingly demand differentiation. Concomitantly, quality standards and legal restrictions dispute with increasing production capacity, constraining constant rates of variability and nonconformity. Therefore, it becomes imperative to monitor and optimize the involved factors within its process. Although commonly associated with operational execution, most cases reveal external factors such as product flow, resource utility, or the raw material's composition.

The dairy industry is characterized by its notorious regulation and specialization. The perishable nature of milk heavily conditions production scheduling, lead times, and overall resource utility. Cheese production, its derivative, consequently, doesn't withstand. Its most crucial performance factor is milk consumption, although the main quality parameter is cheese weight. Numerous operational and intricate factors may affect these two parameters. Uncontrolled supervision of these factors may jeopardize the cheese's final weight, milk yield, as well as variability. This compromises customer satisfaction, legal limits, and, consequently, the business's profit margin.

This project is part of a continuous improvement project developed in the cheese production sector of a dairy company, aimed at achieving strategic growth, competitiveness, and improving resource usage. The under-optimal specific milk consumption, production capacity, and process variability were deemed the most crucial factors. The main objective established aimed to reduce the amount of milk consumed per kilogram of cheese of the main two produced cheese references whilst reducing the overall weight variability. The byproducts may then be transversal to the remaining references. This study focused on the two initial production phases: fabrication and drying. To comprehend the influence of process variables, a deductive approach is employed, based on theoretical foundations and experimental validation.

Initial variable analysis was followed by a detailed examination of the production process through statistical analyses of milk consumption and cheese weight. Fat content stood out amongst all, contributing to 81% of process variability, indicating lower consumption levels with higher fat levels. The cheese's position in the drying chambers also played a significant role, with closer proximity to air ducts resulting in higher ripening rates. This resulted in a 25% reduction in drying time. A tool was developed to regulate milk treatment within the optimal casein-fat range of [0.64, 0.655]. Additionally, operational improvements were identified, such as adjusting the filler machine angle to 30° for quality enhancement and reducing mold sizes by 17mm to minimize cheese giveaway. Inefficient work procedures and product flow were highlighted, emphasizing the importance of standardizing work for process optimization.

A reduction of milk consumption by 6.81%, an increase of 3.34% in production capacity, and a variability decrease of 32.4% were achieved. These demonstrate the value of the Lean Six Sigma methodology as the primary tool in the pursuit of improved operational performance, repaying all the effort put forth in the fight against waste and the quest for excellence.

Resumo

Melhoria da Capacidade de Produção de Queijo numa Empresa de Laticínios: Uma Abordagem Lean Six Sigma para uma Maior Eficiência e Desempenho

A indústria alimentar enfrenta maior competitividade e aumento do consumo, exigindo diferenciação. Os padrões de qualidade e as restrições legais impactam a capacidade de produção, resultando em variabilidade e inconformidades. Torna-se, portanto, crucial monitorar e otimizar fatores como fluxo de produto, utilização de recursos e composição da matéria-prima.

O setor de laticínios é altamente regulamentado e especializado. A perecibilidade do leite afeta a programação da produção, prazos de entrega e eficiência dos recursos. A produção de queijo, um derivado do leite, é especialmente afetada. Para além do consumo de leite, o peso do queijo destaca-se como sendo o principal indicador de qualidade. A supervisão inadequada dos seus fatores impactantes afeta o peso final do queijo, a eficiência do consumo de leite e sua variabilidade, prejudicando a satisfação do cliente, o cumprimento das leis e a margem de lucro da empresa.

Este projeto enquadra-se num projecto de melhoria contínua desenvolvido numa empresa produtora de queijo, com alvo a crescimento estratégico, competitividade e melhor uso de recursos. Os principais fatores considerados são o alto consumo específico de leite, a capacidade de produção e a variabilidade do processo. O objetivo principal é reduzir o consumo de leite por quilograma de queijo nas duas principais referências de queijo, reduzindo também a variabilidade do peso. Os subprodutos podem ser utilizados em outras referências de queijo. O estudo concentra-se nas fases iniciais de fabricação e secagem. Uma abordagem dedutiva baseada em fundamentos teóricos e validação experimental é usada para compreender a influência das variáveis do processo.

A análise inicial das variáveis foi seguida de um exame pormenorizado do processo de produção através de análises estatísticas sobre o consumo de leite e o peso do queijo. Outras investigações foram alargadas aos fatores externos que afectam o peso e a variabilidade do queijo. O teor de gordura destacou-se, contribuindo para 81% da variabilidade, com níveis de consumo mais baixos para níveis de gordura mais elevados. A posição do queijo nas câmaras de secagem também desempenhou um papel significativo, com maior proximidade das laterais resultando em maiores taxas de maturação e uma redução de 25% no tempo de secagem. Uma ferramenta foi desenvolvida para regular o tratamento do leite dentro da faixa ideal de caseína-gordura de $[0,64, 0,655]$. Além disso, foram identificadas melhorias operacionais, como o ajuste do ângulo da máquina de enchimento para 30° e redução do tamanho dos moldes por 17mm para minimizar o desperdício de queijo. Os procedimentos de trabalho ineficientes e o fluxo de produtos foram destacados, enfatizando a importância da normalização do trabalho para a optimização do processo.

Uma redução do consumo de leite em 6,81%, um aumento de 3,34% na capacidade de produção e uma diminuição da variabilidade de 32,4% foram alcançados. Estes demonstram o valor da metodologia *Lean Six Sigma* como a principal ferramenta na busca de um melhor desempenho operacional, recompensando o esforço colocado na luta contra o desperdício e busca pela excelência.

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*"Build yourself upon the small things you do every day, and the end results will be no more than
a byproduct of that."*

Anonymous

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Acronyms and Symbols

KPI	Key Performance Indicator
SMC	Specific Milk Consumption
PC	Production Capacity
SS	Six Sigma
LSS	Lean Six Sigma
ANOVA	Analysis of Variance
DMAIC	Define, Measure, Analyse, Improve and Control

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Chapter 1

Introduction

The following master thesis' project¹ focuses on an intervention proposal for operational improvement in an industrial enterprise in the food market, specified in cheese production.

In this chapter, a brief presentation and contextualization of the project and industry is made, alongside a thorough description of the objectives and adopted methodology to achieve them.

1.1 Contextualization of the project and motivation

The cheese industry over the years has grown into an industrialized global enterprise with mass production and immense complexity (Kindstedt, 2012). Consequently, its technological advancement has enabled the production of predictable cheeses, propelling notable competition and the urge for continuous improvement in its production process. Notwithstanding, due to the intricate nature of cheese, guaranteeing consistency amongst the many factors in its production process such as quality, yield, and waste continues to be a significant challenge within the industry (Tunick, 2014).

This project, thus, emerges from the opportunity to analyze how the company in question can improve its production process from a sustainability and efficiency standpoint, maximizing the amount of cheese produced with the same quantity of milk used. This can be achieved by minimizing waste and optimizing processes and resource usage. The critical stages identified for improvement are the production and drying phases. These issues, if persisting, may escalate a significant increase in raw product and human resources waste and, thus, production costs, compromising the company's market share and client satisfaction.

The analysis conducted thoroughly inspects the production process and resource management, seeking to establish a standardized methodology governing our approach, whilst defining a variance control methodology for the company.

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1.2 The food industry in Portugal

The food industry in Portugal is a significant contributor to the country's economy, with a diverse range of products from dairy, meat and fruits to processed foods (Manuel Laranja, 2009). Although fragmented, in its entirety, marks a significant role in the national economy. According to recent data from Pordata (2023), the food and beverage industry accounted for approximately 4.95% of the country's GDP in 2019.

Although its growth was considerably consistent, significant oscillation in customer behavior and product delivery has been observed, as a result of COVID-19 pandemic. According to Eurostat (2021), a slight contraction was observed in 2020, coinciding with the initial spread of the pandemic in the country. Nevertheless, an increase of approximately 8.5% of retail sales was observed in 2020 (Statista, 2022), resulting from a shift of customer behavior to online shopping, focusing on health and safety concerns (Lamy et al., 2022).

Table 1.1 represents each subsector's influence within the industry in 2020, obtained from (INE, 2021) (see Appendix B for more details). Meat-based, dairy, and bakery products stand out significantly amongst the subsectors.

Table 1.1: Distribution of sales within the food industry in Portugal

Subsector	Sales (B.€)	%
<i>101- Animal slaughter, meat preparation, and preservation of meat and meat-based products</i>	2.967	22.25
105 - Dairy industry	1.565	11.74
<i>109 - Manufacture of animal feed</i>	1.555	11.67
<i>107 - Manufacture of bakery products and other flour-based products</i>	1.552	11.64
<i>102 - Preparation and preservation of fish, crustaceans, and mollusks</i>	1.258	9.43
<i>104 - Production of animal and vegetable oils and fats</i>	1.141	8.56

Sales volume-wise, meat-based products lead the market (22,25%), followed by bakery or dairy products (11,74%) and animal feed (11,67%). Bakery products and other flour-based products equally show a significant percentage of the sales distribution (11.64%), contributing as a whole to a majority of sales within the Portuguese market.

Although mainly driven by the primary raw material, milk, the dairy industry subdivides itself into several derivatives. The graphs shown in Figure 1.1 represent the sales distribution within the dairy industry, as well as the amount of produced goods in 2021, adapted from INE (2021). Although quantities produced show significant discrepancies, with milk standing out with the majority (72%), the sales distribution shows more balanced results, with milk (26%), cheese (22%), and yogurts (11%) leveraging the market significantly. Several factors may justify this behavior, namely complexity and lead time discrepancies between the production process, the prior necessity for milk treatment for cheese or yogurt production, and shelf life differences (Janzen et al., 1982).

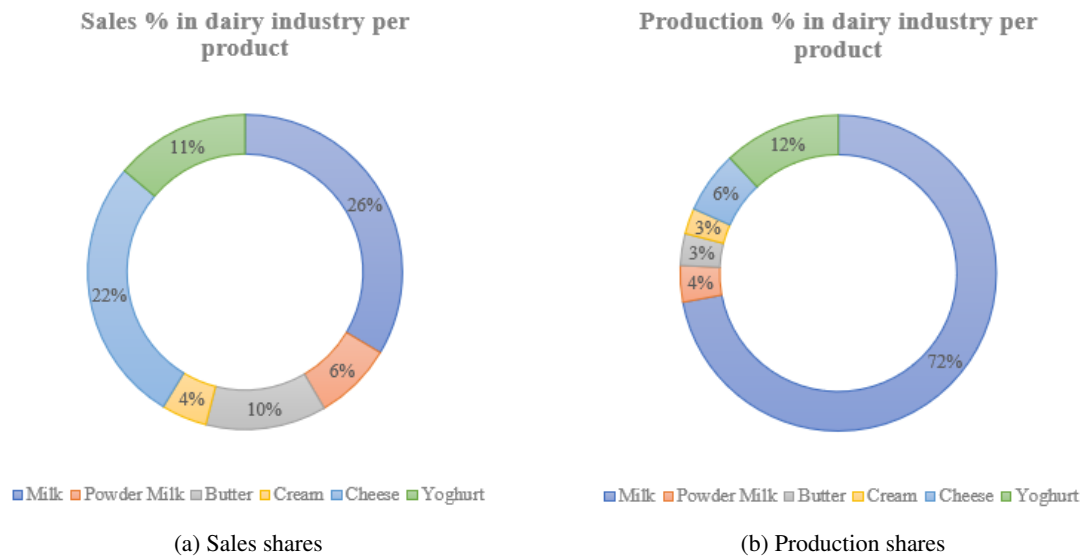


Figure 1.1: Dairy industry production and sales values in Portugal

BPStat (2022) provides additional data on the subsectors of the industry, namely the number of employees and enterprises. Regarding the first, it diverges significantly, with bakery products overtaking the majority (55,32%), followed by meat-based products (11,19%) and, only then, dairy products (6,1%). Notwithstanding, the number of employees shows proportionality to the number of enterprises, with bakery products leading the market (34,59%), followed by meat-based products (21,65%) and dairy products (8,33%).

To more accurately position the food industry within the market, a value chain analysis was developed to further describe the steps, intervenients, and main supportive pillars of the dairy industry in Portugal. This can be consulted in Appendix C.

1.3 Project description

Cheese production represents a permanent activity of the company subject to this study. Its abiding presence in the market transpires from the reputation and pride of producing quality cheese in large magnitudes, aiming to reach higher standards. Thus, investing in development and continuous improvement becomes crucial for maintaining high levels of productivity and service level, a long-term strategy that has been followed by the company throughout the years. Hence the sprouting of this improvement project started in September of 2022, aims to reduce waste within the production phase and improve flexibility, and predictability in a traceable manner. Improving quality through optimizing lead times, movement flows and product giveaways were stamped as the main areas of intervention.

Among the several improvement opportunities, this project will target the sub-optimal production capacity during the first production phase, referred to as fabrication, more specifically its efficiency and efficacy. These translate into minimizing the amount of raw material used to produce

one unit of finished product, whilst simultaneously minimizing lead times and variability. Unoptimized chemical compositions, inefficient unmolding of cheese, combined with inefficient flows of product in its intermediate stages, although minimal, can lead to significant profit repercussions from a macroscopic standpoint. These can be expressed as guaranteeing product traceability, maximizing automation of targeted operations, and eliminating inefficiencies during the drying phase will parallelly be targeted.

1.4 Objectives and research questions

After a diagnosis of the process, two product references were deemed as our research subjects: bar and ball-shaped cheeses. The first consists of a rectangular-shaped cheese, mainly produced for slicing, whereas the second one represents a sphere-shaped variety, usually divided into portions or sold whole. By identifying the main sources of variation within the process and its current state, the production capacity was deemed as our main research subject, subdivided into process efficiency (liters of milk per kilogram of cheese) and efficacy (kilograms of cheese per hour). For these, goals of 8.32 and 8.67 liters of milk per kilogram of cheese (not including 5.67% of waste) and 1233.2 kilograms of cheese per hour (considering 88 available vats) were defined, respectively.

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

- *What are the main factors that directly impact raw milk's consumption and the final weight of cheese?*
- *What are the ideal target values and implementations to simultaneously minimize variability, whilst maintaining or improving the production capacity?*
- *How can the Lean Six Sigma methodology maximize efficiency and efficacy amidst the most critical stages that directly impact milk consumption?*

These questions steered this research project. By answering them, significant changes can be made in the entire cheese production lifecycle, whilst being applicable to other cheese references.

1.5 Methodology

This project was developed parallelly through 2 main programs, both being divided into 5 main phases: Problem characterization, root-cause problem definition, solution testing, standardization, and training. The timeline for both can be observed in Appendix A.

After defining the most critical cheese references, a thorough analysis of the production process was conducted, identifying each stage and operating procedures. This analysis, beyond observation and data, was heavily conducted through statistical support, mainly focused on the Lean Six Sigma methodologies. The main premise focused on visiting the infrastructures (GEMBA) and being able to identify any wasteful task, activity or behavior (MUDA). Through these, an adequate alignment and goal definition with the enterprise was possible.

With the crucial factors defined, a cause analysis was conducted, adequately associating critical waste identification to its possible originator.

Parallely, according to priority and executability, an action plan was developed, scheduling each test and conducting each aforementioned cause. These tests should directly address the identified root causes. These consisted of small-scale tests or pilot projects implemented to evaluate the effectiveness of the proposed solutions. The test was carefully designed and measured to collect relevant data and feedback according to the industry's capabilities and existing measurements. According to each test, the results were evaluated and analyzed through the statistical analysis software Minitab.

The following standardization and training amongst the involved operators stood out significantly, being conducted as the new changes were analyzed, proving to be beneficial for the work ethic and longevity of this project.

1.6 Project structure

The project is divided into 7 main chapters, within which a more thorough explanation of the context, methodology, and solutions is provided. This chapter introduces the topic of the thesis, alongside its background and motivation, its objectives, and the methodologies followed.

Chapter 2 provides a comprehensive review of existing literature on the topic, identifying the key theories, concepts, and findings that have informed and supported the research.

Chapter 3 presents an overview of the existing process and production and operational processes that this project seeks to improve, followed by an identification and description of the problem.

Chapter 4 details the specific problems, diving into the analysis and interpretation of the conducted experiments. The main conclusions are stated.

Chapter 5 outlines the results, proposed solutions to the problem and respective implementations to further guarantee continuous improvement.

Lastly, chapter 6 closes the research project, reflecting on its main conclusions and improvement suggestions for future researchers.

Chapter 2

Literature Review

2.1 Research Methodology

In this paper, an adaptation of the PRISMA framework was used for transparent reporting and a systematic review of literature (Page et al., 2020). The following steps are discussed:

- Definition of the research questions: guidance for identifying relevant papers;
- Search process: research strategy and selection of scientific sources;
- Screening process: criteria applied to select the most relevant papers.

2.2 Definition of the research question

Despite the increasing efforts in implementing improvement methodologies such as Lean and Six Sigma for the last two decades, the food sector is still significantly far behind other industries (Azalanzazllay and Halim-Lim, 2020). The most prominent problems arise from the reduced flexibility of businesses, especially the main market competitors, with overwhelming business foundations based on fixed and traditional principles. Moreover, the dairy industry stands out on this paradigm, with external concerns such as the sensibility of the raw material itself, milk. In order to understand the current scenario, applications and difficulties stated, the following research questions were formulated to guide the following literature review:

- *What are the key Lean Six Sigma applications and benefits within the food industry for improving production capacity?*
- *What are the key challenges faced by the dairy industry and how can Lean Six Sigma tools address these challenges?*
- *What are the best practices and success stories of implementing Lean Six Sigma in the dairy industry?*

2.3 Research Process

This section provides the theoretical background on quality control, process variability and Lean Six Sigma supporting this case study.

2.3.1 Quality Control in the Food Industry

Volatility and complexity accurately define the food industry's behavior. The perishable behavior from its intervenients, the delicate processing stages within production, and the seasonal oscillation associated adequately justify its inefficiency and lack of competitiveness (Dora et al., 2013). Moreover, it being closely networked with other industries such as agriculture and packaging (Dora et al., 2013) reinforces synergies with quality control measurements and methodologies.

Growing consumers' expectations and concerns for quality, alongside increasing requirements from legislative and supply chain standpoints, are the key drivers for improvement in quality control and management systems (Sikora and Strada, 2006). With quality in the food industry being often used in several contexts such as food safety and regulatory compliance, it becomes imperative to distinguish its applications in the sector. Sikora and Strada (2006) provide a diagram, with an adapted scheme shown in Figure 2.1, dissecting the concept of "food quality" into its several components and applications.

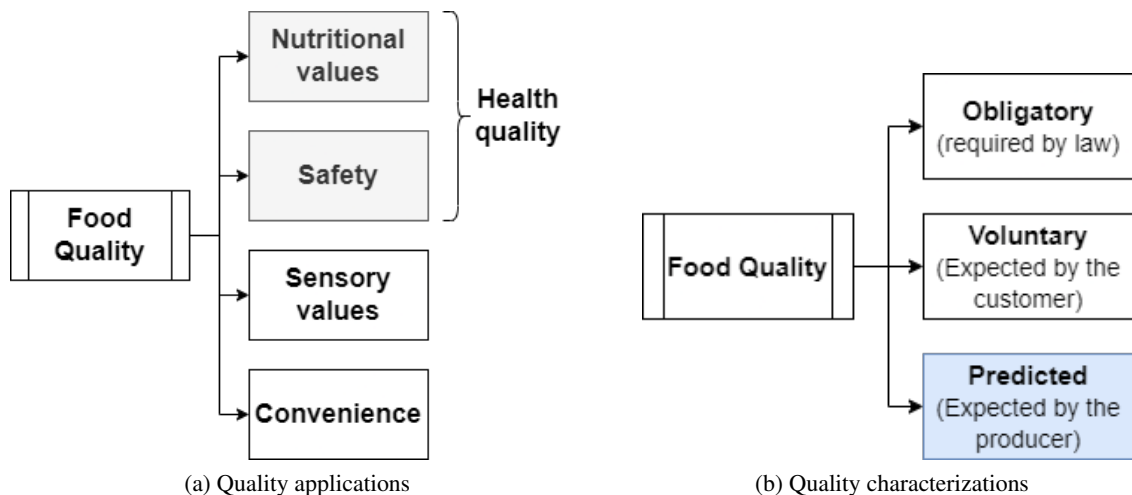


Figure 2.1: Quality control in the food industry - adaptation of T. Sikora and A. Strada (2006)

Although not mentioned in the original paper, this project will glance at quality control from the producer's perspective. More specifically, tests to identify and address any deviations, defects, or non-conformities in order to maintain and improve the quality of the end results, whilst focusing on profitability and efficiency. The producer's standpoint, although significantly steered by the customer's expectations and behaviors, differs completely from the customer's perspective on quality. It encompasses everything that makes a product valuable to its producer (Smith, 2006). Thus, maximizing the product's value, whilst parallelly increasing profitability and customer satisfaction, become the main pillars for the producer.

Quality improvement is an unending matter (Hubbard, 2003). Quality control in the food industry has become the defining measurement amongst the competitive realm (Dora et al., 2013). Its implementation can directly improve costs, quality, delivery, and company dependence (Bititci et al., 2001), crucial for defining competitive traits (Shah and Ward, 2007). Beyond the obligatory need for quality in global trading, quality certification becomes a necessary need for any market, in the search for customer satisfaction (Talib et al., 2014).

The recent literature review conducted in Zhu et al. (2022) on quality management in the food industry has shown a significant increase in papers on the topic (31 between 2018 and 2022), revealing the increasing importance of its applications on a global scale. Although its positive impact has been proven, the high cost of adopting a quality system, changes in internal organizations, and doubtfulness still remain the main obstacles to its implementation in most food industries (Yadav et al. (2021); Talib et al. (2014); Nguyen et al. (2004)).

2.3.2 Process variability

Variability refers to the tendency to shift or change. It translates into any oscillation occurring in the measure of any variable involved within a process (Montgomery et al., 2008). It can originate from numerous external or internal factors that directly impact the process. These range from the manufacturing technique, inconsistent measurement techniques or even human error. Swamidass (2004) categorizes these factors as common causes, normally predictable, ongoing, and consistent, and chance causes, inherent to the manufacturing process. Common causes can be eliminated, whereas chance causes can only be minimized. These, when eliminated or avoided through control systems, allow for a predictable final product, fewer nonconformities and, thus, significant advantages to the business.

Food processing is one of the many industries that is heavily affected by variability. The commonly witnessed proportionality between weight and cost reveals the direct impact that inconsistent tracking has on profitability and business success.

Several relevant studies were found on minimizing variability within the food processing industry, although the topic has a significant lack of development. Bourquard et al. (2022) have recently studied the impact of managing variability in raw materials, wheat flour, originating from biological traits. By strategizing raw material selection by focusing on quality or price, the latter has shown to be the ideal driving force in its selection. On a more statistical approach, Gomez et al. (2014) studied the overweight factors in frozen food, identifying the root causes of variation in the net weight through data analysis. A very similar approach was taken in Carneiro and Azevedo (2018), applying six sigma methodologies in a biscuit manufacturing industry, in order to minimize package overweight and deviations.

Few papers were found on any approach taken at minimizing variability in the cheese manufacturing industry. Its rigorous production process, as well as material handling, becomes transversal to the many industries dealing with similar perishable goods.

2.3.3 Lean

Lean consists of a management philosophy and set of principles, originated from the Toyota Production System (TPS), that has been widely adopted across various industries. It has presented itself as a systematic approach to improve operational efficiency, reduce waste, and enhance customer value (Womack and Jones (1997); Liker (2004)). The core concept of Lean is to eliminate non-value-added activities, or "waste", from processes, and optimize the flow of value-added activities to achieve higher quality, better productivity, shorter lead times, and lower costs (Ohno, 1988). Said "waste", which is commonly referred to as "Muda" in Japanese, is categorized into several categories: overproduction, waiting, transportation, overprocessing, inventory, motion and defects.

Researchers have emphasized the importance of identifying and eliminating these types of waste in Lean implementation to achieve process efficiency, cost savings, and improved customer value (Shah and Ward (2007); Liker (2004)). Lean tools, such as Value Stream Mapping, 5S (Sort, Set in Order, Shine, Standardize, Sustain), Kanban, Poka-Yoke (error-proofing), and Total Productive Maintenance (TPM), among others, are commonly used in Lean implementations to address these types of waste and achieve process optimization.

Lean has gained significant attention in the food industry, where operational efficiency, food safety, and product quality are critical considerations (Costa, 2019). The application of Lean principles and tools in the food industry has been shown to improve process performance, reduce waste, enhance product quality, and increase customer satisfaction (Costa et al. (2018a); Lopes et al. (2015)). Several studies have highlighted the successful implementation of Lean in various food industry sectors, such as meat processing, bakery, and fruit and vegetable processing (e.g. Hung and Sung (2011); Sreedharan and Raju (2016)).

2.3.4 Six Sigma

The ever so growing significance of quality improvement amongst businesses, from distributors and manufacturers to customer service and banking agencies, has turned it into a powerful competitive tool. By establishing a consistent quality level, assuring high service levels with minimal mistakes becomes a critical role for long-term business success and competitive advantage (Montgomery et al., 2008).

Six Sigma emerges as a tool for quality improvement in businesses, developed by Bill Smith at Motorola in the 1980s (Snee, 2010). The name derives from the Greek letter Sigma, commonly used in statistics to measure variability in processes. Thus, this methodology's main premise focuses on guaranteeing the quality standards within a window of the equivalent of 6 sigmas, translating into 3.4 defects per million opportunities (Pyzdek et al., 2010). This methodology, thus, uses the customer's important aspects and preferences as a guide to eliminating nonconformities in business processes (Goh, 2002).

A major key for Six Sigma's success rates derives from the module it bases itself upon: DMAIC (Define, Measure, Analyse, Improve and Control) (Pyzdek et al., 2010). This roadmap

framework, as Anbari (2016) describes it, presents itself as a closed circuit aiming to eliminate nonproductive stages, organizing the use of numerous tools to solve each problem (Costa et al., 2018b). The following table summarizes the research made, describing each step of the framework and tools frequently associated, alongside the most frequent tools and papers found (Uluskan, 2016), with their respective application in food industries.

Table 2.1: DMAIC tools and respective uses in literature

Phase	Description	Tools	Research
D	<i>Set project goals, identify requirements and determine scope</i>	5W+2H	Carneiro and Azevedo, 2018
		VoC	Desai et al. 2015
		QFD	Chakraborty et al. 2013
M	<i>Collect data, analyse performance and validate measurements</i>	Pareto Analysis	Hung and Sung 2011 Chakraborty et al. 2013
		Control Charts	Chowdhury and John, 2021 Desai et al. 2015
		Process Map.	Gkionis et al. 2011 Desai et al. 2015
A	<i>Identify root causes, prioritize improvements and gain insights</i>	Brainstorming	Carneiro and Azevedo, 2018
		FMEA	Carneiro and Azevedo, 2018
		Fishbone D.	Hung and Sung, 2017 Chowdhury and John, 2021 Desai et al. 2015 Nandakumar et al. 2020 Chakraborty et al. 2013
I	<i>Implement solutions, test effectiveness and refine the process</i>	Implementation Plan	Nandakumar et al. 2020
C	<i>Sustain and implement improvements, monitor performance</i>	SPC	Chowdhury and John, 2021
		Control Plan	-

Due to the overwhelming popularity of the Six Sigma and DMAIC methodologies, a wide range of tools have been developed for each stage (Uluskan, 2016). In fact, this phenomenon has led to significant misguidance (Uluskan, 2016) and inefficiency (Antony and Banuelas, 2002), where tools are misused in each step, and the most powerful tools are less frequently used. Thus, this table focuses on the most frequently used tools, according to (Uluskan, 2016).

Although the reduced number of papers and case studies focused on Six Sigma usage, its powerful impact on businesses is predominant in the studies mentioned in the table. This was demonstrated through a study conducted by Wesana et al. (2018). It dealt with semi-structured interviews and focus group discussions with actors in the dairy value chain, including farmers, processors, traders, and policymakers. The authors found that there is a significant potential to

reduce food and nutrient losses or waste in the dairy value chain in Uganda, particularly at the production and processing stages. However, the readiness of different actors to adopt strategies to reduce losses or waste varies, with farmers being the least ready due to limited knowledge, skills, and resources. More recently, a case study on milk production, Deepa and Krishnan (2021) used several metrics to assess the impact of Six Sigma. The number of defects per million opportunities (DPMO) decreased from 8,000 to 250 after its implementation. This translates to a significant reduction in the number of overall nonconformities. Additionally, the process capability index (Cpk) increased from 0.69 to 2.09, indicating that the dairy production process became more consistent and predictable. Finally, the process sigma level increased from 2.31 to 4.04, translating into a more efficient and effective production process, with fewer errors or defects.

2.3.5 Lean Six Sigma

Businesses keep striving in order to achieve higher levels of service and quality, with Lean and Six Sigma serving as essential tools to achieve so. Lean Six Sigma (LSS) is a business management methodology that combines these two well-established process improvement approaches, to increase the efficiency and effectiveness of organizational processes. LSS aims to eliminate waste and improve flow. The integration of these two approaches provides organizations with a structured, data-driven, and customer-focused problem-solving methodology (Snee, 2007). This

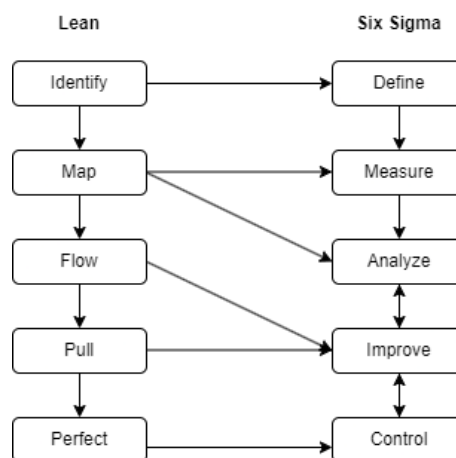


Figure 2.2: Synergy between Lean and Six Sigma - adaptation of Salah et al. (2010)

synergy has been thoroughly explored through literature, exploring ways of integrating the two techniques and respective frameworks for maximum efficacy (Salah et al., 2010). Salah et al. (2010) presents a schematic merging Lean frameworks onto Six Sigma's notorious methodology, DMAIC, shown in Figure 2.2.

A similar crossover has been explored within tools from both methodologies. Figure 2.3 shows the common ground between the two forces, showing significant levels of synergy.

The immense power of this methodology is shown by its applications in many industries, including the food industry, to optimize processes, reduce waste, and increase efficiency (Costa

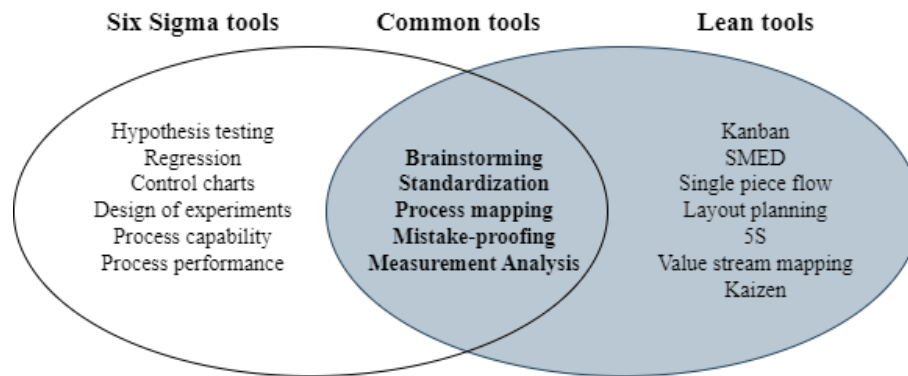


Figure 2.3: Common tools between Lean and Six Sigma

et al., 2018b). The food industry is particularly well-suited for LSS, given the complex nature of food production, the need for high levels of quality control, and the importance of ensuring food safety. However, numerous difficulties in its implementation are highlighted, namely the need for a robust quality control system, supplier management, and employee training. Moreover, the often conservativeness and resistance to change associated with the food industry (Hung and Sung (2011); Bigliardi and Galati (2013)) shows the lack of studies on the topic (Costa et al., 2018b).

Other studies have focused specifically on the application of LSS to food safety and quality control in the dairy industry. For instance, Nader (2022) found that the application of Lean Six Sigma methodologies heavily improved the definition of the optimal combination of speed and pressure in bottling milk. Similarly, Segovia et al. (2021) applied LSS concepts to a cheese production industry in Ecuador and was able to reduce variability by 83%.

Analyzing these results, a beneficial pattern can be observed, with increasing control over the process, leading to higher profit margins and, thus, a competitive advantage amongst the competitors. However, none of the aforementioned case studies go into detail on the company's effort to sustain the application of these strategies. Thus, a significant shift in the progressiveness and longevity of these applications is still sought, as it represents a significant role in changing for the better (Latham, 2008).

Chapter 3

Problem Description

The following chapter analyzes the problem at stake and provides a thorough description of the production process for a more precise understanding of the project's purpose, development and implemented solutions.

3.1 Characterization

A DMAIC approach, inspired by the 5W2H framework, was taken for the following characterization, more specifically the Define phase, for a more comprehensive review.

3.1.1 Scope

The enterprise is facing significant variability in cheese weight, caused by inefficiency and instability through its production process, leading to overflowing milk consumption per weight unit of cheese, reduced quality and, thus, significant overall waste.

Variability is defined by the difference between the net weight and the registered weight value in the final product. It can be subdivided into two categories: predictable and non-predictable. The first focuses on a standardized weight margin established by the company in order to ensure legal conformance. The latter branches into numerous factors that directly impact the process's efficiency, thus leading to waste and overconsumption. Said factors will lead the investigation conducted in this project.

3.1.2 Metrics

Two measurement tools will be utilized to adequately measure the process: Specific Milk Consumption (SMC) and production capacity (PC).

SMC corresponds to the quantity of milk, in liters, consumed in order to produce a kilogram of cheese, calculated through formula 3.1:

$$SMC = \frac{\text{Quantity of milk (L)}}{\text{Quantity of cheese produced (kg)}} \quad (3.1)$$

PC refers to the amount of cheese produced, in kilograms, per productive hour, calculated through the following formula 3.2:

$$PC = \frac{\text{Quantity of cheese (kg)}}{\text{Productive time (Hours)}} \quad (3.2)$$

The post-pasteurization phase was deemed the most adequate for the cheese weighing in formula 3.1. It should be noted that the SMC is tracked for each cheese variant, with an overall measurement that tracks the average performance of all the references.

3.1.3 Study subject

Although the overall production process is similar between cheese types, significant differences between variables such as moulding, added yeast, fat content or even the drying period.

In order to ensure a more efficient approach, it becomes imperative to restrict our focus to the most impactful variables for the business. The two most relevant references observed were the ball-shaped and bar-shaped cheeses. These contribute to the majority of sales and were deemed the most opportunistic for significant improvement.

To further confirm this choice, an overview of historical data on production was made. Data from 2021 was gathered, as shown in Table 3.1. Consumption values, as well as benefits generated, were obtained alongside the production numbers, given their direct impact on the business. Due to confidential concerns, the benefits provided represent a percentual proportion of the total.

Table 3.1: Production data and benefits

Reference	Cheese (kg)	Milk (L)	SMC (L/kg)	Benefits (%)
Bar	2.813M	29.097M	10.34	68.71
Ball	1.089M	12.656M	11.62	7.80
Ref. C	1.314M	13.076M	9.95	4.91
Ref. D	1.171M	10.963M	9.36	6.46
Ref. E	0.727M	6.638M	9.12	4.34
Ref. F	0.517M	4.723M	9.12	7.77

Significant production discrepancies can be observed, although a significant majority is represented by bar cheese, proportional to its potential benefits. The ball reference, on the other hand, although showing lower production values, its potential is evidenced by the possible benefits, following the bar reference. Thus, the latter references were proven to be the most beneficial for the business. Important to note that, given the similarities between the production processes, improvements in these references may be transversal to the remaining products, therefore contributing to the overall business performance.

3.1.4 Critical to Quality

Beyond the aforementioned factors, guaranteeing high-quality cheese with minimal defects becomes a significant factor for the enterprise. Moreover, strict legal boundaries for adequate packaging, weighing and product composition must be respected. Global retailers and consumers are the predominant product receptors, thus recognizing the customers' needs and requirements and bridging the Voice of The Customer (VoC) with Critical to Quality (CTQ) factors becomes imperative for this challenge. The Critical to Quality diagram considered is shown in Figure 3.1.

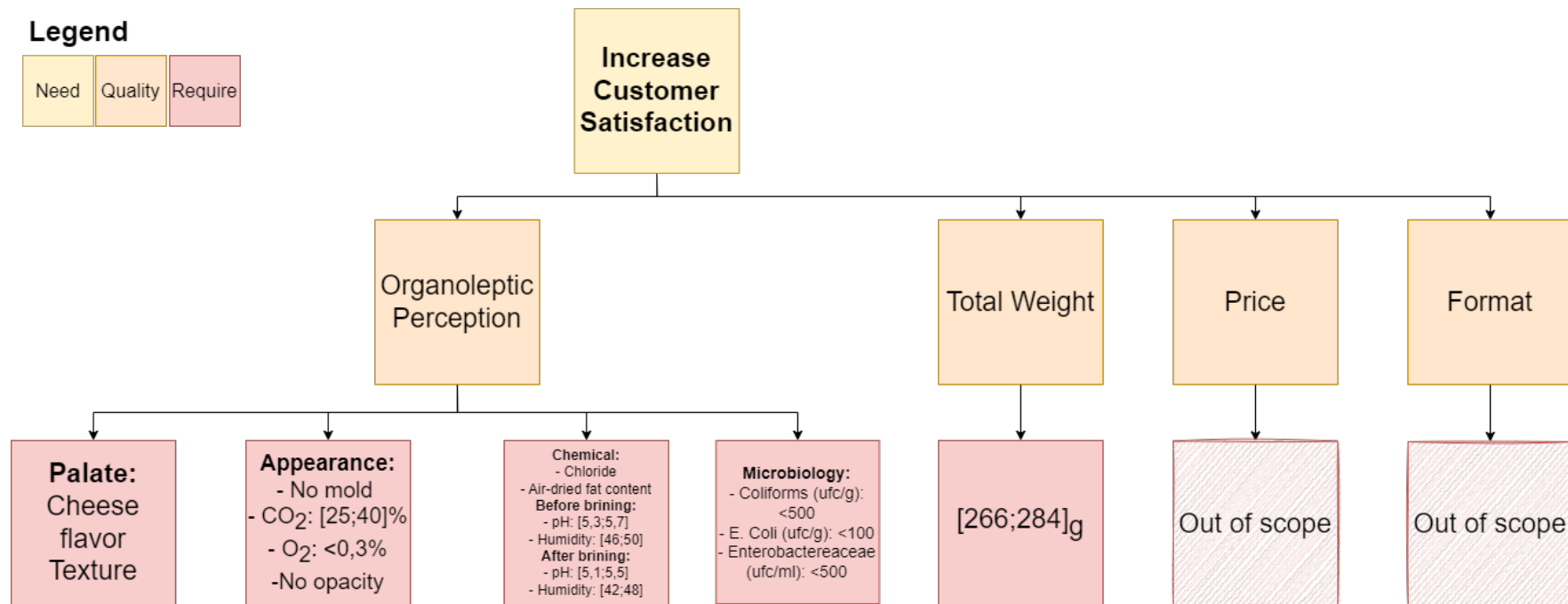


Figure 3.1: Cheese production - Critical to Quality diagram

3.2 Problem definition

Reducing the Specific Milk Consumption and maximizing the Production Capacity are the main objectives for this problem, whilst minimizing weight variability. This translates to producing the same quantity of cheese with less milk consumption, either through waste reduction or maximizing milk's exploitation.

The main goals defined are shown in the following Table 3.2. These values were based on the average of the previous year's 3 best months.

Table 3.2: Base and target values for each cheese reference

	Bar-shaped		Ball-shaped	
	SMC	PC	SMC	PC
Base Value	8.52	1233.2	8.80	1233.2
Target Value	8.32	1252.8	8.67	1252.8

3.3 Production process

Any problem with this dimension and complexity requires a deep understanding of the production process, from raw material retrieval to delivering the final product. Figure 3.2 provides the generic production sequence for both references considered in this study and the main sections that constitute this process (see Appendix K for more details).

The process can be divided into 3 main phases: production (fabrication), drying and packaging. The fabrication phase delineates the primordial stages of cheese, converting milk into a shaped precedent of cheese. The drying phase consists of a less complex stage of cheese drying and added treatments, according to the reference. Finally, the packaging phase finalizes the production process, consisting of slicing, packaging and labeling of the final product.

The fabrication phase is transversal to every existing reference. It initiates with the arrival of milk, previously received from suppliers and adequately sorted for usage. A pasteurization phase kicks off the fabrication process, consisting of a heat-treatment process for bacteria removal. The milk is then transferred to tanks, according to its reference, where specific cultures are added, resulting in coagulation and, consequently, a suspension mixture of liquid and coagulated agglomerates, commonly referred to as curd. The medium is then transferred to a filling machine, filtering a significant percentage of the agglomerates to insert into the mold. The resulting shape is then automatically pressed and removed from the mold. Each individual shape is then transferred to the brine room, consisting of a chemical treatment of cheese by submerging it into a synthetically treated solution, concluding the fabrication phase.

The drying phase sets the decoupling point between references. Cheese bars, after brining, are transferred to baskets, which are transported through pallets to the drying chambers. These settle

for a period of time, during which the cheese dehydrates, consolidates and forms a protective crust.

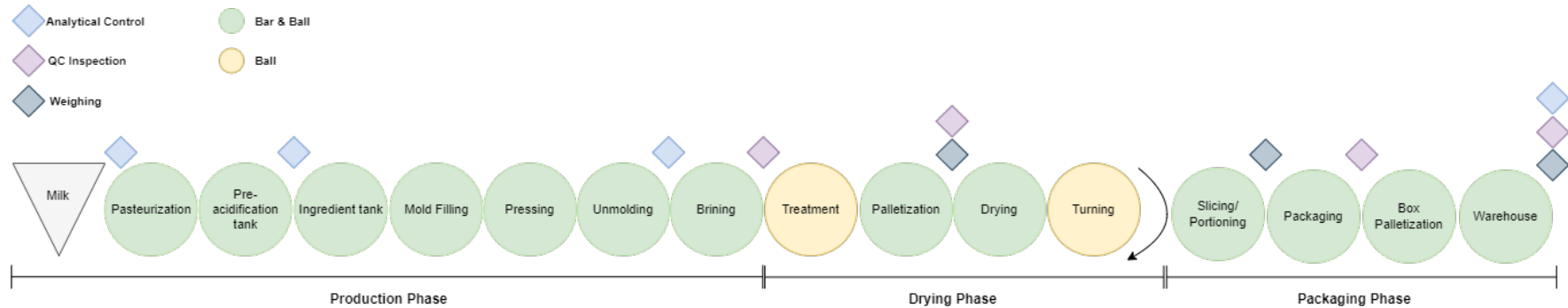


Figure 3.2: Flowchart of the production process

The remaining references follow a more complex procedure involving treatment. After brining, depending on the cheese reference and the production order, the cheese product goes through a treatment phase, consisting of a manual or automatic layer coverage of cheese for protection and preservation. After the treatment settles, these are transported to their respective drying chamber, where they remain until fully dried. Given their specific shape and composition, the cheese's position is manually inverted periodically amidst drying, for a more uniform drying. This upturning provides more exposure of the lower surface to the surrounding air, thus intensifying the dehumidification.

Lastly, the packaging phase concludes the cheese lifecycle before its expedition. The standard procedure divides into slicing, portioning or intact packaging. Cheese bars are transported from the drying chambers to a slicer machine, where it is portioned into individual slices, then packaged and stored. Other references such as cheese ball can be portioned into halves or quarters, packaged in a vacuum-sealed container and then expedited. As for intact selling, commonly forwarded to wholesalers, the cheese can be directly packaged whole, labeled and immediately be expedited.

3.4 Operation detailing

The cheese production process is a significantly delicate and detailed process. This section allows for a better understanding of potential substages, machinery and operations that become relevant for the problem resolution.

3.4.1 Material sourcing

The main ingredients in cheese production, given their perishable characteristics, require ideal storing conditions for conservation and avoiding deterioration. This involves factors such as temperature, air composition and adequate transportation. Milk is the main ingredient used in the dairy industry. It is directly sourced from suppliers, transported and stored within the industrial facility, where it is adequately portioned according to the production plan. Its delicate and short lifespan demands careful storage in temperature and atmosphere-controlled silos before use.

The milk's molecular composition has a major impact on cheese production. As stated in McSweeney (2004), careful milk selection becomes a crucial role in the production of high-quality cheese. The fat content, protein ratio and calcium dosage become the main parameters that influence the cheese's status amidst formation. The fat content directly impacts the flavor, with higher contents typically resulting in a richer cheese, thus directly influencing the customer's perception. The protein content and calcium have a major role amidst production, where protein directly influences the texture and yield, for example, and calcium works as a binder during coagulation, thus intervening in the early stages of fabrication.

Lactic enzymes, or microbial cultures, are another component involved in cheese production. It is responsible for milk coagulation, where the proteins of milk, primarily casein, undergo a transformation from a soluble state to an insoluble state. These molecules aggregate and form a network that traps water, fat, and other milk components, creating a semi-solid mass called the curd (McSweeney, 2004). The specification of each culture may influence different coagulation behavior, as well as texture and flavor differences. Therefore, its composition and selection can severely impact the final product. Given their susceptibility to contamination, these are mandatorily stored in cold environments and air contact is heavily avoided.

The treatment subphase consists of coating the cheese with a treated outer layer. This lining can consist of cheese wax, cellophane layers or even cloth wraps. These act as an artificial cover for cheese, allowing for reduced weight loss (less dehydration), and preventing contamination and spoilage through the control of oxygen and carbon dioxide exchange rate (Costa et al., 2018b).

3.4.2 Filler machine

The filler machine is responsible for transferring the curd suspension from each silo to the cheese mold. It consists of an inclined platform, from where the suspension flows, and a vertical funnel, where the suspension is poured and inserted onto the mold (see Figure 3.3). The inclined platform contains a grid bottom to allow the majority of the liquid to escape, whilst the curd proceeds to the funnel. A positioned sensor activates the deposition of the filtered solution onto the molds. The velocity and inclination of the filler machine heavily influence the liquid and solid ratio that is transferred to the mold. Ideally, the filtered suspension should be exceedingly curd, with enough liquid to cover it. These conditions allow for ideal gravitational compression of curd onto the mold, as well as guaranteeing minimal risk of defects in the final product.

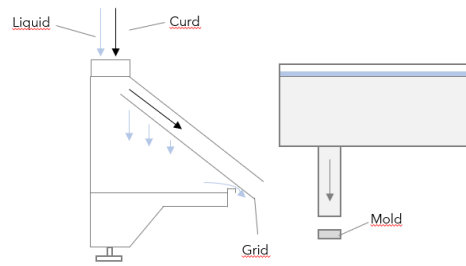


Figure 3.3: Schematic example of the filler machine

3.4.3 Mold

The cheese molds are high-density polyethylene structures that shape the cheese into an adequate pattern (see Figure 3.4). These contain the cheese curd whilst being filled and pressed, compressing it onto the desired shape. The filling pattern roughly determines the final volume and size of each cheese. Thus, defects, variability in the filling process and area discrepancies are major causes of weight variability, causing size standardization to be crucial for minimizing weight oscillation.

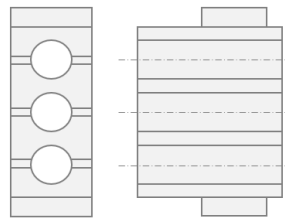


Figure 3.4: Schematic example of a mold

3.4.4 Brining

Cheese brining defines the main contributor for cheese flavor, aroma and salinization. It equally provides natural preservation and adequate microbial growth (Foxx et al., 2017), crucial for the final product's quality. The cheese, whilst being submerged, goes through salt diffusion, where salt ions penetrate the cheese, consequently leading the cheese to lose water content through osmosis (Foxx et al., 2017). Diffusion rates and the water retention capacity of cheese become, thus, two of the many impactful variables for its final weight. Several factors may influence these characteristics. The curd's microbial composition and humidity, as well as brining time, highly influence the salinization procedure. Salt absorption rates follow a decreasing behavior with brining time, gradually lowering the longer it stays submerged (Foxx et al., 2017). This mainly occurs due to a molecular stabilization between the curd and the brine. The brine's chemical composition, in parallel, namely the acidity level and temperature, lead to oscillations in brining times. Higher acidity levels, translated into a lower pH level, are reached during the salinization of cheese, reaching a

natural boundary where salt concentration becomes inhibitory throughout the insides of the cheese (Foxx et al., 2017). Salt uptake has also been thoroughly explored in Fox (2004), showing a 30 to 50% increase in absorption with a temperature increase from 4 to 25°C. This, however, has been shown to be highly dependent on the curd's composition, as observed from our experiments. It is noted that these parameters, although recognized, were not standardized within the company, mainly due to external variables adverting from previous stages of fabrication.

3.4.5 Drying chambers

The drying chambers are responsible for cheese ripening and dehumidification. Cold air is pumped and removed inside the chambers, causing convection currents across the chamber and through the cheese pallets and, thus, drying the cheese. Theoretical ripening times depend on the cheese reference, going from 4 days up to 2 weeks of drying time. Temperature and airflow are adequately controlled within the chamber, heavily impacting the uniform distribution of air and, thus, normalizing the drying time amongst the present cheeses. Longer drying times lead to a significant weight loss of the final product, thus causing significant loss to the enterprise, as well as variability within the process. Each chamber's capacity highly impacts air dispersion, where in high-demand periods, weight differences amongst cheeses reach up to 1 kilogram. Adequate planning and chamber distribution become, thus, crucial to consider within this project's ambition.

Some references, for uniform ripening, require manual periodical rotations of their position. This leads to heavy traffic rates within the chamber, as well as significant productivity loss, due to unstandardized rotation periods, as well as the sporadic worker relocation from other sectors.

3.4.6 Summary

This chapter provides a comprehensive analysis of the problem at hand and offers a detailed description of the production process. The scope of the project focuses on minimizing variability, whilst maximizing the production capacity. A DMAIC approach based on the 5W2H tool is used to provide a comprehensive review of the problem's scope, focusing on the variability in cheese weight, leading to inefficiency and waste in the process. It distinguishes between predictable and non-predictable variability and highlights the factors impacting the process's efficiency.

Two metrics were defined for this project, Specific Milk Consumption (SMC) and Production Capacity (PC), to measure the process. SMC represents the quantity of milk consumed per kilogram of cheese produced, while PC measures the amount of cheese produced per productive hour. Historical production data is analyzed, indicating the potential benefits and production volumes of two key cheese references: ball-shaped and bar-shaped cheeses. The importance of high-quality cheese and adherence to legal requirements is emphasized through the discussion of critical-to-quality (CTQ) factors. The main objectives, including reducing specific milk consumption, maximizing production capacity, and minimizing weight variability, were discussed. A detailed description of the production process, including the fabrication, drying, and packaging phases, along with operation detailing and the equipment involved is provided.

Chapter 4

Statistical Analysis and Findings

A concise and careful initial approach becomes crucial to any problem-solving methodology, for a better understanding of its complexity, ramifications, and an adequate plan for future intervention. Thus, maintaining the guidance through the DMAIC framework, the following chapter will focus on the Measure and Analyse phases.

4.1 Variables measured

Accurate measurement and understanding of the variables affecting cheese weight and, thus, the production yield, are essential for identifying potential sources of variability and formulating strategies for improvement. The following relationship diagram shown in figure 4.1 subdivides cheese weight into the several variables involved. Variables were characterized as independent, dependent and intermediate. Independent and dependent variables can be directly modified during each experiment, allowing the hypothesis testing conducted during each sample testing.

Intermediate variables are directly influenced by the process performance and execution. Thus, the goal is to minimize the amount of variability of controllable measures whilst maximizing the production capacity through analysis on its impact on the final weight of cheese.

The most crucial variables and/or parameters shown in Figure 4.1 were filtered and selected according to their impact on variability and overall production capacity. Table 4.1 shows the conducted experiments.

Table 4.1: Conducted experiments and respective focuses

Study subject	Focus	#
<i>Milk age</i>	Impact of milk age, casein, humidity and fat	1
<i>Calcium-Casein ratio</i>	Relationship between calcium and casein concentrations	1a
<i>Brine pH</i>	Optimize brine pH for minimal brining time	2
<i>Pallet position</i>	Pallet positioning in drying chambers	3
<i>Filler machine</i>	Rate of curd arrival in the filler machine	4
<i>Mold sizing</i>	Impact of mold sizing	4a
<i>Cheese turning</i>	Impact of cheese turning	5

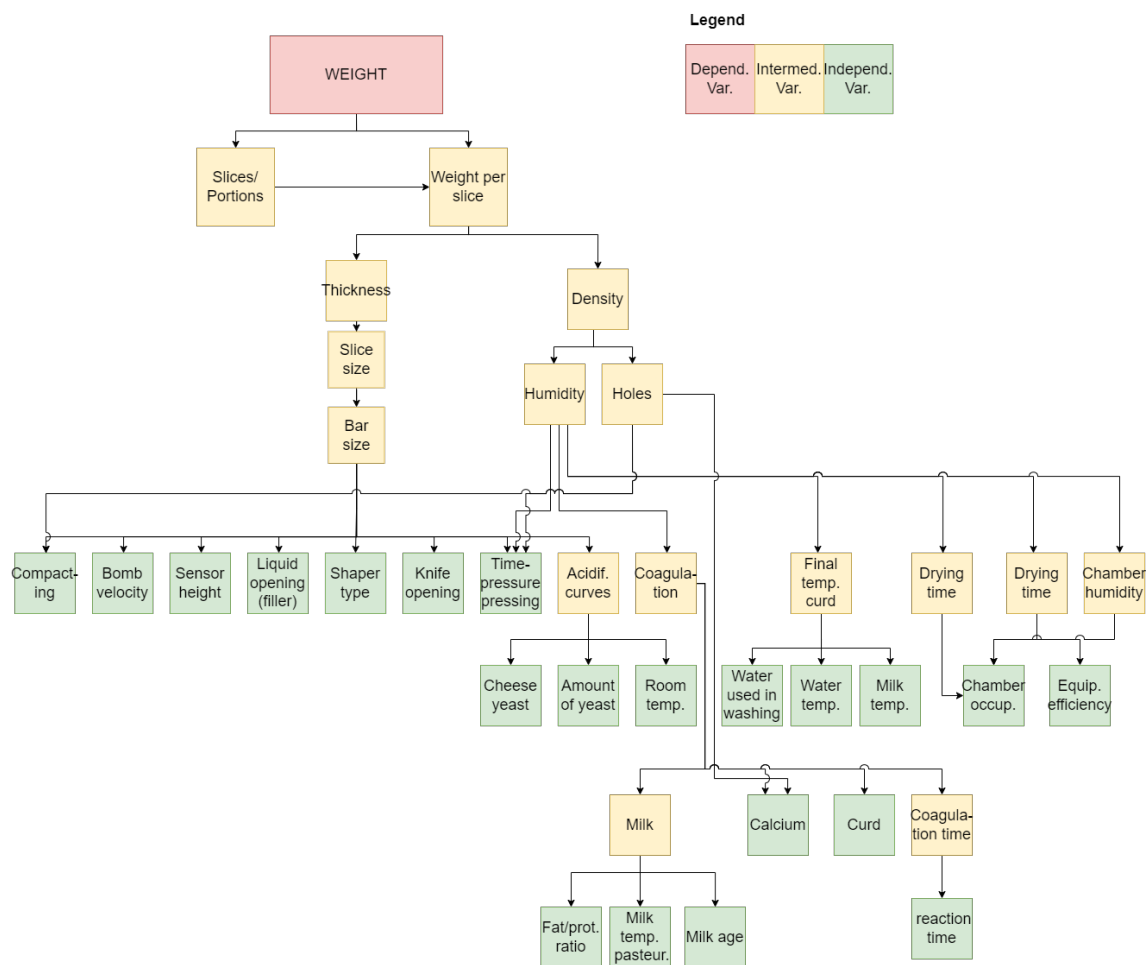


Figure 4.1: Cheese weight relationship diagram

These sprouted the conducted study, which then branched into other statistical tests according to either the results obtained or empirical knowledge from the team. Several operational inefficiencies were identified by the team, whose process is explained in the following section.

4.2 Production process analysis

Beyond the 4 initial variables aforementioned, the team noted several operational inefficiencies occurring during the project. These negatively impact the SMC and cheese quality. Thus, during a brainstorming session, a fishbone diagram was utilized as a structured tool for exploring the causes and sub-causes related to a central issue, shown in Figure 4.2. The diagram visually organized potential factors into distinct branches, promoting comprehensive analysis and facilitating effective problem-solving strategies. Appendix E shows some practical examples during its discussion and implementation with the team.

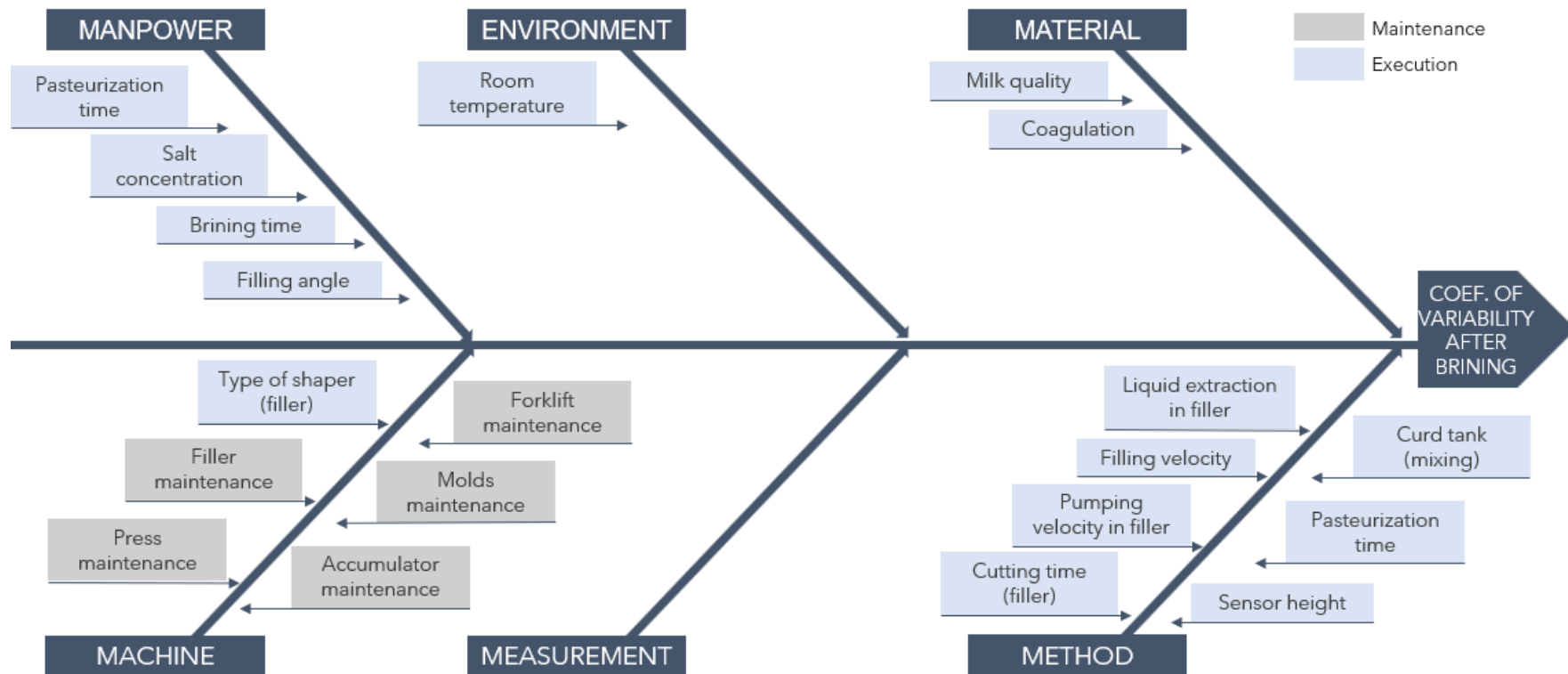


Figure 4.2: Coefficient of variability - fishbone diagram

A brief description of each cause is provided, for a better understanding of the operational and technical insights.

Manpower

- **Pasteurization time measured by the operator:** Depending on the reference being produced, a specific pasteurization time is associated. The theoretical times for adding the cheese yeasts are manually consulted by each operator, leading to time oscillations and, thus, affecting the pasteurization procedure;
- **Salt concentration:** Salt is manually added to the brine according to the pretended salt concentration levels, causing variations in concentration that directly impact brining time and the quality of cheeses;
- **Brining time:** The total amount of time the cheese stays brining is not standardized;
- **Filling angle:** No defined angle of the filling curve in the filler machine that affects the transferring of cheese curd into the molds.

Environment

- **Room temperature:** No accurate regulation of the temperature in which the fabrication and brining phases occur.

Material

- **Milk quality:** The inconsistent molecular constitution of the milk allocated for cheese production;
- **Coagulation:** The chemical phenomenon during coagulation is not consistent, affecting the curd concentration

Machine

- **Type of shaper:** Physical differences between the shapers due to wear and tear (volume differences);
- **Maintenance issues:** Damage or malfunction of the following machines: filler, press, fork-lift, accumulator and molds.

Method

- **Liquid extraction in filler:** No standardized measurement for liquid removal in the filler machine - manually defined through velocity and angle levels;
- **Filling velocity:** Standardized values for filling velocity are not controlled and the velocity level is manually altered by the operator;
- **Brining time:** Standardized values for pumping velocity in the filler machine are not controlled and the velocity level is manually altered by the operator;
- **Cutting time:** Unstandardized timing for cutting the curd transferred into the molds;
- **Mixing procedure:** The mixing procedure is not consistent between production orders.

These parameters were filtered and scheduled according to priority, impact and needed effort to obtain the required samples.

4.3 Measurement and sampling

Cheese weight directly defines the production yield. It depends on the stage of its production process it is weighted, given the weight reduction suffered throughout. The following graph shown in Figure 4.3 represents an estimated evolution of cheese weight from a production sample. This sample was obtained through a 2-week span, consisting of 11 production orders (roughly 45000 units).

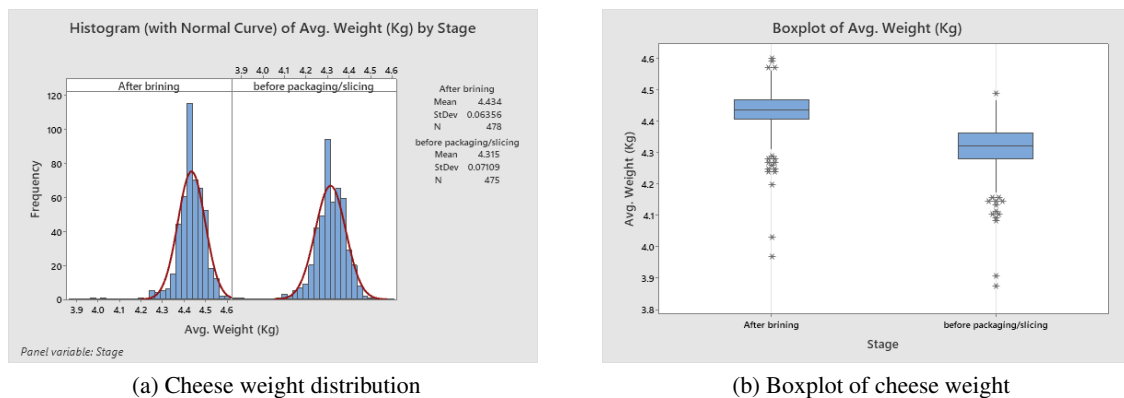


Figure 4.3: Weight distribution and average weight boxplot - obtained from 01/02/2023 to 12/02/2023

An average weight loss of 2.63% across the sample was observed. Although minimal when considering each unit, this translates to approximately a 5242.5 kg loss overall. Thus, understanding the weight differences along the production chain allows us to eliminate external factors for weight loss and adequately measure its evolution. Production was conducted through periodic orders, usually equivalent to 88 pallets, with consistent production conditions. Thus, these were used as comparison groups during our analysis. Due to company constraints, as well as the inconsistency of cheese, weighing before brining was deemed inconsistent and, thus, not utilized within the scope of this project.

Cheese weight data were collected with an analytical scale in pallets¹, after brining, individually, before packaging (or slicing), as well as individually as final product², to more thoroughly comprehend the weight variations across the fabrication and drying phases. The average weight of each unit in each pallet allowed us to analyze weight oscillation throughout, whereas the SMC only provided us with a proportion ratio between the total weight produced and the amount of milk used. To further understand the relationship between these two variables, a Pearson correlation test was conducted on the previous sample, resulting in the matrix shown in Figure 4.4.

Through the dispersion of each data point, a decreasing tendency can be observed. Given the p value being inferior to 0.05, there is enough statistical evidence to confirm a significant correlation between the two variables. The r value was equal to -0.593, translating into higher weight averages

¹The weight of the pallets and each individual cheese basket were subtracted

²For sliced cheese, the package weight was subtracted

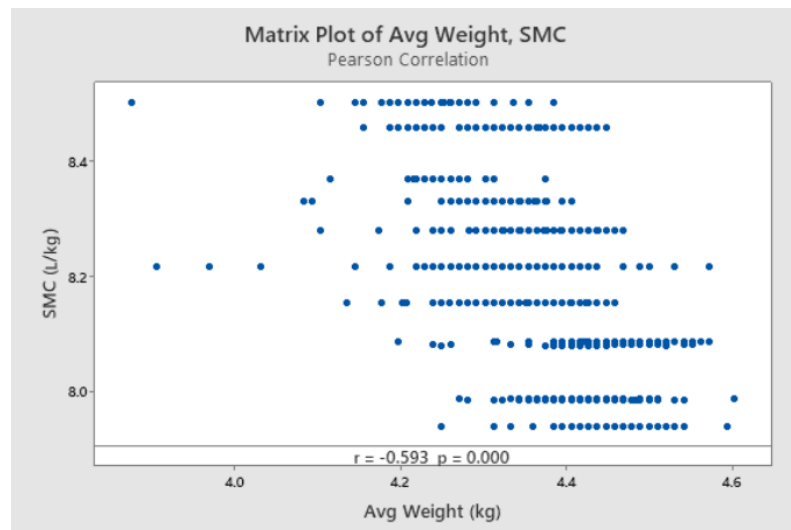


Figure 4.4: Correlation between average weight and SMC

for a lower SMC. In fact, with a higher total weight, for the same number of units, a decrease on the SMC ratio is to be expected. Thus, the overall statistical analysis will cover both variables.

The remaining factors, given their significant impact on quality and safety issues, were obtained via quality control stages throughout the production process.

4.4 Exploratory examination

This exploratory examination focused on identifying statistical patterns, significance and evidence. For analyzing variance, the ANOVA test was used. The following framework shown in Figure 4.5, adapted from (Carneiro and Azevedo, 2018), describes the methodology followed during the statistical analysis.

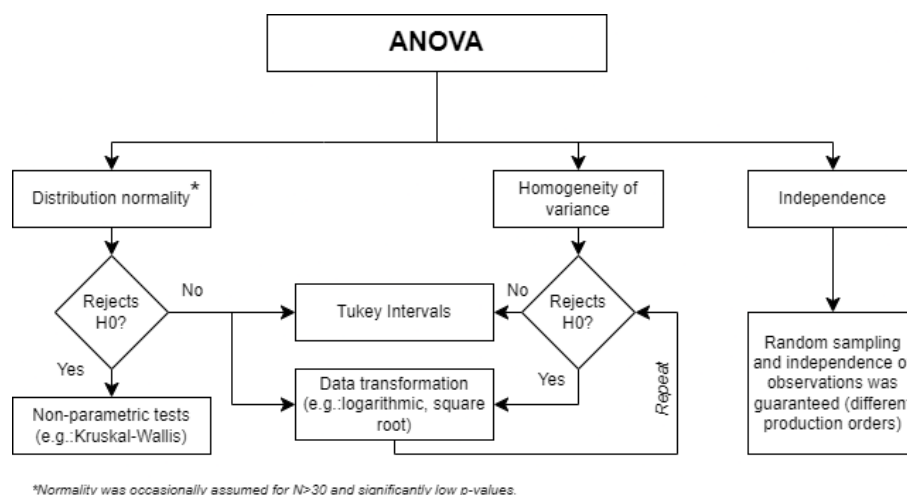


Figure 4.5: ANOVA framework (adapted from Carneiro and Azevedo, 2018)

4.4.1 Milk age

Milk is commonly stored for 12, 24 or 48 hours before its processing for cheese production. Casein content and humidity were also measured during this study. Table 4.2 provides a summary of the statistical significance, effect sizes (where applicable), and conclusions derived from the analysis.

Table 4.2: Overview of statistical results - milk age³

#	Dep. Variable	Ind. Variable	Statistical test	N	<i>p</i>	<i>R</i> ²	Main Conclusions
1.1	Average Weight	Process Stage	<i>Kruskal-Wallis</i>	953	<0.05	-	Heavier cheese after brining
1.2		Milk age	<i>ANOVA</i>	1294	<0.05	4.81%	Older milk yields heavier cheese
1.3		Casein - after brining	<i>Kruskal-Wallis</i>	478	<0.05	-	Parabolic trend (2.614% is optimal)
1.4		Casein - before packaging	<i>Kruskal-Wallis</i>	475	<0.05	-	Parabolic trend (2.614% is optimal)
1.5	Milk Age	Casein/Humidity after brining	<i>Descriptive Analysis</i>	64	-	-	Visually correlated - no pattern
1.6		Casein/Humidity before packaging	<i>Descriptive Analysis</i>	64	-	-	Visually correlated - no pattern
1.7	Average Weight	Casein/Humidity/Milk Age after brining	<i>Descriptive Analysis</i>	187	0.34	-	Statistically insignificant - insufficient data dispersion
1.8	SMC	Process Stage	<i>ANOVA</i>	953	<0.05	66.03%	Confirmatory study
1.9		Milk Age	<i>ANOVA</i>	953	<0.05	11.54%	Confirmatory study
1.10		Casein/Humidity after brining	<i>Kruskal-Wallis</i>	953	<0.05		Confirmatory study
1.11		Casein/Humidity before packaging	<i>Kruskal-Wallis</i>	953	<0.05	-	Confirmatory study
1.12	SMC	Process Stage	<i>Descriptive Analysis</i>	475	-	-	Older milk yields heavier cheese with influence from other metrics
1.13	SMC	Calcium	Regression	552	0.251	0.15%	No statistical impact on SMC
1.14		Fat Content	Regression	645	<0.05	80.57%	[0.640, 0.655] is the optimal range
1.15	Optimization	All parameters	-	-	-	-	-

³The results shown are a culmination of numerous iterations and refinements to ensure reliability and validity.

From study 1.2, observing the dispersion of the cheese yield for each age, shown in figure 4.6, a significant superiority of older milk (48 h) was observed, showing a higher average weight, as well as a smaller range of dispersion.

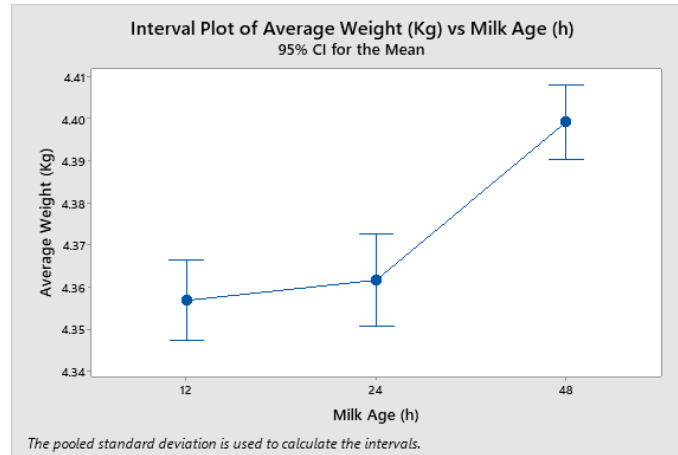


Figure 4.6: Boxplot for milk age

To further understand its impact on cheese yield, a one-way ANOVA was conducted for average cheese weight. With a p-value inferior to 0.05, there is significant statistical evidence to assure that the milk's age impacts the overall cheese weight, showing higher values the older the milk is. This concept was observed and proven in Olson et al. (2007), similarly showing statistical significance in the optimal utilization of cheese for older cheese. However, this phenomenon explained only 4.20% (according to the r-squared value) of the overall variability of our process, prompting a significant effect from other parameters.

To confirm the previous results, the relationship between casein and milk age was studied, as was the impact of casein on the average weight of cheese. The two interval plots obtained are shown in Figure 4.7.

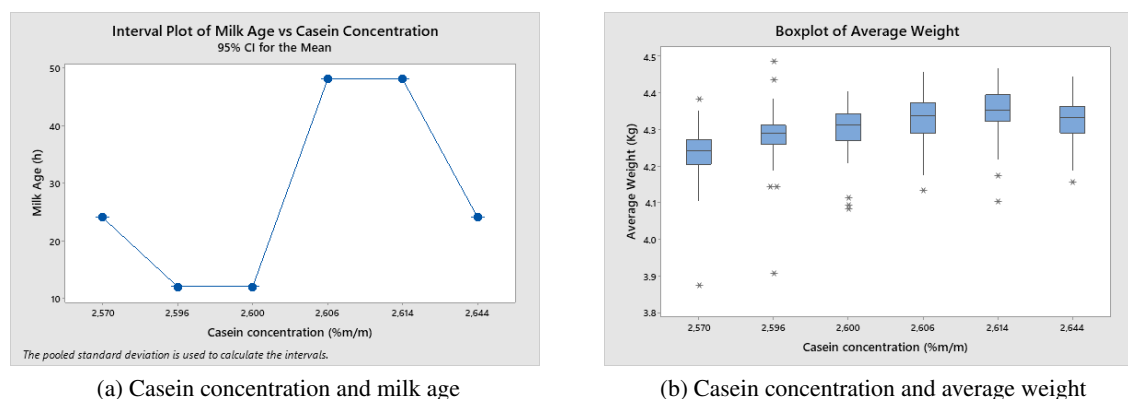


Figure 4.7: Milk age and average weight according to casein concentrations - interval plot and boxplot

As suspected, the casein distribution amongst the milk age samples was uneven, potentially jeopardizing the obtained results. Furthermore, for each casein concentration, only one milk age index is associated, compromising any ANOVA analysis. Adding to these discrepancies, parallel analysis shows significant oscillation of the average cheese weight with casein concentration, following a parabolic pattern. As noted by the team, humidity takes a major role in molecular behavior. In fact, higher humidity rates translate to higher water content and, thus, a heavier weight. This interaction has been proven in other cheese variants in recent literature. Monteiro et al. (2009) studied the effect of pH on the microstructure and characteristics of cream cheese, concluding that protein-to-water interactions heavily increased depending on the pH of cheese. Several studies were conducted between milk age, casein concentration, and humidity from 1.5 to 1.7. These can be found in the technical report.

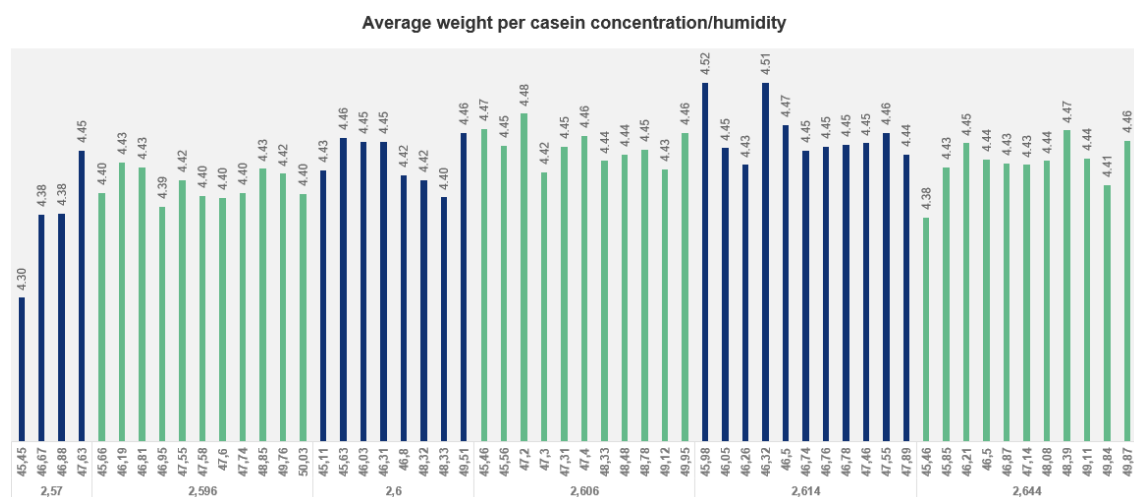


Figure 4.8: Average weight of humidity per casein concentration

The SMC analysis presents confirmatory results on the previous conclusions. From study 1.9, beyond the statistical significance shown, SMC dispersion amongst the age groups has shown to have a smaller span for either 12-hour-old milk (coefficient of variance of 1.63) or 48-hour-old milk (coefficient of variance of 1.52). Although promising, the potential influence of other variables may be taking the spotlight.

The results from these analyses created uncertainty about their stability, potentially correlating with or being influenced by external factors not taken into consideration. To further confirm if the milk age, casein, and humidity have an impact, further studies were conducted with adequate isolation, aiming to optimize these factors. Moreover, a deeper focus was given to the operational side of the production process, dissecting its potential causes of variability through a fishbone diagram. From this, parallel studies were conducted accordingly.

The results obtained in 1.9 branched into several hypotheses as to how casein influences cheese weight. More importantly, as pointed out by the team, an overlooked variable may have caused the parabolic behavior shown in studies 1.3 and 1.4. Calcium establishes the main structure during coagulation, thus heavily interacting with casein. Its influence on cheese weight was analyzed

through a study conducted parallel to the previously mentioned rehearsals. The following graphs in Figure 4.9 show the results obtained from study 1.13.

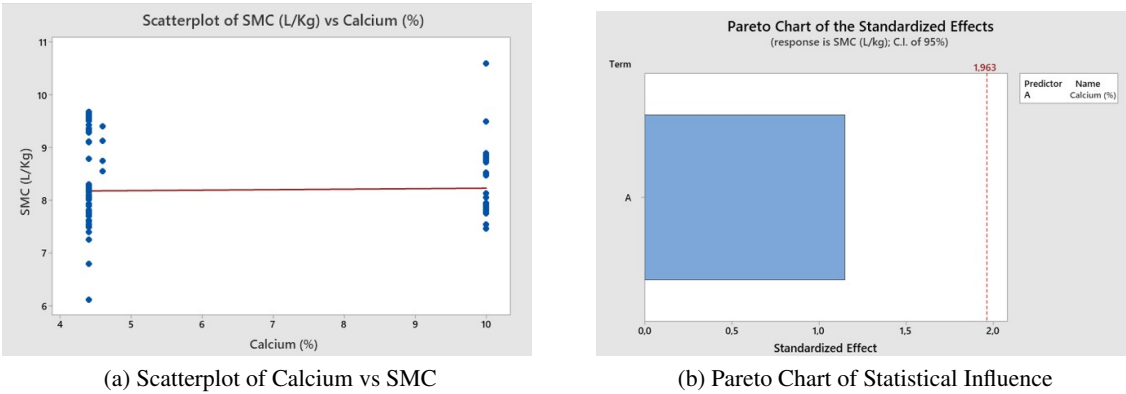


Figure 4.9: ANOVA results for Calcium vs. SMC

Inadvertently, even though calcium levels are restricted to a few standardized levels (4.0% to 10.0%), it showed little influence on the average cheese weight. Moreover, reanalyzing the casein's behavior, the parabolic effect shown in previous studies was not confirmed. In fact, the previously stated optimal level of 2.614 %m/m was not confirmed with these results. This volatility can be justified by the main component that defines cheese, which is fat content. The milk's chemical treatment before entering the production process involves dosing the fat content according to the casein concentration. This is usually measured through a ratio between fat content and casein intake, which has been thoroughly adjusted throughout the years to produce ideal cheese quality and weight-wise. In order to understand how fat content may influence cheese weight and the SMC, study 1.14 was conducted. The *pareto* chart results are shown in Figure 4.10.

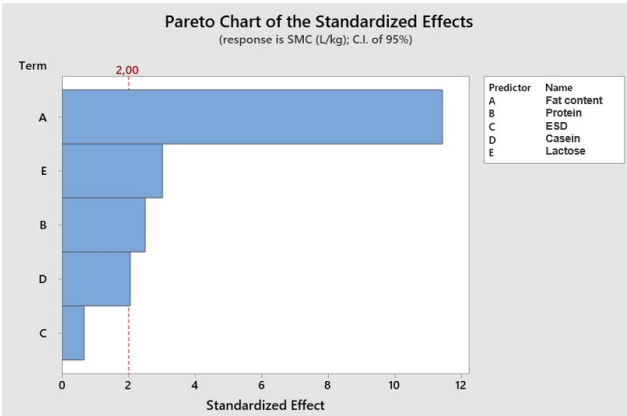


Figure 4.10: Pareto chart - statistical significance in SMC

To our considerable satisfaction, the results obtained corroborated our initial theoretical framework: fat content shows the majority of statistical significance. This phenomenon has been shown in the literature. Verdier-Metz et al. (2001) studied the relationship of casein-fat ratio with cheese yield on 189 manufacturers, resulting in a linear correlation between both. It accounted for 77%

of fresh yield and approximately 87% of dry matter yield variability. This facilitates new opportunities of heavily impacting cheese yield and, consequently, minimizing the SMC. However, due to legal constraints and quality standards, a controlled balance between casein and fat is imperative. A regression model of historical data was performed, resulting in equation 4.1.

$$\text{SMC} = 5.472 + 3.748 \times \text{Ratio} \quad (4.1)$$

This equation provides an approximation of the ideal ratio for minimal SMC, whilst maintaining the overall integrity and quality traits of cheese. An initial iteration aimed for an SMC of 7.9 L/kg was made, resulting into an approximate ratio of 0.65. A week's worth of production orders was used as sampling for a total of 327 pallets. The results are shown in Figure 4.11.

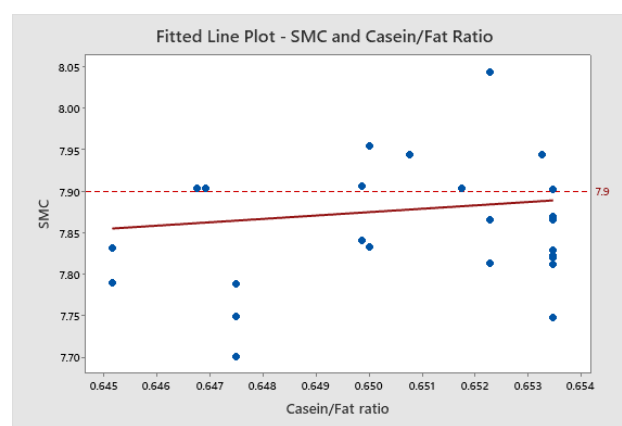


Figure 4.11: Fitted line plot - SMC and casein-fat ratio

As predicted, the results corroborate the predicted relationship, only slightly showing lower SMC values. This facilitates opportunities for drastically reducing the overall milk consumption and, more importantly, more accurately predictable cheese weight. The optimal range considered initially for the casein-fat ratio was 0.640 to 0.655, for a small and controlled range.

Main Conclusions

- Milk age impacts the average weight of cheese, with older milk (48 hours) resulting in higher average weights and a smaller dispersion range.
- Casein concentration after brining and before packaging initially followed a parabolic trend with an optimal level of 2.614%. However, studies showed inconsistency and inconclusiveness.
- Humidity plays a major role in the weight of cheese, with higher humidity resulting in heavier weights, thus jeopardizing our analysis. However, it can only be minimized.
- Calcium levels showed little influence on average cheese weight.
- The ratio between fat content and casein concentration heavily impacts cheese weight and SMC. An optimal range of [0.640, 0.655] was initially defined for lower SMC and minimal impact on quality. Further studies aim to narrow down the range

4.4.2 Brine pH

The pH is one of the many crucial factors in cheese production. Its influence on the quality of cheese has been studied by Monteiro et al. (2009), as previously mentioned. As pointed out through experimentation, balancing the pH of cheese with the brine liquid accelerates the reverse osmosis, potentially minimizing the overall brining time of cheese and humidity variability. The following Table 4.3 summarizes the conducted analyses.

Table 4.3: Overview of statistical results - brine pH⁴

#	Dep. Variable	Ind. Variable	Statistical test	N	<i>p</i>	<i>R</i> ²	Main Conclusions
2.1	<i>Average Weight</i>	Drying time	<i>Descriptive Analysis / Regression ANOVA</i>	100	<0.05	22.17%	Weight decreases at a rate of 1.5g per hour
2.2		pH level			<0.05	6.12%	The pH level significantly impacts cheese weight
2.3		Drying time / Cycle / Pallet #	<i>Descriptive Analysis</i>	919	-	-	Average weight varies by pallet per cycle
2.4		Drying time / Cycle	<i>Descriptive Analysis</i>	919	-	-	Average weight varies per cycle
2.5	<i>pH</i>	Drying time	<i>Descriptive Analysis</i>	64	-	-	pH level influences weight and oscillates
2.6	<i>SMC</i>	Chlorides	<i>ANOVA</i>	100	0.553	0.17%	No statistical significance
2.7		Humidity	<i>Kruskal-Wallis</i>	104	<0.05	17.6%	Statistical significance but for a small reduction of variability

To understand how the pH level can be manipulated to minimize variability, it becomes imperative to study the cheese's natural pH behavior. This allows us to adequately measure the optimal pH value whilst compromising quality traces such as flavor and texture.

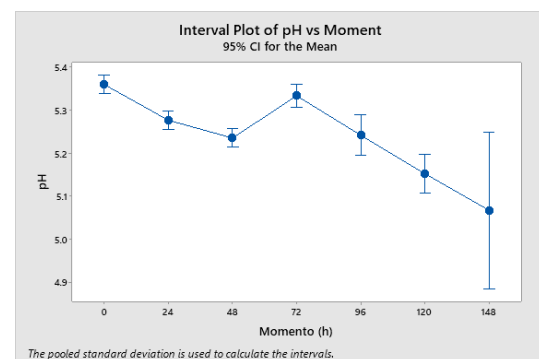
⁴The results shown are a culmination of numerous iterations and refinements to ensure reliability and validity.

Thus, study 2.1 was conducted to further confirm weight reduction during this phase. A loss rate of 1.5g per hour was estimated for cheese bars through a regression model, explaining 22.2% of the overall variability. Several factors may be affecting these results, more specifically differences between pallets from the same production order. As stated by the team, the first and last pallets show notable differences compared to intermediate pallets. This was justified by the different production factors such as compression in the filler machine, leading to less dense and, thus, lighter cheese. This triggered a focus on the operational procedures stated in chapter 4.5.

A regression model was equally conducted between weight and pH in 2.2. Although the R^2 value was significantly low, the pH showed a significant impact on the average weight. This leads to believe that, not only the pH significantly, but it also oscillates during the drying phase. Results from 2.5 prove this hypothesis, showing the Tukey intervals from the ANOVA, as well as the corresponding interval plot, both in Figure 4.12.

Moment (h)	N	Mean	Grouping
0	224	5,3592	A
24	225	5,2760	C
48	223	5,2346	C
72	150	5,33280	A B
96	44	5,2411	C D
120	50	5,1517	D
148	3	5,06667	B C D

(a) Tukey distribution groups



(b) Interval plot of pH

Figure 4.12: ANOVA results for pH levels

The intervals clearly identify a hyperbolic behavior of the pH, further proven by the interval plot. Given that the chosen reference's maximum drying time corresponds to 4 days, the minimal natural pH level to aim for in the brine liquid is approximately between 5.30 and 5.20. Following this effort, study 2.7 was conducted, comparing the standard levels with the reduced pH levels.

Although the results show statistical significance, a very minimal overall decrease in variability was observed from the results. Given the significant effort to minimize the pH level and the minimum expected return, this study was deemed as non-prioritized. Nonetheless, the pH levels were kept low to minimize the amount of chemical components needed for the brine.

Main Conclusions

- Study 2.1 showed weight reduction during the drying phase, estimating a loss rate of 1.5g/h.
- The pH level oscillates during the drying phase, showing a hyperbolic behavior (lowest natural pH level recorded at 5.23).
- The optimal brine pH range is 5.20 to 5.30 to maintain desired cheese characteristics.
- Efforts to minimize pH levels help reduce the need for chemical components in the brine.

4.4.3 Drying chamber

The drying phase is a crucial step for cheese ripening. It represents the majority of lead time, responsible for up to 20% of cheese weight loss. The drying chamber for bar and ball-shaped cheeses is rectangular-shaped, fitting linear rows of pallets (4 pallets of depth and 3 pallets high). Between rows, vertical tubes pointing downwards expel a controlled airflow, which is then extracted through air evacuation pumps laterally positioned. E shows a schematic of the layout and distribution. Several factors may impact the drying rate of cheese, as well as weight variability. Appendix 4.4 summarizes the conducted analyses.

Table 4.4: Overview of statistical results - drying chamber⁵

#	Dep. Variable	Ind. Variable	Statistical test	N	<i>p</i>	<i>R</i> ²	Main Conclusions
3.1	Average Weight	Position	Descriptive Statistics	93	-	-	Weight loss increases with height Weight loss decreases with distance to evacuation pumps
3.2		Position / Air extraction	Descriptive Statistics	24	-	-	Weight loss decreased with height
3.3		Air Velocity	Descriptive Statistics	95	-	-	Weight loss increased with height
3.4		Drying Time	ANOVA	24	0.17	4.21%	Lateral pallets' drying time reduced by 1 day

Several factors may influence the curing velocity and uniformity. For once, airflow becomes the main factor. Ideally, dry air must be dispersed uniformly across the chamber for a balanced cure. However, humidity from the cheese, as well as the chamber's layout, creates turbulence. This leads to a much faster drying for cheeses in contact with less humid air, causing heavier weight losses, as well as jeopardizing weight variability. Pallet location becomes, thus, a significant factor for weight variability.

In the current layout, air is pumped into the chamber through the ceiling between each row. This allowed for better vertical dispersion of air amongst the pallets, as well as more directed airflow. Process analysis study 3.1 was conducted to further understand weight loss according to the pallet's position. 2 main variables were studied: vertical (Bottom, Middle, and Top) and lateral positioning (Center, Lateral).

⁵The results shown are a culmination of numerous iterations and refinements to ensure reliability and validity.

The first one studies the proximity to the air dispensers, whereas the latter focuses on the proximity to the lateral evacuation pumps. Each individual row depth position was tracked, numbered from 1 to 12 (see F for details). The results from study 3.1, alongside a heat map of weight loss, are shown in Figure 4.13.,

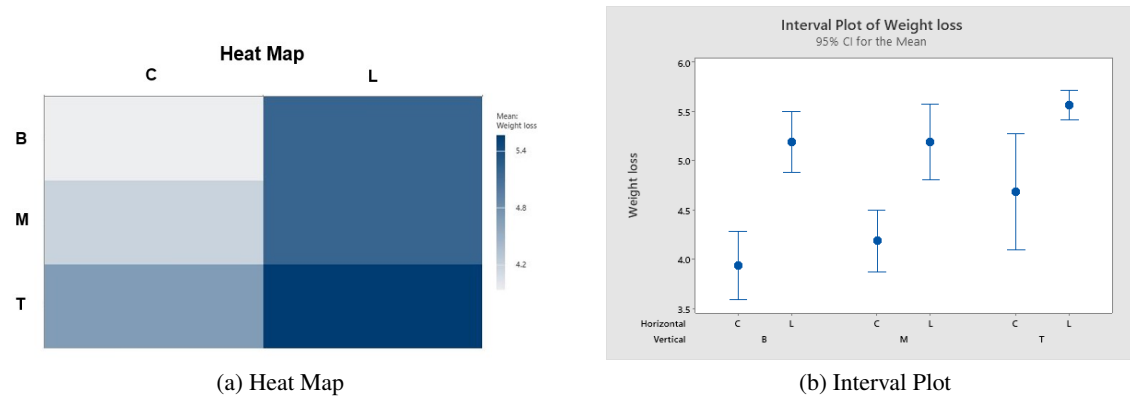


Figure 4.13: Results from study 3.1 - heat map and interval plot of weight loss

As expected, higher weight loss rates are heavily focused on top and lateral pallets, given their proximity to the air pumps. However, a significant concentration is focused on the top-lateral pallets. This phenomenon occurs due to the positioning of the evacuation pumps. Currently, 3 working levels of pumps are distributed vertically. The top one, being slightly above the pallet towers, forces the air being expelled to immediately be evacuated, thus jeopardizing air flow for lower pallets.

To further confirm this theory, study 3.2 was conducted. Its execution consisted of 2 full rows of pallets on each side of the chamber. On one side, the 3 evacuation pumps are working (standard), whereas on the other side, only the bottom two are active (test). The following results shown in Figure 4.14 were obtained.

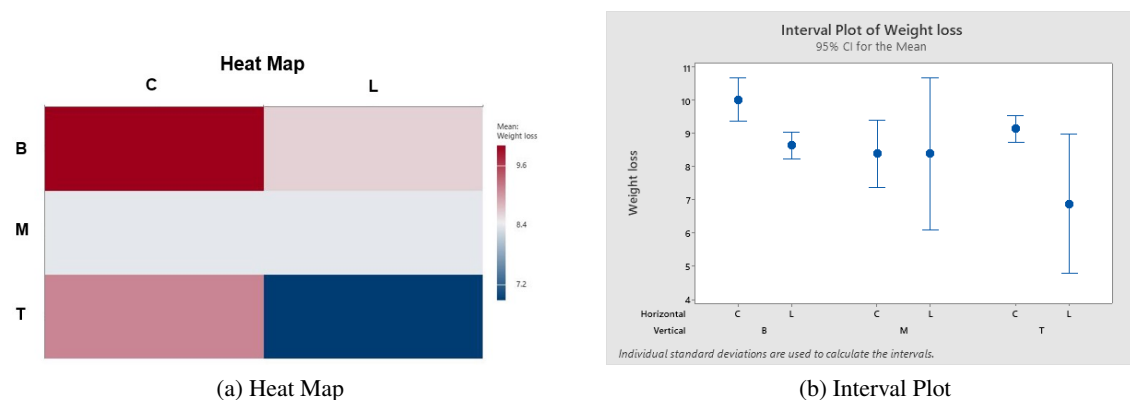


Figure 4.14: Results from study 3.2 - heat map and interval plot of weight loss

Inadvertently, the bottom row shows a larger weight loss compared to the top ones. This further confirms the impact of the chamber's occupation on air distribution. The conditions on

which study 3.2 was conducted led to a wider spread of air in the middle of the chamber, thus reaching the floor and draining onto the sides, reaching the bottom pallets first. In fact, overfilled chambers have shown weight discrepancies significantly larger than emptier ones. In this scope, pallet flow and chamber management measures were taken, to be explored in the following chapter.

To further extract the full potential of this phenomenon, study 3.4 was conducted. It consisted of exploring the possibility of reducing the lead time by 1 day of lateral pallets. This will not only improve production capacity but also material flow, avoiding overfilling chambers. Figure 4.15 shows a comparison between 4-days and 3-day curing weight losses.

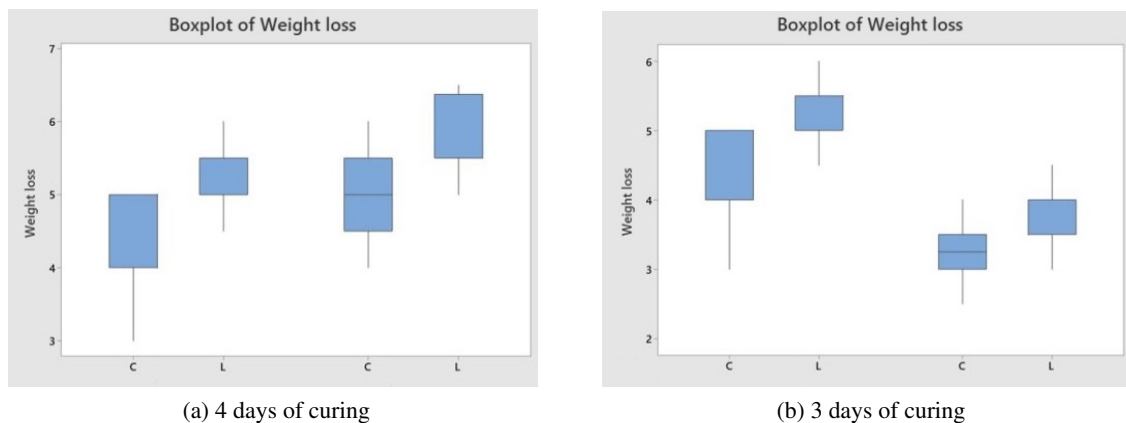


Figure 4.15: 4-day-old and 3-day-old dried cheeses - boxplot comparison

As hypothesized, the results show significant similarities between the 3-day curing of the lateral pallets and the 4-day curing of center pallets. The ANOVA results in Table 4.4 further confirm that, statistically, no weight differences were found between 4-day-old center pallets and 3-day-old lateral ones. Furthermore, quality traits were equally analyzed, showing no significant differences in taste, texture, or shape.

Main Conclusions

- Factors such as pallet position and proximity to air pumps and evacuation pumps impact weight loss and variability.
- Study 2.1 showed weight loss increases with height and decreases with distance to evacuation pumps, caused by turbulence originating from airflow and the chamber's layout
- Overfilled chambers result in larger weight discrepancies compared to emptier ones.
- Study 3.2 confirms the influence of chamber occupation on air distribution and weight loss, with the bottom row experiencing higher weight loss.
- Study 3.4 confirms reducing the lead time by one day for lateral pallets does not significantly affect the weight or quality traits.

4.4.4 Filler machine

The filler machine stands in the earliest stages of the production process. Its initial setup, as stated by the team, can heavily impact the quality traits and structure of cheese in its final stages. The velocity and angle, explained in the previous chapter, are the most relevant factors, becoming imperative to find their optimal state. The following Table summarizes the studies conducted.

Table 4.5: Overview of statistical results - filler machine⁶

#	Dep. Variable	Ind. Variable	Statistical test	N	<i>p</i>	<i>R</i> ²	Main Conclusions
4.1	<i>Average Weight</i>	Angle	<i>ANOVA</i>	184	<i><0.05</i>	32.37%	Angle influences avg. weight 25° is the optimal angle
4.2		Angle (5° interval)	<i>ANOVA</i>	153	<i><0.05</i>	42.54%	25°-35° is the optimal range Humidity may influence results
4.3	<i>SMC</i>	Angle	<i>ANOVA</i>	184	<i><0.05</i>	58.35%	Not enough distinct SMCs
4.4		Angle (5° interval)	<i>ANOVA</i>	154	<i><0.05</i>	77.28%	Angle influences SMC 30° is the optimal angle

The angle and velocity are independently changed by the operator, according to the reference. The velocity was deemed intrinsic to the production procedure, with standardized velocity ranges for each reference. Thus, our statistical analysis only focuses on the angle. Two studies were conducted. Study 4.1 confirms that, in fact, the angle does correlate with the average weight of cheese. Figure 4.16 shows the results.

⁶The results shown are a culmination of numerous iterations and refinements to ensure reliability and validity.

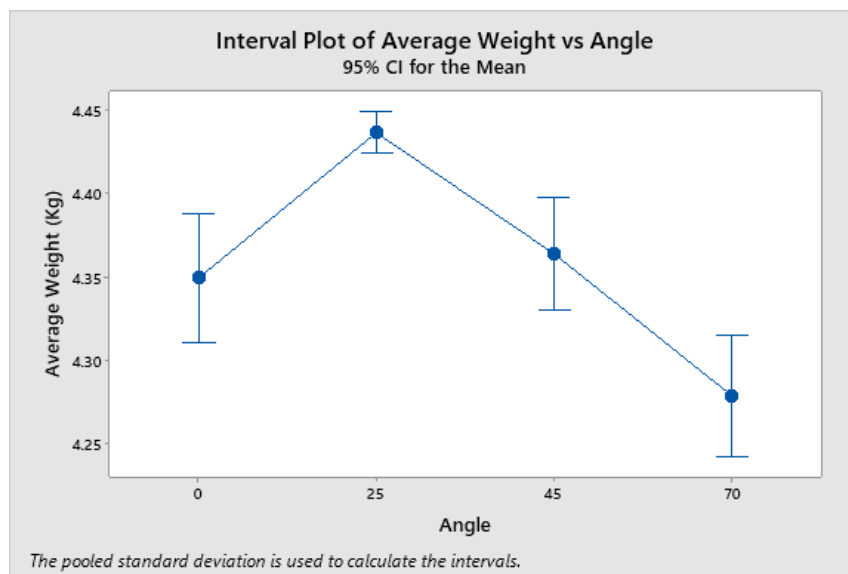


Figure 4.16: Interval plot of average weight per angle

Given the restricted interval angle defined for this study, a finer interval of 5° was defined for study 4.3. This allows us to understand the optimal angle on which the filler machine should operate for optimal compression and filtering. Figure 4.17 shows the interval plots obtained for SMC.

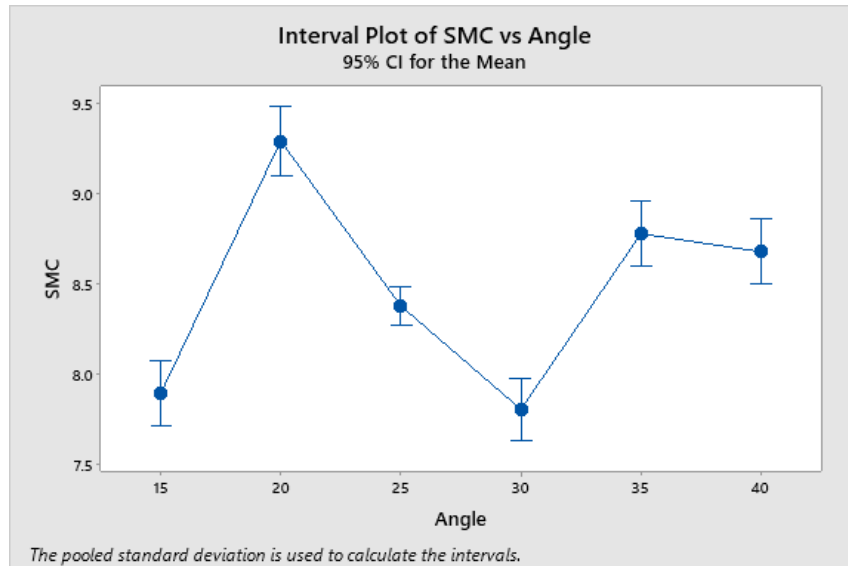


Figure 4.17: Interval plot of SMC per angle

Analyzing the graphs, 30° shows optimal results. Although the results seem adequate according to the team's prior experience, the humidity was suspected to have influenced the obtained results. In fact, both the angle and humidity have been shown to have statistical significance in the results (2.49 of standardized effect). Thus, a second iteration of study 4.3 was conducted.

Although the humidity still showed significant, yet uncontrollable influence, with the angle being the most critical variable, 30° was still the optimal value.

Mold Sizing

Parallel to the operational concerns of the filler machine, the mold structure onto which the curd for ball-shaped cheese is inserted directly impacts its volume and, thus, the overall process variability. Beyond the legal restrictions of cheese giveaway, meaning, the minimal legal weight of the final product, a significant weight overleap was detected. From a statistical standpoint, this translates into a slight deviation of the overall process from the current target. By adequately measuring the current average volume of curd being inserted, compared to the cavity's volume, the redimensioning of the mold can correct and redirect the current values closer to the target.

Historical data was gathered, averaging to approximately 1.511 kg per cheese, with a targeted value of 1.450 kg⁷. This equals to an average of 4.13% of giveaway per cheese. In order to realign this value, ideally, a 4.13% worth of cheese volume must be removed from the mold.

The cavity onto which the curd is inserted into is cylindrical shaped. Due to operational concerns, the diameter of each cavity cannot be increased or decreased. Thus, the mold's height, currently at 171 mm, will be our focus. The current volume of the cavity is approximately 1994 mm³. Thus, for a target of 1.45 kg, the optimal volume is calculated as follows:

$$\text{Optimal Volume} = \frac{1994 \times 1.45}{1.511} = 1913.5 \text{ mm}^3 \quad (4.2)$$

Maintaining the same radius of 63 mm, the optimal height value can be obtained:

$$\text{Height (h)} = \frac{V}{\pi \times r^2} = \frac{1913.5}{\pi \times 63^2} \approx 153.5 \text{ mm} \quad (4.3)$$

This means that the height must be reduced in approximately 17 mm for adjustment.

Main Conclusions

- Study 4.1 shows that angle has a significant influence on the average weight of cheese.
- Study 4.4 shows that angle significantly influences SMC. The optimal angle obtained for optimal SMC is 30°.
- Humidity may influence the results, but the angle still remains the critical variable.
- Despite the potential influence of humidity, the angle remains the most critical variable, and 30° is still considered the optimal value.
- Reducing the mold's height in 17 mm significantly reduced the overall weight giveaway, reducing total costs and weight deviations.

⁷This value already includes a "safety" percentual increase from the legal requirements, to ensure conformity with regulation

4.5 Operational Analysis and Findings

While statistical analysis forms the backbone of our investigation, it is crucial to acknowledge that our study encompassed an exploration of various operational concerns beyond purely statistical measures. We recognized the significance of not only understanding the quantitative aspects but also delving into the intricacies of operational management to maximize the potential for improvement. This included a detailed exploration of flow management amongst drying chambers, product traceability, quality assurance, and related factors.

4.5.1 Drying chamber occupation

Effective management of drying chamber occupation is of paramount importance in the cheese-making process. The careful arrangement and organization of cheese within the drying chamber significantly influence the quality, texture, and flavor development of the final product. Properly managing the occupation ensures optimal airflow, uniform moisture removal, and even drying, resulting in consistent and desirable characteristics throughout the cheese.

The optimal range for chamber occupation should be distributed between 50% and 75%. This interval allows for a uniform distribution of pallets within the chamber, promoting desirable air currents, as well as more fluid stock management when inserting or removing pallets. Due to the strong seasonal behavior of cheese demand, optimal cheese distribution during high-demand periods becomes a constraint for the company. Pickers are forced to intuitively distribute cheese pallets across the available chambers according to their occupation. This not only jeopardizes quality and the overall lead time, but also traceability concerns. The following Figure 4.18 shows the theoretical occupation of one of the chambers throughout the year. This was based on sales data from 2021, as well as the theoretical production flow for each reference.

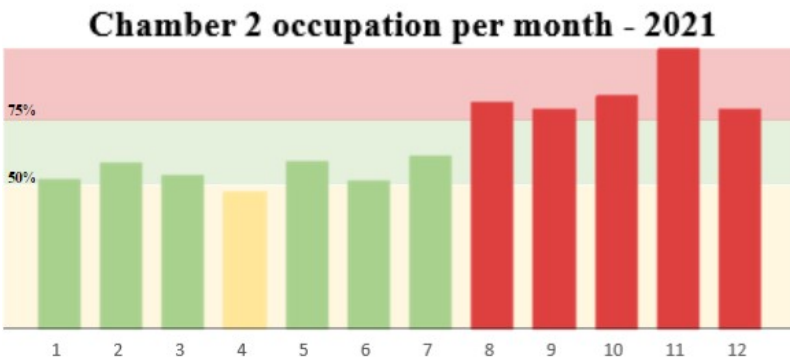


Figure 4.18: Proportion of chamber occupation - data from 2021

Analyzing the graph, throughout the first half of the year 2021, theoretically, the chamber occupation maintained approximately within the ideal boundaries. However, from months 8 to 12, a clear overleap was reached, even surpassing the overall capacity in month 11. This suggests that, theoretically, each chamber cannot handle the average demand rate.

Synergies between the cheese references allow for a balanced distribution between the chambers. This means that, for this to be manageable, whilst guaranteeing the traceability of cheese, an occupation tracker should be developed. This would allow pickers to consult the daily occupation predicted for a certain time span. From this, adequate cheese allocation and distribution can be reached.

4.5.2 Manual cheese turning

Whilst in the drying chamber, in order to guarantee even ripening across the cheese's perimeter, a manual turning of the cheese is periodically planned. As mentioned in the previous chapter, this allows for better contact with the air current, thus allowing surfaces with less exposure to dry at a constant rate. A study was conducted to fully comprehend how cheese turning influences the cheese's final composition. Figure 4.19 compares the average weight loss, as well as the coefficient of variance, between cheese that is manually turned in on alternate days and cheese flipped daily. A sample of 68 pallets was used, equivalent to approximately 1088 cheeses.

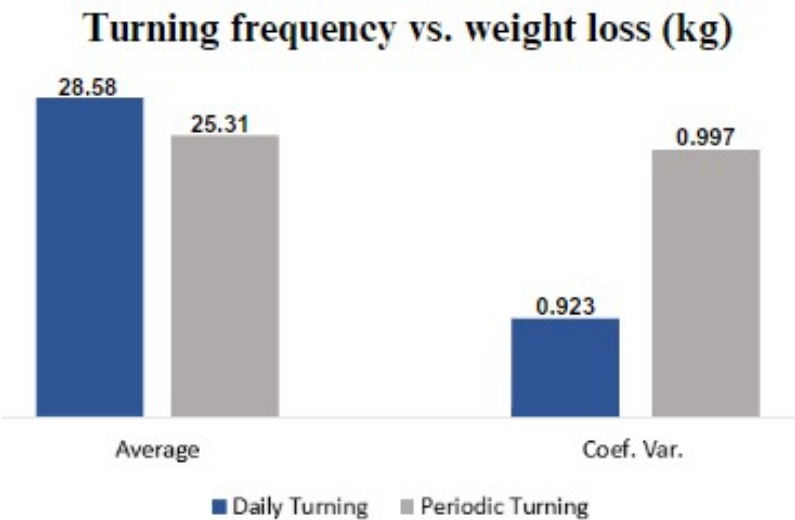


Figure 4.19: Average weight loss and coefficient of variance - comparison between turning frequencies

As expected, by increasing the number of times the cheese is rotated, more air exposure is guaranteed and, thus, faster drying. Furthermore, a significant reduction of variance was witnessed, reducing the overall coefficient associated. Parallel to the statistical analysis, the interior cure was significantly more uniform and consistent, according to quality testing. These results suggest that faster drying time and, thus, reduced lead time can be achieved with more frequent rotation, whilst minimizing the overall variability of the process.

However, the current process is done manually and unplanned. This compromises work allocation, as well as increases opportunity costs between tasks being executed. A solution to this concern would be to acquire a cheese-turning machine. In order to comprehend the potential investment and its respective payback, cost and benefit estimates were calculated and explored,

further evaluating the impact of its acquisition on the business. These will be more detailed in the following chapter 5.

4.6 Summary

In this chapter, statistical analysis was conducted to examine the variables that affect cheese weight and production yield. We focused on milk age, casein concentration, humidity, calcium levels, fat content, and brine pH as the key variables. The analysis aimed to identify sources of variability and obtain insights for improving cheese production.

Through a comprehensive examination of the production process, we identified operational inefficiencies that negatively impacted cheese quality and standard moisture content (SMC). A fishbone diagram was utilized to explore the causes and sub-causes of these inefficiencies. Measurement and sampling were conducted at various stages of the production process to accurately assess cheese weight and SMC. Pearson correlation tests were employed to investigate the relationship between cheese weight and SMC.

The exploratory examination of the data revealed important findings. Milk age was found to significantly impact cheese weight, with older milk (48 hours) resulting in higher average weights and smaller dispersion ranges. However, these results show significant influence from casein concentration and humidity. Brine pH was identified as a crucial factor in cheese production, although not showing a statistically significant influence on cheese weight. Balancing the pH of cheese with the brine liquid's pH allowed minimal reduction of humidity variability, as well as preserving the overall cheese quality traits.

Furthermore, the positioning of pallets within the drying chamber was investigated as an additional factor influencing cheese weight and production yield. The study found that pallet position had a significant effect on moisture evaporation during the drying process, ultimately impacting the final weight of the cheese. A reduction of 1 day for faster drying positions was implemented, increasing productivity, and product flow and minimizing chamber usage.

While casein concentration, humidity, and calcium levels showed limited statistical significance in relation to cheese weight, fat content was found to have a significant impact. A positive correlation between the casein-fat ratio and cheese yield was observed, suggesting the opportunity to optimize the ratio for minimal SMC while maintaining cheese quality.

These findings highlight the importance of fat content and drying conditions in achieving desirable cheese characteristics, showing the most impact from our search. Further improvements in adjusting the casein-fat ratio are to be made in the future.

Chapter 5

Solution Proposal and Action Plan

This chapter presents a concise overview of the proposed solutions and respective results aimed at addressing the identified challenges.

5.1 Implemented Actions

Following our statistical analysis, numerous improvement measures were implemented within the company. These are divided into 3 main categories: operational improvements, quality control and standardized work. The first focuses on streamlining processes, eliminating waste, and optimizing efficiency to enhance overall operational performance. Quality control involves systematic changes within the process that guarantee consistent output and legal requirements and the latter involves establishing standardized procedures, meeting routines, and best practices to promote consistency and reduce variability.

5.1.1 Operational improvements

casein-fat ratio tool

The studies conducted in the previous chapter have proven the relationship between the fat and casein ratio and overall milk consumption. The previous treatment procedure was based on dosing the casein concentration until the desired value, with little to no alterations in the fat content. In order to optimize the concentrations, whilst maintaining the same methodology, a dosing tool was developed. This tool, according to the desired ratio, indicates to the operator the optimal casein dosage to insert. This is obtained through a regression model originating from historical data. Small adjustments according to the reference can be done prior to initiating production.

Size reduction of molds

Through the conducted study in chapter 4, in order to reduce the excessive giveaway for bar-shaped cheese, a reduction of the molds' height by 17mm was made. This adjusted the quantity of curd being inserted in each cheese, resulting in a deviation of the overall weight. Follow-up analyses were done after its implementation, showing significant improvements and proving this concept.

Filler machine angle

The studies to find the best angle for the filler machine showed optimal results for a 30° angle. Thus, the angle was standardized and defined for all references. This allowed for good quality cheese, and ideal compression whilst minimizing nonconformities.

Automatic cheese turning machine

In order to fully automate the cheese-turning process, the acquisition of an automatic turning machine was proposed. This would have major impacts in the long run, reducing the number of operators needed for the task, maximizing chamber utility by turning more frequently and, thus, optimizing ripening times. Before acquiring the machinery, a payback analysis was conducted. This allows us to understand the potential of its acquisition and a time estimate for when it is fully paid through the obtained benefits. Accounting space, lead time and worker allocation benefits, an estimate of 18 weeks was obtained.

5.1.2 Quality control**Factory path mapping**

Contamination is the primary factor for hygiene principles in the food industry. The most common contaminate in cheese production is *phages*, a virus easily transported by any worker. In order to minimize its spreading, as well as adequately align each worker's expected area of work, a path marking map was implemented within the installations (see Appendix I).

Cheese traceability

The production process shown in 3 displays the clear absence of control points amidst each stage. Accurate tracing of cheese allows for more precise and accurate statistical analyses for identifying trends, patterns or even malfunctions. Moreover, logistical registers were misaligned with the physical stock within the factory, thus leading to excessive backlogs and sales incoherence.

An initial overview of the main stages and where cheese is traced was made (see Appendix K). The stages missing a tracking methodology were highlighted and improvement opportunities were discussed with the team. From a global standpoint, amongst each production order, the product was not distinguished from the origin tank or pre-acidification tank. To further narrow and adequately study potential discrepancies between them, a color label was implemented. Each color is associated to a tank, individually associated to each pallet. This allows for visual identification, as well as adequate registration of its full process origin.

Drying chamber occupancy tool

The previous tracking system for chamber occupancy was supported merely by the operator's intuitiveness and empirical knowledge. This led to the chamber ultimately reaching higher levels of capacity in high-demand periods. The system's tracing procedure registers pallet entries and exits from each chamber. Thus, by registering each pallet's theoretical journey, the entry and exit dates and their respective reference, an occupation tracking was developed. This tool was developed in *Excel*, allowing daily registering of each chamber's capacity, updating according to any entries or exits. The mathematical procedure supporting this tool is as follows.

- N - Total number of references
- M - Total number of chambers
- O_{ik} - Occupation of chamber i in day k
- I_{ik-1} - Inventory of chamber i in day k
- A_{ijk} - Pallet entry in chamber i of reference j in day k
- B_{ijk} - Pallet exit in chamber i of reference j in day k
- X_{ijkl} - Pallet switch from chamber i to l of reference j in day k
- $\sum_{j=1}^N A_{ijk}$ - Total number of pallets of reference j inserted in chamber i for day k
- $\sum_{j=1}^N B_{ijk}$ - Total number of pallets of reference j removed from chamber i for day k
- $\sum_{j=1}^N X_{ijkl}$ - Total number of pallets of reference j switched from chamber i to chamber l in day k

Thus, the occupation of chamber i in day k is equal to:

$$O_{ik} = I_{ik-1} + \sum_{j=1}^N A_{ijk} - \sum_{j=1}^N B_{ijk} - \sum_{i=1}^M \sum_{j=1}^N X_{ijkl} + \sum_{l=1}^M \sum_{j=1}^N X_{ljk i}$$

A visual representation can be seen in Appendix H. To further support this procedure, a decision tree was developed for pickers, as well as a compendium of optimal practices (see Appendix J). This serves as a guide to understand the adequate procedure for each circumstance.

5.1.3 Work process streamlining

Work standardization

Work standardization is a pivotal approach to bolstering the reliability and consistency of cheese production processes. It entails the establishment of explicit standardized procedures and comprehensive work instructions that serve as a reference framework for all personnel engaged in the production process. Several areas and tasks were targeted for standardization. By fostering uniformity in operational tasks, minimizing inherent variability, and providing clear-cut guidelines, work standardization endeavors to optimize operational efficiency and elevate the overall quality of cheese production. Appendix G further identifies the implemented procedures, visual examples and the respective competency matrix.

Weekly meetings and *Steering*

Guaranteeing efficient information flow throughout the enterprise becomes crucial. This allows a global recognition of each improvement project's status, changes and results. Thus, weekly meetings were scheduled with each project's participants. Each leader would present the project's current status, concluded actions, and next steps until the following meeting. A monthly meeting alongside the administrators and sponsors, formally known as *Steering*, would occur monthly, with an overview of implemented actions, allowing a broader dispersion of the implemented improvements and potentially resolving constraints.

Daily Kaizen

In order to assure efficient shift changes, communication and KPI analysis, daily meetings, denominated *Daily Kaizen*, were established amongst each production sector. These consisted of short reunions to properly transmit information, complaints and potential solutions between the team. These are supported by a physical dashboard with KPIs, goals and improvement opportunities. These allowed each team member to autonomously implement the principles of Continuous Improvement, whilst assuring each work standard is respected, sprouting an improvement mindset onto the team.

5.2 Main Results

To more adequately evaluate the overall performance of the implications, the overtime of cheese in drying chambers and the SMC were deemed the most transparent indicators. Data collection was conducted meticulously throughout the aforementioned rehearsals and implementations, ensuring comprehensive coverage of the study period. Figure 5.1 shows the overall evolution of the SMC for bar-shaped cheese, as well as the coefficient of variation oscillation throughout the selected period. These result from data gathered from 4 months, from February to June 2023.

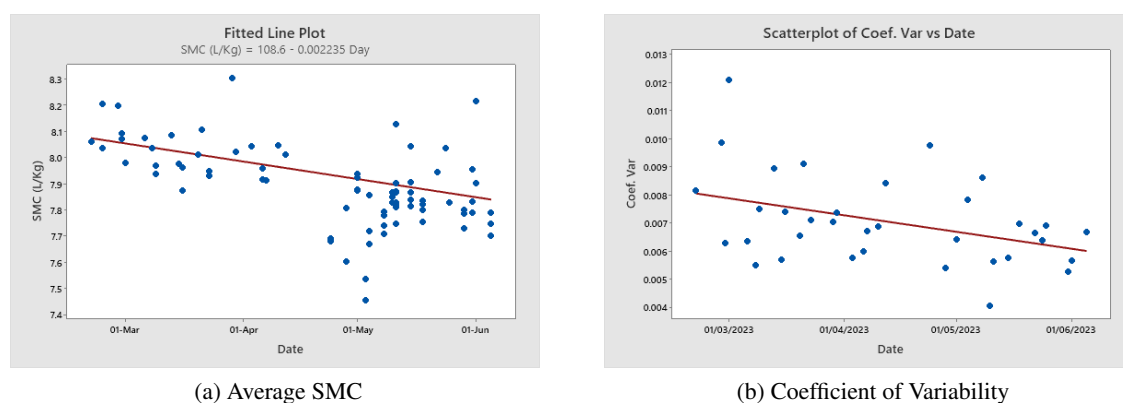


Figure 5.1: Scatterplots of SMC evolution

Observing the data, a clear reduction in overall milk consumption is evident. From February to June, an overall SMC reduction of 3.1% was observed. This translates to 0.3 liters of milk saved per kilogram of cheese produced. Considering historical data on production quantities from 2021, the overall yearly savings is over 900 thousand liters of milk, from just bar-shaped cheese.

Analyzing the coefficient of variance, a similar downward pattern is observed. the negative tendency of the scattered data maintains consistency throughout the observed months. These findings offer promising avenues for optimizing milk consumption stability and industry planning, ushering in a new era of informed decision-making and resource allocation in the dairy industry.

The overall average number of remaining overtime of cheese within the drying chambers was reduced significantly. That is, the number of days the product remained in the chambers beyond its expected date of exit. Data from January until May show a decrease of 1.2 days of the overtime period of cheese within chambers for all references. Figure 5.2 shows the obtained results.

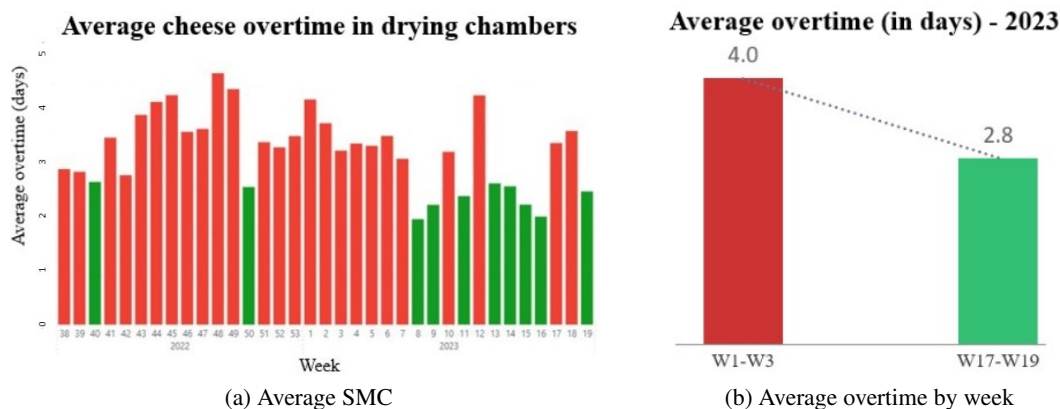


Figure 5.2: Average overtime in drying chambers - Results

Beyond these results, the implementation of these changes in cheese production has engendered numerous benefits and opportunities. The optimization efforts have led to a more streamlined and efficient production flow. This resulted in improved throughput and reduced lead times. Moreover, the enhanced product flow has facilitated better inventory management, ensuring optimal stock levels and reducing the risk of overproduction. Additionally, the increased process control and predictability have enabled the identification of potential areas for further improvement and innovation in the peculiarities of the milk’s chemical composition.

5.3 Summary

This chapter presents an overview of the proposed solutions and the corresponding results to address the challenges identified in the previous chapters. The solutions are categorized into operational improvements, quality control measures, and work process streamlining.

Operational improvements included streamlining processes, optimizing efficiency, and eliminating waste. Actions taken included developing a casein-fat ratio tool, reducing mold size, and acquiring an automatic cheese-turning machine.

Quality control measures aimed to minimize contamination and ensure consistent output. These measures included implementing a factory path mapping system, improving cheese traceability, and developing a tool to optimize drying chamber utilization.

Work standardization emphasized reliability and consistency in cheese production. Standardized procedures and instructions were established for tasks such as disinfection, filter cleaning, pump control, mold checks, and maintenance. Regular team meetings facilitated efficient shift changes, project updates, and information flow.

The main results showed reduced milk consumption and decreased overtime in drying chambers, indicating improved production flow and lead times. These improvements enhanced product flow, inventory management, and operational efficiency. The changes also brought immeasurable financial benefits, improved resource utilization, and inventory management.

Chapter 6

Conclusions and Future Work

The food industry is a vital sector of the global economy, encompassing a wide range of activities from agriculture and food production to retail. Its high regulative standards lead to significantly low levels of efficiency and production discrepancies. This study aimed to improve the production capacity of cheese in a dairy company, whilst minimizing process variability.

This project is a result of an intervention to lower the particular milk consumption per kilogram of cheese produced, with the goal of reducing variability to improve process control. The specified aims are focused on determining all variables that affect cheese weight while developing new techniques and technologies that not only regulate the process but also enable prompt responses. The goal was to create a product that meets all needs of the consumer while allowing the business to minimize waste, maximize the use of raw materials, and maintain high standards of quality.

The proposed solution involved numerous interventions within the production process, providing a global improvement. After identifying the overall concern, through brainstorming sessions and visits to the production room, a mapping of potential factors affecting cheese weight was laid out and prioritized. These were characterized as having a direct impact on milk consumption, an indirect impact of intermediate parameters. Subsequently, a series of studies and statistical analyses were conducted on the chosen variables. The main tools utilized were linear and multiple regressions, ANOVA and Kruskal-Wallis tests.

The analyses aimed to identify key factors affecting milk consumption and cheese weight, driving improvement opportunities. Crucial variables were identified, leading to reduced milk consumption while maintaining high-quality cheese. A separate analysis focused on the drying phase, aligning with the main objective. Throughout the project, key indicators were identified, work standards implemented, and machine functions enhanced, all contributing to improved operational efficiency and business outcomes. The success opened doors for applying these methodologies to other dairy products like butter and milk derivatives.

6.1 Main conclusions

In this chapter, the research questions posed are addressed, alongside their main conclusions.

RQ1: What are the main factors that directly impact raw milk's consumption and the final weight of cheese?

From our studies, amongst the numerous factors that impact the SMC, the casein-fat ratio stands out the most, explaining 81% of the process's variability. Other external factors such as the brine's pH, casein concentration and calcium, although pointed out initially as having a significant impact, show no statistical consistency or significance.

RQ2: What are the ideal target values and implementations to simultaneously minimize variability, whilst maintaining or improving the production capacity?

Amidst this project, operational improvements, quality control measurements, and work standardization were implemented. For operational improvements, an assistance tool for balancing the casein-fat ratio was introduced. This guides the milk treatment team to adjust the casein concentration according to the optimal ratio range of 0.64 to 0.655. The filler machine angle was redefined to 30°. This spotlighted a related concern, which was mold sizes. A reduction of 17mm of cheese molds was calculated and determined to have an optimal influence on the cheese give-away. This allowed for a deviation of the average cheese weight, reducing the overall excess weight in each package whilst maintaining within legal restrictions. The acquisition of an automatic cheese-turning machine was proposed, for an estimated payback of 18 weeks. Given its major impact on quality and its completely manual execution, its automation reduces overall costs, worker allocation and lead time during the drying phase.

For quality control, to minimize phage contamination and define each worker's operational perimeter, a path marking map was implemented. This consists of standardized floor paths with labeled colors that define where and how each worker should move between sections.

Color labeling for each production order was implemented to improve cheese traceability. This consists of colored labels for each pallet, each associated with a production tank. Alongside this, a drying chamber occupancy tool was implemented. This tool provides a dashboard for the theoretical occupancy of cheese in each chamber, optimizing distribution during high-demand seasons and contributing to the overall product traceability.

Throughout these implementations, several work standardization procedures were parallelly defined. In this context, it was imperative to raise awareness among the company's employees regarding the issue and the appropriate course of action, enabling them to proficiently execute the process and ascertain whether the product complies with specified limits.

RQ3: How can the Lean Six Sigma methodology maximize efficiency and efficacy amidst the most critical stages that directly impact milk consumption?

These aforementioned were the result of numerous statistical analyses conducted throughout the project, based on a Lean Six Sigma methodology. Beyond the financial benefits yielded, significant improvements in productivity and a reduction in milk consumption and variability were observed. Table 6.1 provides an overview of the results obtained.

Table 6.1: Summary of results - before and after comparison

	Before	After	Δ
<i>Specific Milk Consumption (L/kg)</i>			
<i>Bar</i>	8.52	7.94	-6.81%
<i>Ball</i>	8.8	8.43	-4.20%
<i>Ref. F</i>	9.35	8.62	-7.80%
<i>Ref. D</i>	8.57	7.70	-10.1%
<i>Production Capacity (kg/h)</i>	1233.2	1276.4	3.34%
<i>Overtime in Drying Chamber (days)</i>	4.0	2.8	-30%
<i>Coefficient of Variance (%)</i>	0.91	0.61	-32.4%

As stated, a clear surpass of the established objectives for PC (2% increase) and the SMC (2% decrease) was reached, saving the company approximately 900k liters of milk yearly from bar cheese only. Moreover, significant improvement was made in the overall variability, with a coefficient of variance decrease of 32.4%. The project was, thus, able to satisfactorily answer the research questions, showing substantial evidence of the favorable influence of the implementation of LSS methodologies.

6.2 Future work perspectives

Building upon these promising results achieved thus far, it is evident that further actions need to be taken to advance the production capacity of cheese. These aim to improve the business' performance, as well as contribute to the global dairy industry with scientific findings.

Amongst the many areas to be improved, two key parameters are the most promising: the impact of calcium and the optimal casein-fat ratio. By investigating these aspects, we aim to maximize specific milk consumption while simultaneously reducing variability even further. Although showing controversial results, the outstanding significance of calcium in cheese production is still undeniable. Several studies support its statistical influence on cheese yield (Wolfschoon-Pombo (1997); Santos et al. (2013); Ustunol and Hicks (1990)), even though the conducted studies do not corroborate this phenomenon. The range of calcium concentration considered in the conducted rehearsals (4.0% to 10.0%) wasn't large enough to show statistical significance. This was mainly due to legal restrictions, as well as the unstable results caused by other factors. Moreover, a greater magnitude of effects was, in fact, observed for more extreme values.

The casein-fat ratio also showed the most significant results of all variables. Although statistical evidence of lower SMC for lower ratios, subsequent research is crucial to identify the optimal ratio for each reference. Moreover, although the fat content justifies approximately 81% of the variability, the remaining 19% are yet to be identified. Thus, a finer-grained analysis of the remaining factors is yet to be conducted.

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Appendix A

Project Chronograms

Phase	Description	W05	W06	W07	W08	W09	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26
D	Problem Characterization																						
D	AS-IS mapping																						
M	Cause identification																						
A	Prioritization																						
A	Solution designing																						
A	Solution testing																						
I	Improvement implementation																						
C	Standardization & training																						

Figure A.1: Chronogram for production capacity improvement

Phase	Description	W06	W07	W08	W09	W10	W11	W12	W13	W14	W15	W16	W17
D	Problem Characterization												
M	Identify improvement opportunities												
A	Solution defining & discussion												
I	Solution implementation & testing												
C	Standardization & training												

Figure A.2: Chronogram for drying chamber management

Appendix B

Food Industry in Portugal

Portugal		unidade: 10 ³ €
Valor de Vendas	2019	2020
10 - Indústrias alimentares	11,777,403	11,699,155
11 - Indústrias das bebidas	2,998,785	2,750,334
101 - Abate de animais, preparação e conservação de carne e de produtos à base de carne (a)	2,474,350	2,448,272
102 - Preparação e conservação de peixes, crustáceos e moluscos	1,265,663	1,259,905
103 - Preparação e conservação de frutos e de produtos hortícolas	1,122,719	1,091,759
104 - Produção de óleos e gorduras animais e vegetais	961,016	...
105 - Indústria de lacticínios (b)	1,385,107	1,398,715
1051 - Indústria do leite e derivados	1,314,168	1,335,047
Leite	338,231	352,047
Leite em pó	84,368	84,599
Manteiga	132,953	130,185
Nata	46,243	49,121
Queijo de vaca	287,505	287,955
Iogurtes	145,508	145,639
1052 - Fabricação de gelados e sorvetes	70,939	63,669
106 - Transformação de cereais e leguminosas; fabricação de amidos, féculas e de produtos afins	...	...
107 - Fabricação de produtos de padaria e outros produtos à base de farinha	1,540,065	1,468,696
108 - Fabricação de outros produtos alimentares (d)	1,123,099	1,079,510
109 - Fabricação de alimentos para animais	1,295,902	1,329,600
1091 - Fabricação de alimentos para animais de criação	1,204,601	1,227,086
1092 - Fabricação de alimentos para animais de companhia	91,301	102,514
110 - Indústria das bebidas	...	2,750,334
120 - Indústria do tabaco	604,319	676,303

(a) Não inclui as peles.

(b) Não inclui os "sumos de laranja congelados, não concentrados, não fermentado e sem adição de álcool".

(d) Não inclui os vinagres.

(e) Não inclui "desperdícios resultantes da destilação (bagaços de frutas), excepto cereais".

(f) Não inclui "desperdícios da produção do vinho (inclui bagaço de uva); borras e tártaro em bruto".

(g) Não inclui "Borras e desperdícios (dreches) da indústria da cerveja e da destilação".

Figure B.1: Food industry sales in Portugal from 2019 and 2020 (adapted from INE (2021))

Appendix C

Value Chain Analysis - Dairy Industry

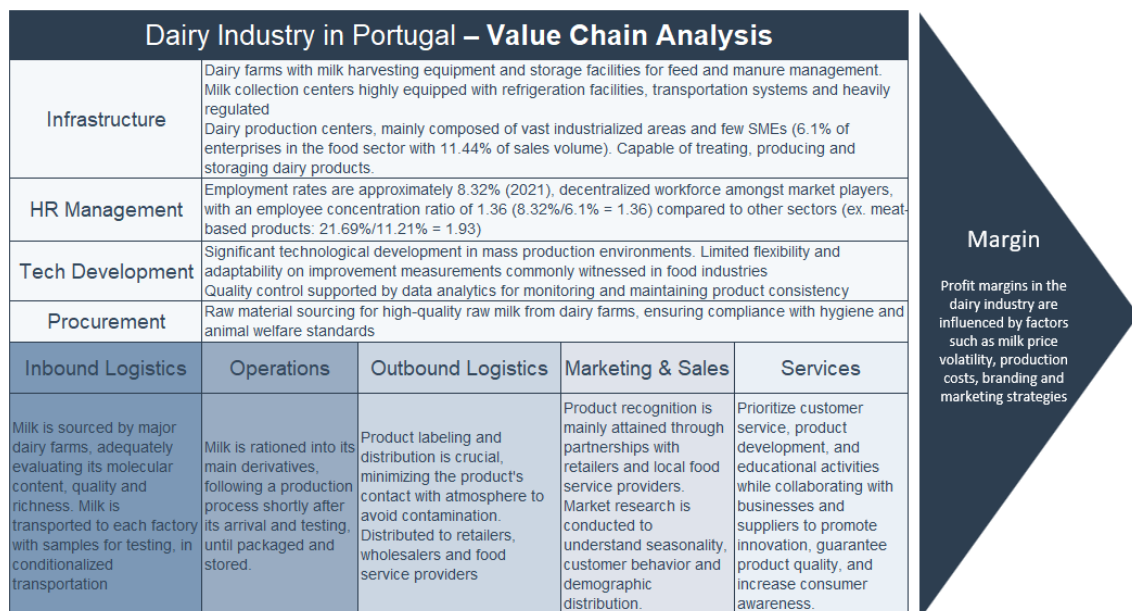


Figure C.1: Value Chain Analysis - Dairy industry in Portugal

Appendix D

Literature Review Framework

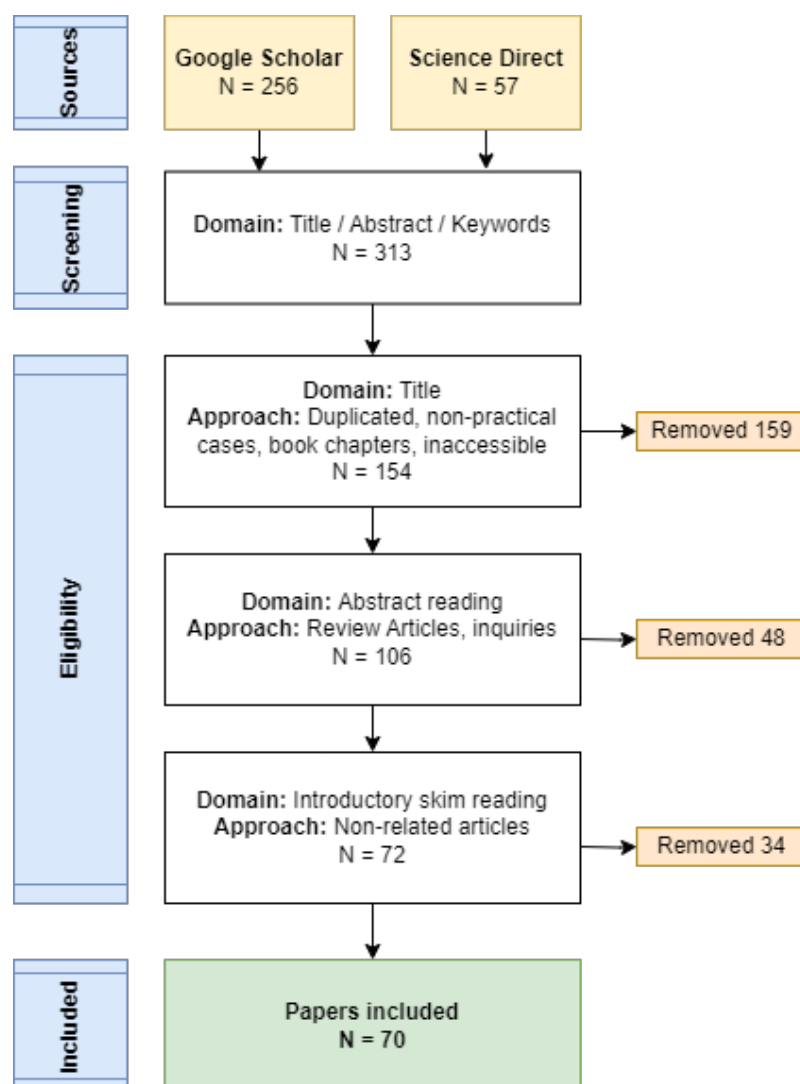


Figure D.1: Literature review framework (adaptation from PRISMA framework)

Appendix E

Brainstorming Sessions

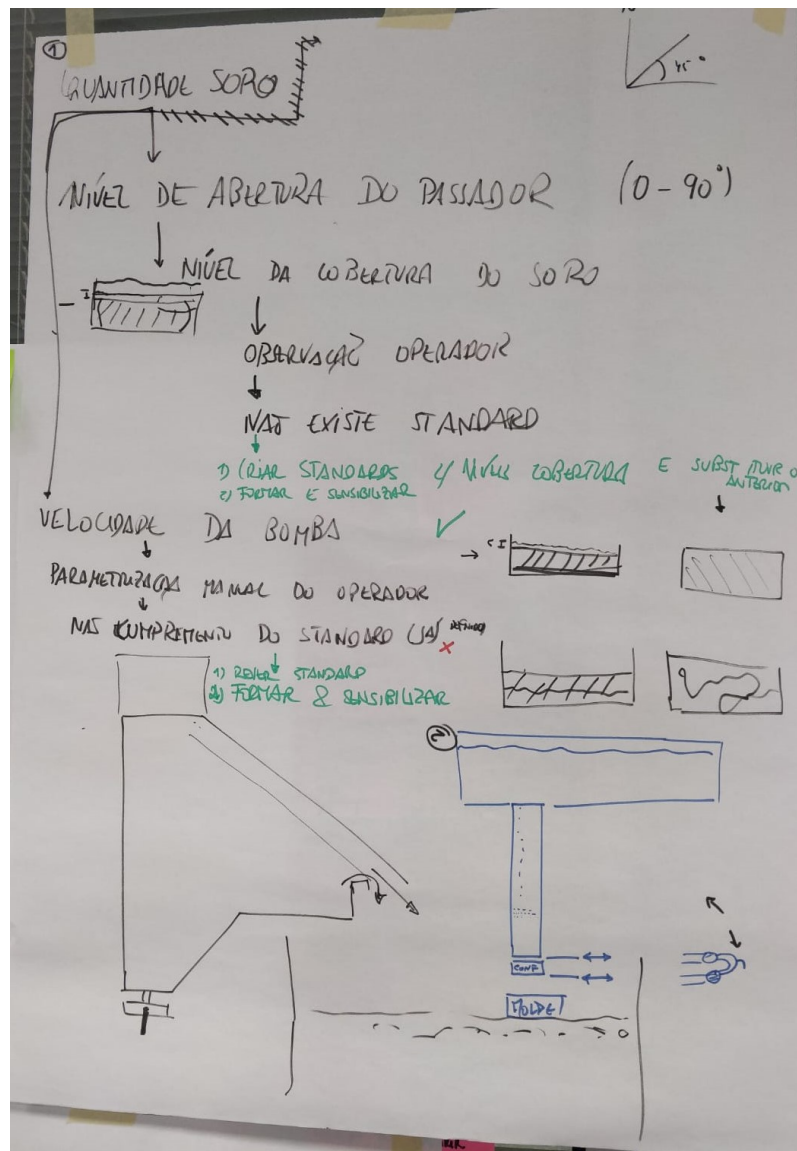


Figure E.1: Filler machine efficiency - sketch



Figure E.2: Fishbone diagram - coefficient of variance

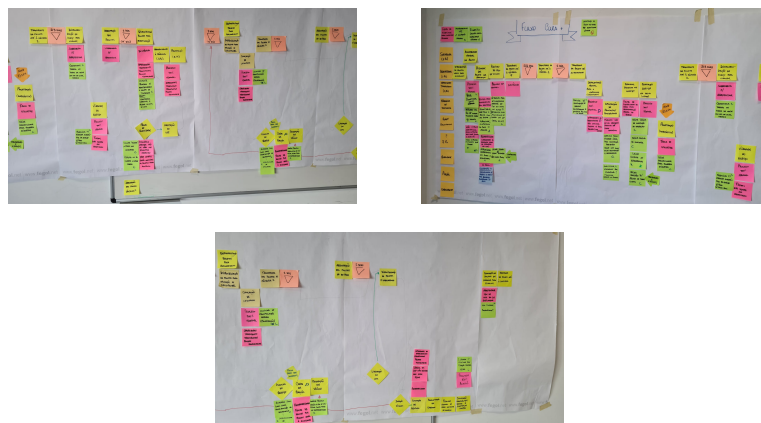


Figure E.3: Drying chamber flow mapping

Appendix F

Drying Chamber Layout and Pallet Allocation

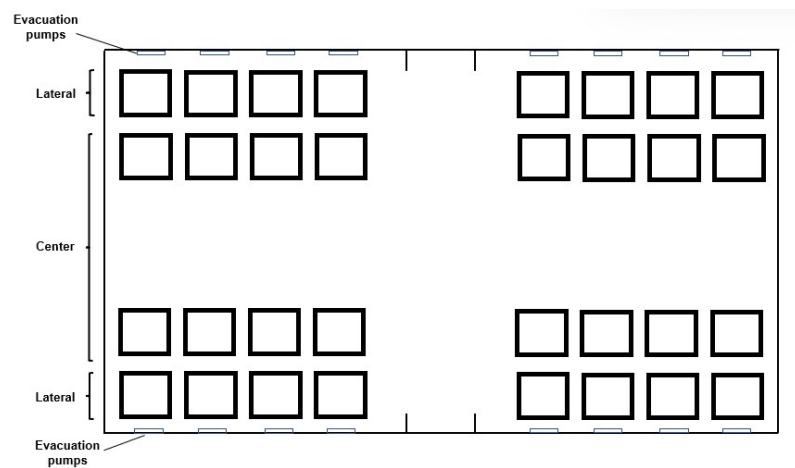


Figure F.1: Chamber layout - Top view

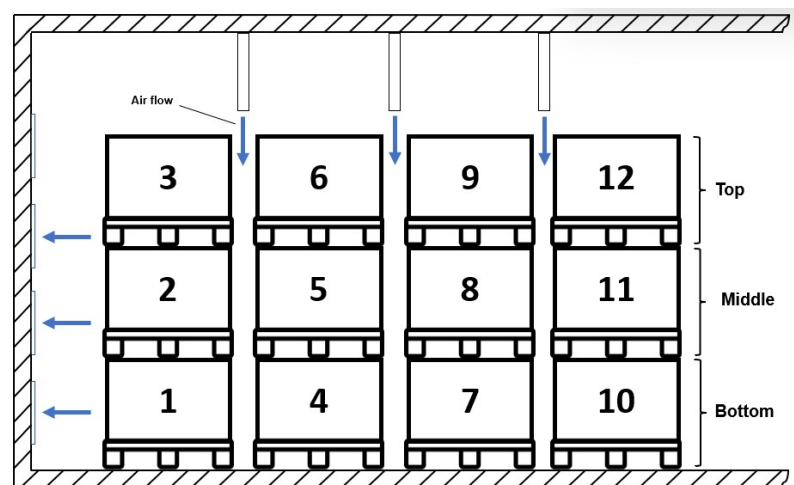


Figure F.2: Chamber layout - lateral view

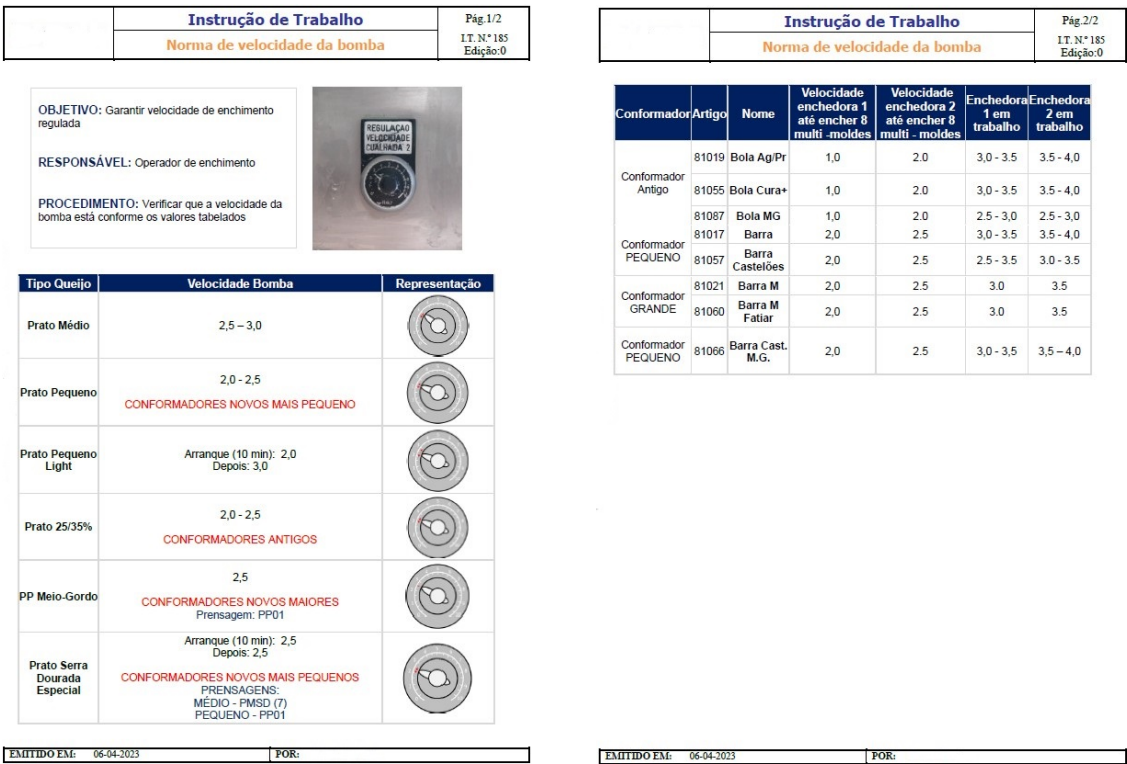
Appendix G

Standardized Procedures

Table G.1: Standardized work developed and respective purposes

Task	Purpose	Areas of concern
<i>Ditch Disinfection</i>	Adequate disinfection of ditches	Product contamination from phages
<i>Brine Filter Cleaning</i>	Periodic cleaning of curd filters in the brine room	Avoid curd deposits Minimize pH oscillation
<i>Pump Velocity</i>	Standardized filling velocity	Avoid undesirable changes in curd filling Avoid curd coagulation during filling
<i>Filler - Liquid Level</i>	Ideal liquid level for optimal filling	Adjust liquid/curd ratio Avoid liquid agglomerates during filling
<i>Mold Conformity</i>	Periodic check of mold conditions	Removal of damaged molds Avoid spilling or malfunctions Undesirable cheese quality
<i>Cheese treatment</i>	Manual treatment spreading	Avoid uneven distribution Minimize cheese rejections
<i>Autonomous Maintenance^a</i>	Empower frontline workers for periodic maintenance	Minimize downtime due to breakdowns

^aCorresponds to several standardized procedures throughout the production process



	Instrução de Trabalho	Pág. 1/1
	Norma de desinfecção de calhas de esgoto	I.T. N.º 3000 Edição: 0

(1/4)

Curso da calha

APLICAR PRODUTO NA TOTALIDADE DA CALHA DO ESGOTO

MATERIAL NECESSÁRIO:

- Viseira
- Borrifador de pressão líquido

Exemplificação de material necessário

FREQUÊNCIA: Semanal, após conclusão do plano semanal de fabrico

RESPONSÁVEL: Operador da sala de fabrico

SISTEMA:

Representação do sistema

EMITIDO EM:	POR:
--------------------	-------------

Figure G.2: Standardized procedure - example #2 (censored due to privacy policy)

[illegible]

Figure G.3: Competency matrix for autonomous maintenance (censored due to privacy policy)

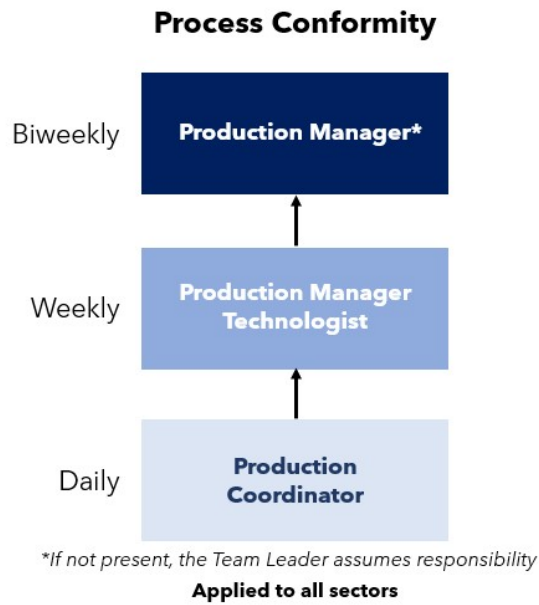


Figure G.4: Process conformity - process flow

Process Conformity	
Area: Brining room	
Daily: Air filter hygienization Manually clean the brine filters	
Biweekly: Disinfection and cleaning of ducts	
Date:	Auditor:

Process Conformity	
Area: Brining room	
Daily: Air filter hygienization Manually clean the brine filters	☐ ☐
Biweekly: Disinfection and cleaning of ducts	☐
Date:	Auditor:

Figure G.5: Process conformity - checklist

Appendix H

Chamber Occupation Dashboard

Chamber	20/05/2023	21/05/2023	22/05/2023	23/05/2023	24/05/2023	25/05/2023	26/05/2023	27/05/2023	28/05/2023	29/05/2023	30/05/2023	31/05/2023	01/06/2023	02/06/2023
1	25%	25%	25%	56%	56%	56%	56%	56%	56%	34%	34%	34%	34%	34%
2	74%	74%	74%	74%	74%	87%	87%	87%	87%	67%	67%	67%	67%	67%
3	57%	27%	27%	27%	27%	27%	43%	43%	43%	43%	43%	43%	43%	43%
4	10%	10%	10%	14%	14%	14%	14%	7%	7%	37%	37%	37%	37%	37%
5	42%	42%	42%	42%	42%	42%	61%	61%	61%	61%	61%	61%	61%	61%
6	56%	56%	56%	56%	56%	56%	56%	52%	52%	52%	52%	52%	52%	52%
Drying	19%	19%	19%	19%	19%	19%	19%	37%	37%	37%	37%	37%	37%	37%
8	54%	54%	54%	54%	54%	54%	54%	54%	71%	71%	71%	71%	71%	71%
9	85%	85%	85%	85%	93%	93%	93%	93%	82%	82%	82%	82%	82%	82%
GLOBAL	65%	67%	67%	65%	67%	69%	68%	67%	68%	67%	67%	67%	67%	67%

Figure H.1: Chamber occupation dashboard

Appendix I

Path Mapping for Workers

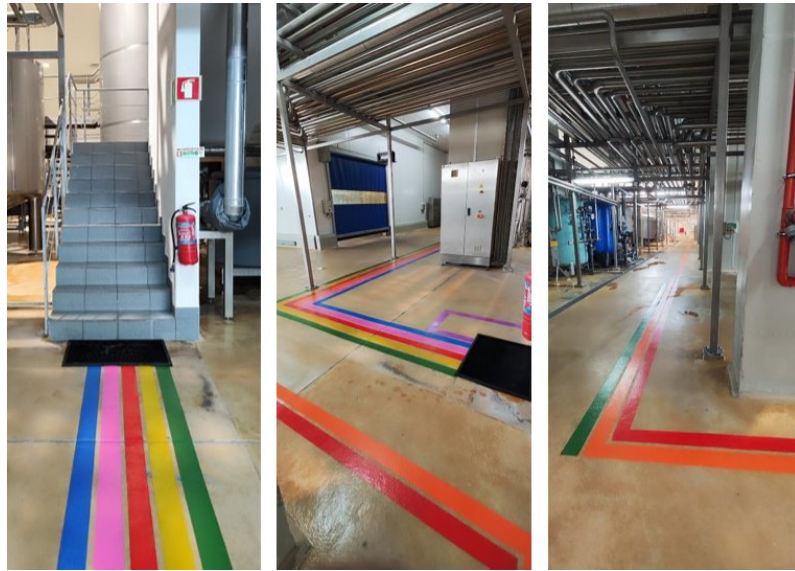


Figure I.1: Example pictures of path mapping

Appendix J

Decision Tree and Optimal Practices for Pickers

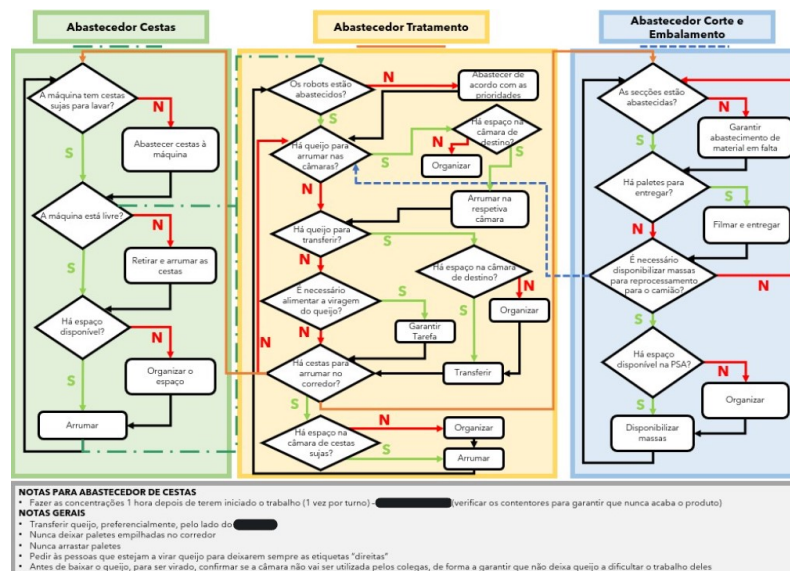


Figure J.1: Decision tree for pickers

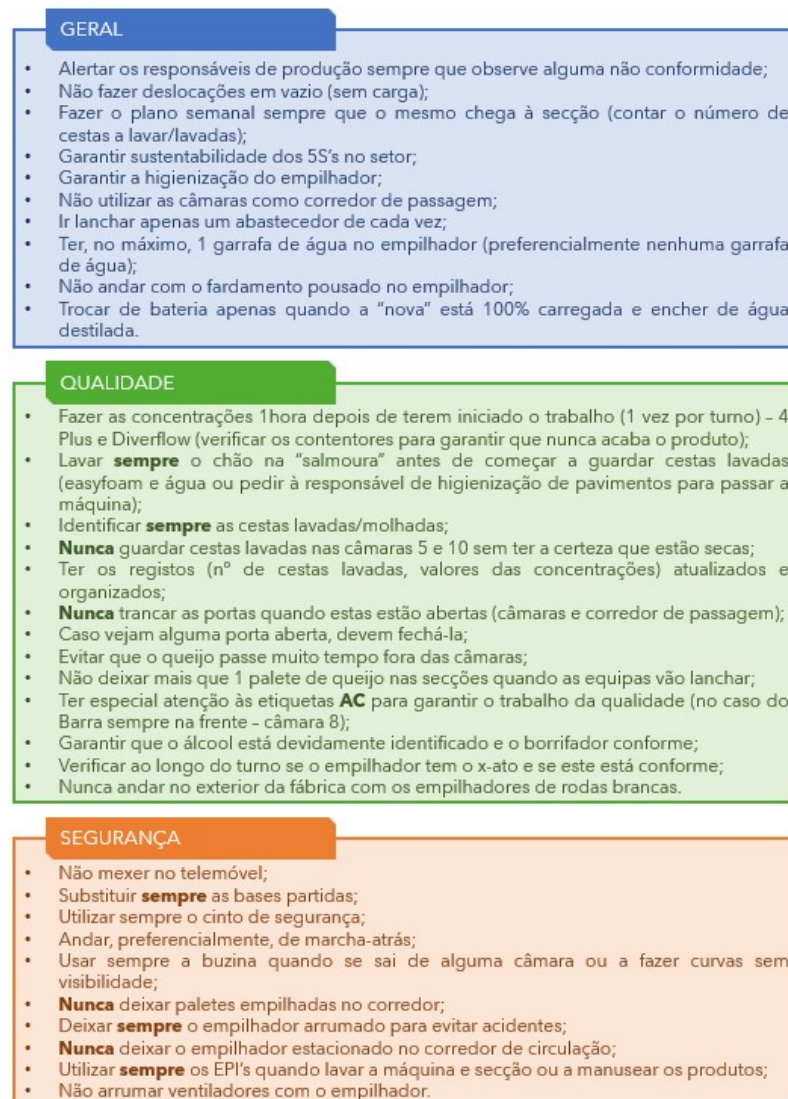


Figure J.2: Compendium of optimal practices for pickers

Appendix K

Production Process and Drying Phase

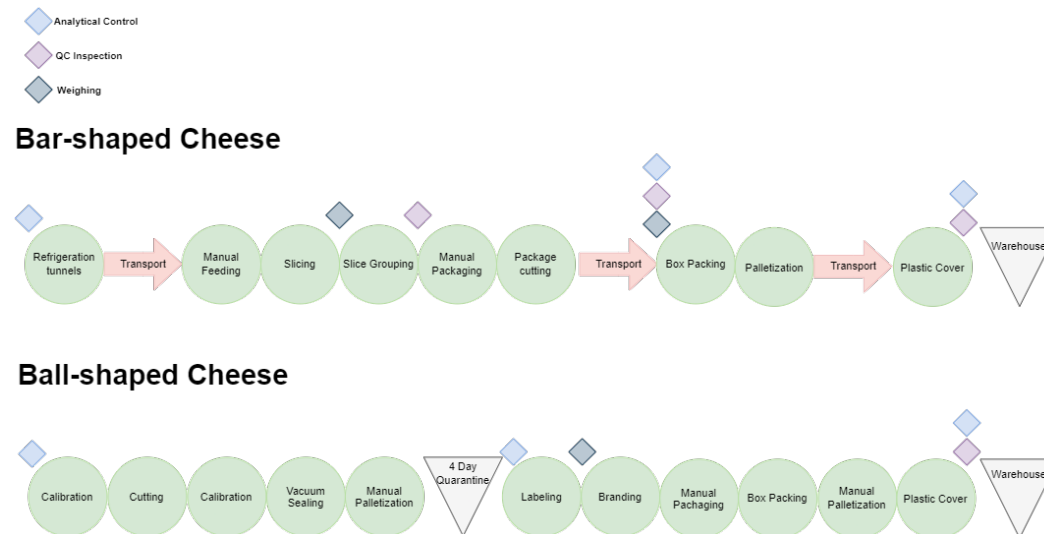


Figure K.1: Drying and packaging - bar and ball cheeses

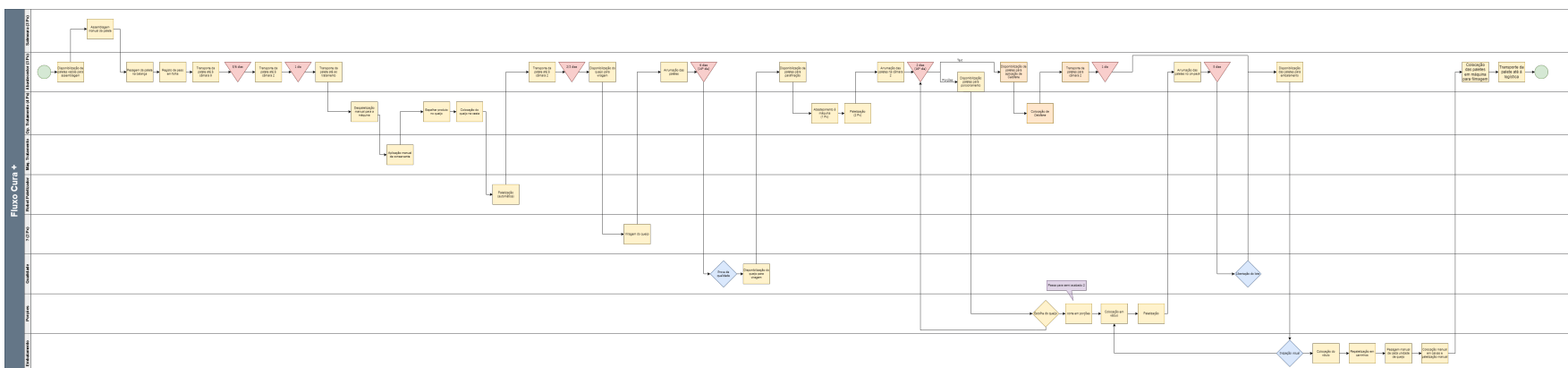


Figure K.2: Sketch of the swimlane for the drying phase