Linköping University | Department of Management and Engineering [IEI]
Master's thesis, 30 Credits | Logistics and Quality Management
Spring 2025 | LIU-IEI-TEK-A--25/05183--SE

Statistical Process Control Implementation within the Dairy Industry

– A case study at Arla Foods Dairy, Linköping

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Abstract

This thesis conducted in collaboration with Arla Foods as a case study, explores the integration of Statistical Process Control (SPC) into dairy production, focusing on monitoring and controlling fat content, a critical parameter for texture, taste, and product quality. The key motivation for this initiative is the ongoing challenge of fat content variation in Arla's dairy products, which has led to considerable additional costs, particularly due to fat giveaway. While the company recognises the potential of SPC to address such issues, its current use remains limited, and a structured approach to its implementation across production processes is yet to be developed. This gap between recognition and implementation prompted the investment in this research, aimed at gaining deeper insights into SPC and establishing a more systematic approach to its integration within the production process.

The aim of this thesis is to investigate how SPC can be effectively integrated into dairy production processes to better control fat content and improve consistency. The study is guided by two research questions: (1) What process step(s) in dairy production would benefit most from the integration of SPC, particularly in relation to controlling fat content to maintain product consistency? and (2) What actionable steps in a roadmap can be taken to integrate SPC into dairy operations?

To address these questions, the research method combined a structured literature study, current state visualisation, process prioritisation, and practical roadmap development. Current state visualisation involved data collection, data analysis, and measurement system analysis, providing a necessary foundation to accurately map and assess the existing conditions at the case company. A prioritisation matrix was then applied to systematically identify the process step(s) where SPC integration would have the greatest impact on fat content control, providing an evidence-based foundation for the study.

The findings revealed that the standardisation and hydrolysis process steps are the most suitable for SPC integration to maintain fat content consistency. In response to the second research question, a practical roadmap for SPC integration was developed, divided into three phases: Pre-Implementation, Implementation, and Anchoring, each containing clearly defined actionable steps.

Although SPC principles are well-established in industries such as in traditional manufacturing industries, their application within dairy production remains underexplored. This thesis contributes a tailored, process-specific framework for SPC integration in dairy operations and highlights the need for further industry-specific research to strengthen and expand SPC adoption within the broader food sector.

Keywords: Statistical Process Control (SPC), SPC implementation, SPC Integration, Roadmap, Prioritisation Matrix, Process Prioritisation, Dairy Production, Dairy Industry, Food Industry, Fat Content.

Acknowledgments

This thesis proudly presents our master's research in quality management, focusing on the implementation of Statistical Process Control at Arla Foods Dairy in Linköping. It marks the final semester of our studies at the Division of Logistics and Quality Management Engineering, within the Industrial Engineering and Management master's program at Linköping University.

We would like to begin by expressing our sincere gratitude to Arla Foods for the opportunity to conduct our thesis work within the organisation. Without their support and collaboration, this project would not have been possible.

Our heartfelt thanks also go to our university supervisor, Mattias Elg, whose expertise and guidance were invaluable throughout the process. His advice, especially during the more challenging phases of the thesis, played a crucial role in its success. We would also like to thank Promporn Wangwacharakul for her continuous feedback and support throughout the thesis.

We are equally grateful to our supervisor at Arla Foods, whose continuous support and insights guided us throughout the project. We would also like to thank the employees at Arla Foods for their help and openness during our research.

We would like to thank Daniel Mansoob for his constructive feedback and encouragement along the way. His perspective often helped us view our challenges from new angles, and the discussions we had with him were both motivating and highly valuable.

Last but certainly not least, we would like to express our deepest gratitude to our families. Their unwavering support, understanding, and encouragement have been the foundation that allowed us to stay focused and motivated throughout this journey. We are truly thankful for their presence, which made this achievement not only possible but meaningful.

Abbreviations

A list of abbreviations encountered in the thesis is provided below:

SPC	Statistical Process Control
SQC	Statistical Quality Control
MSA	Measurement System Analysis
UTL	Upper Tolerance Limit
LTL	Lower Tolerance Limit
MR-chart	Moving Range Chart
ESL	Extended Shelf Life (dairy products)
P1	Pasteurisation 1
P2	Pasteurisation 2
FGS	Finish Goods Storage
StDev	Standard Deviation
Gauge R&R	Gauge Repeatability and Reproducibility
RCA	Root Cause Analysis
QFD	Quality Function Deployment
TQM	Total Quality Management
SIPOC	Supplier-Input-Process-Output-Customer
VOC	Voice Of Customers
VOP	Voice Of Process
FMEA	Failure Mode and Effect Analysis
ERP system	Enterprise Resource Planning System
QMS	Quality Management System
KPIs	Key Performance Indicators
AI	Artificial intelligence
UCL	Upper Control Limit
LCL	Lower Control Limit
CL	Centre Line
CSF	Critical Success Factor
AHP	Analytic Hierarchy Process
OCAP	Out-of-control Action Plan
SOP	Standard Operating Procedure
QM	Quality Management
I-chart	Individual Chart
MR-chart	Moving Range Chart
R-chart	Range Chart
S-chart	Standard Deviation Chart
CUSUM	Cumulative Sum Control Chart
EWMA	Exponentially Weighted Moving Average

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1. Introduction

This chapter provides a comprehensive background to the study's subject area, followed by a company description, the purpose of the study, research questions, delimitations, an outline of the report structure and project safety and reliability.

1.1 Background

Statistical Process Control (SPC) was introduced in the 1920s by Walter A. Shewhart, who also pioneered the broader concept of Statistical Quality Control (SQC). At its core, SPC is rooted in the pursuit of quality - ensuring that products or services consistently meet defined standards and customer expectations. Quality, in this context, refers not just to the final outcome, but to the stability and predictability of the processes that produce it. Central to Shewhart's work was the theory of variability, which posits that all processes inherently exhibit variation. Regardless of how refined or optimised a system becomes, some level of variation is unavoidable. Shewhart classified process variation into two categories [1]:

- *Common cause variation*: This refers to the natural and inherent variation within a process, which occurs due to unavoidable factors. Examples include slight differences in raw materials, normal machine wear, or minor environmental changes like temperature and humidity fluctuations [1].

- *Special cause variation*: This refers to unnatural and avoidable variations caused by specific, identifiable factors. These variations often indicate a problem in the process, such as faulty machinery, human error, or incorrect raw material composition. Unlike common causes, special causes require intervention to prevent defects and maintain process stability [1].

The objective of SPC is to enhance process performance by identifying and reducing special cause variation, to achieve stable, consistent, and predictable operation - core principles of quality as defined within Total Quality Management (TQM). By applying statistical methods, SPC enables organisations to monitor and control processes more effectively, reducing defects and ensuring that products or services meet established quality standards. Widely used in manufacturing, healthcare, food processing, and service industries, SPC supports quality improvement by minimising waste, reducing rework, and increasing customer satisfaction [1].

Despite its effectiveness, the application of SPC in the food industry is lagging compared to the manufacturing sector. Research by Lim et. al [2] highlights several factors contributing to this slow adoption, such as a lack of technical expertise, resistance to change, the perceived complexity of SPC, and a shortage of clear implementation guidelines. Despite these barriers, the potential benefits of SPC in the food industry are substantial. As discussed in the study, SPC can help reduce process variation, minimise scrap and rework, and ensure consistency in production. Therefore, as stated in the paper, "SPC can be a versatile technique for managing

quality improvement efforts in the food industry and sustaining food process quality. " [2, p. 187].

1.1.1 SPC in Food Industry

In recent years, the food industry has received increased attention regarding food quality, driven by strict government regulations, rising consumer expectations, and the need to remain competitive in a market where product quality directly impacts a company's reputation. Continuous product rejections, scrapping, and recalls not only damage a brand's image but also have serious financial consequences [3]. As Lim et.al [4] notes, improving food quality has become a growing priority for companies. However, despite the recognised importance of quality control, the adoption and implementation of SPC within the food industry remain relatively limited compared to traditional manufacturing sectors [2].

This lag is often attributed to the unique characteristics of food products, such as variability in raw materials, perishability, and complex processing conditions which make standardised control methods more challenging to apply [2,4]. Furthermore, existing research tends to focus primarily on the technical aspects of SPC, such as the application of control charts, while giving limited attention to how these practices can be effectively operationalised, institutionalised, and sustained over time within food production environments [3,4].

While SPC is widely recognised for its ability to reduce process variation, minimise rework, lower defect rates, and reduce costs [3], the food industry continues to be an area where practical applications and long-term integration of SPC practices are still developing. This highlights a need for further research not only on the implementation process itself but also on how to embed SPC practices effectively within the operational culture of food processing companies.

Although research on SPC in the food industry remains limited, section *2.3, Previous Studies on SPC in the Food Industry*, highlights several case studies that demonstrate the potential and effectiveness of SPC in both food and dairy processing.

1.2 Company Description

Arla Foods is one of the largest manufacturers and exporters of dairy products globally. As a multinational dairy cooperative, it is owned by over 7 600 farmers from various countries, Sweden, the Netherlands, Belgium, Denmark, Germany, United Kingdom and Luxembourg [5,6]. Arla Foods is the world's largest producer of organic dairy products. The company has over 20,000 employees across more than 30 countries [7]. This vast cooperative network enables Arla to maintain a strong presence in the global dairy market while supporting local farming communities.

Arla produces a wide range of dairy products to meet diverse consumer needs, such as yogurt, cheese, milk, cream, cottage cheese, and lactose-free alternatives. The company is also known for its numerous well-established brands. Some of the most popular are Yoggi, Svensk Smör, Pucko, Bregott, and Arla Ko [8,9]. Arla's products are distributed to approximately 146 countries worldwide, making it a truly global brand. In 2023, the company achieved a revenue of 13.7 billion euros and employed around 23,000 people, underscoring its vast reach and significant presence in the global dairy industry [10].

Arla is deeply committed to sustainability and achieving global climate goals. The company aims to reach net-zero carbon emissions by 2050, indicating its dedication to reducing its environmental impact. Arla's global mission is to produce high quality dairy products while remaining environmentally responsible, ensuring that sustainability is at the core of its operations. This commitment drives the company to innovate and work alongside farmers to minimise their carbon footprint and contribute to a more sustainable future [6,11].

Arla's strong commitment to sustainability and high-quality dairy production naturally aligns with the principles of SPC. By adopting SPC, Arla can systematically monitor and control its processes, reducing waste, minimising defects, and improving overall efficiency, all of which contribute to its environmental and quality assurance goals.

1.2.1 Arla Foods Dairy in Linköping

Arla Foods in Linköping is a manufacturer of approximately 300 different dairy products. The site currently produces dairy products such as milk, sour cream, lactose-free crème fraiche, yogurt, and more (see Figure 1). The facility was built in 1977 and has currently 290 employees [12].

Arla in Linköping produces 220 million kilograms of milk annually, which is sourced from Arla's dairy farms. By 2030, Arla aims to reduce its greenhouse gas emissions by 63% [12].

Figure 1: Some of the dairy products that are produced at Arla Foods in Linköping.

1.2.2 SPC in Arla Foods Dairy Linköping

Arla Foods in Linköping has recognised the need to strengthen its knowledge and application of SPC within its operations. The facility aims to use the insights from this study to gain a deeper understanding of SPC and make full use of its benefits.

One of the primary reasons for this initiative is the issue of fat content variation in their dairy products, which has led to significant additional costs, particularly due to fat giveaway. Currently, SPC is not widely implemented across Arla's production processes, it is used only to a limited extent in the filling area, with minimal effort. While the company acknowledges the power of SPC and is aware of its potential benefits, a structured approach to its integration is lacking. This inspired the investment aimed at gaining more knowledge of and integrating SPC into their production process.

To tackle this, Arla Foods in Linköping will serve as a case study for this thesis, providing a practical foundation for exploring how SPC can be effectively incorporated into dairy production to enhance quality control, reduce waste, and improve overall efficiency.

1.3 Purpose & Research Questions

The objective of this thesis is to explore the integration of SPC in dairy production, with a particular focus on monitoring and controlling fat content - the proportion of milk fat in a dairy product, typically measured in percentages. The fat content of any dairy product plays a key role in determining its texture and taste; thus, it directly impacts overall consumer satisfaction, making it a critical quality parameter. The study aims to identify which process step(s) within dairy production where SPC can be effectively integrated, and to develop a practical roadmap for its integration.

To achieve these objectives, the study seeks to answer the following research questions:

- **Research Question 1:** What process step(s) in dairy production would benefit most from the integration of SPC, particularly in relation to controlling fat content to maintain product consistency?

- **Research Question 2:** What actionable steps in a roadmap can be taken to integrate SPC into dairy operations?

1.4 Project Scope and Limitations

To ensure the project is completed on time, clearly defining its scope and limitations is essential. This helps define the scope of the research and set realistic expectations for what the project will address and what falls outside its focus.

- The project will focus on a single quality parameter, the fat content in dairy products. This parameter has been explained in section 1.3 *Purpose & Research Questions* as a critical to quality parameter, hence the reason for the delimitation.

- The study will focus exclusively on the Linköping dairy and will not include other dairies in Sweden.

- This research will focus on identifying key areas within the dairy production process where SPC can be effectively implemented, as well as outlining a roadmap with actionable steps for its integration. However, due to time constraints, the findings of the study will not be implemented or tested in practice during the study period.

- To enable a reasonable quantitative analysis, the study will focus on data spanning approximately one year from 2024 to 2025.

1.5 Outline

This section provides an overview of the remaining structure of the thesis. Below is an outline of the structure of the thesis:

- Chapter 2: *Theoretical Framework* presents the theoretical foundation of the study.
- Chapter 3: *Method*, which explains the chosen research approach.
- Chapters 4 and 5: *Findings*, outline the study's key findings.
- Chapter 6: *Discussion & Conclusions*, examines these findings in relation to the research questions, reflects on the method selection, offers recommendations for the case company and captures the limitations associated with the study.

1.6 Project Safety and Reliability

The information in this thesis will be reviewed and approved by Arla Foods to ensure that no sensitive data that could harm the company is published. As a result, some details in the report may be censored to maintain privacy and confidentiality.

Today, generative artificial intelligence (AI) tools like ChatGPT are increasingly used for tasks such as idea generation, report structuring, and text refinement. In this thesis, AI tools were responsibly utilised to assist with grammar refinement and the organisation of ideas. Their use was carefully managed to uphold academic integrity and ensure originality in the research and analysis.

2. Theoretical Background

With the introduction outlined, this chapter presents the theoretical foundation for the study, outlining key concepts and frameworks necessary to understand the research context.

2.1 SPC as a part of TQM Strategy

Total Quality Management (TQM) is essential for organisations across all sectors. According to Bergman and Klefsjö [13], TQM is described as "a holistic concept, where values, methodologies and tools are combined to attain higher customer satisfaction with less resource consumption" [13, p.37]. Essentially, TQM is a management philosophy focused on continuous improvement, where the goal is to enhance customer satisfaction, improve the quality of products and services, and maintain competitiveness in the market [13]. Within this framework, SPC serves as a critical tool for implementing the principles of TQM. By providing a structured, data-driven approach to monitoring and reducing process variation, SPC supports TQM's goals of continuous improvement, customer satisfaction, and cost efficiency.

TQM is built upon six fundamental cornerstones, all aimed at achieving or exceeding customer satisfaction while minimising costs. These cornerstones include customer focus, process orientation, committed leadership, employee involvement, continuous improvement, and fact-based decision-making (see Figure 2).

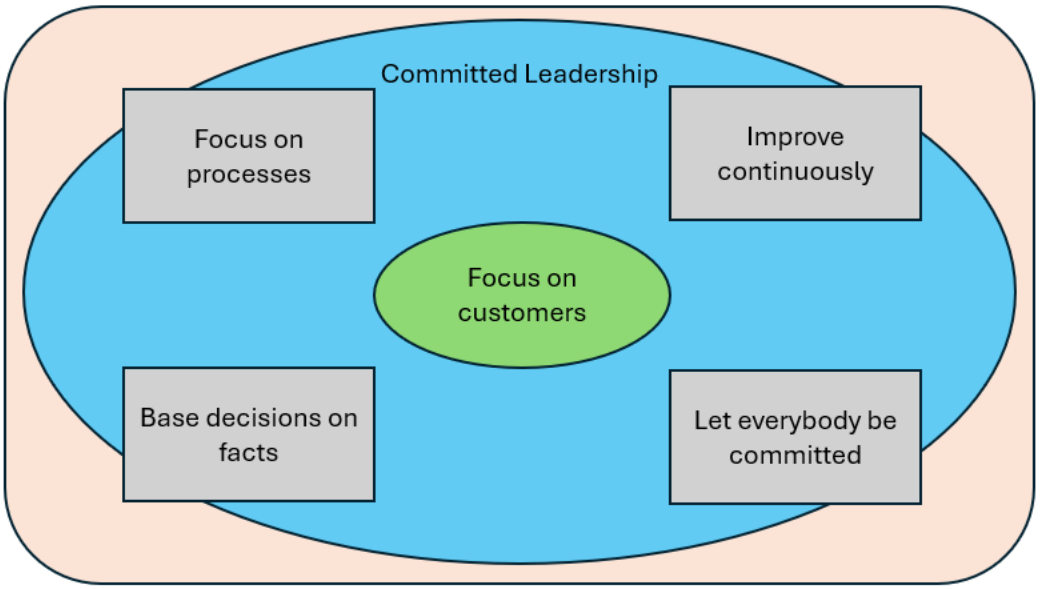

Figure 2: The six cornerstones of TQM.

Each cornerstone is briefly described below [13]:

- Focus on customers: Understanding and identifying customer needs and expectations are crucial when developing and manufacturing products or services.

- Base decisions on facts: Decisions should be made based on data and analysis rather than intuition or gut feelings, for example by the seven quality tools (described further in the report).
- Focus on processes: Optimising processes by using minimal resources while still achieving high customer satisfaction.
- Improve continuously: Constantly enhancing products and services to remain competitive and successful in the market.
- Let everybody be committed: Engaging employees in decision-making and improvement initiatives to ensure sustained quality enhancements.
- Committed leadership: Top management must actively promote a culture of continuous improvement and quality excellence. This cornerstone is particularly critical, as strong leadership is one of the key factors in ensuring a successful TQM implementation.

2.1.1 What is Quality?

One of the key cornerstones of TQM is focus on customers, which is closely tied to the definition of quality. The quality of a product is defined as "its ability to satisfy, or preferably exceed, the needs and expectations of the customers" [13, p. 23]. Quality is essentially about meeting or exceeding customer expectations by delivering products or services that fulfil their needs. Quality is not just about technical specifications but also about how well a product or service performs in real-world use. A high-quality product is reliable, durable, and free from defects, ensuring that customers can trust it over time. However, quality is also about perception, what one customer considers high quality might differ from another's expectations. Companies that prioritise quality focus on continuous improvement, making small but meaningful adjustments to enhance performance. This requires a deep understanding of customer needs, efficient processes, and strong leadership committed to maintaining standards. Quality is not a one-time achievement but an ongoing process that evolves with market demands and technological advancements. It extends beyond products to services, where factors like responsiveness, professionalism, and consistency play a key role. Organisations that embrace quality as a core principle gain a competitive edge, as satisfied customers are more likely to return and recommend their offerings. Ultimately, quality is about creating value, ensuring that what is delivered not only works well but also provides a positive experience for the user [13].

Quality Variation: Special and Common causes

Every production process has some natural variation, known as background noise (common cause), which is unavoidable and considered normal. When only this variation is present, the process is in statistical control. However, larger variations can occur due to machine issues, human errors, or poor materials. These are called assignable causes (special causes) and indicate problems that need to be addressed. When assignable causes are present, the process is out of control. The main goal of statistical process control is to quickly spot any issues

causing process shifts so they can be investigated and fixed before too many defective products are made [1].

2.1.2 What is a Process?

Focus on processes is also one of the key cornerstones of TQM. Understanding a company's processes is essential for identifying which activities add value for customers. The main objective is to continuously optimise workflows, reduce non-value-added activities, and maintain high customer satisfaction. A strong process focus is closely aligned with the principle of continuous improvement, ensuring that efficiency and quality are consistently enhanced over time [13].

A process as a series of interlinked activities that utilise resources to repeatedly transform inputs into outputs. The goal of this transformation is to create value for the customer. Processes are designed with a strong focus on customer needs, continuously refined for improvement, and managed effectively to ensure optimal performance and results [13]. Similarly, a process is described as a structured set of activities aimed at achieving a specific outcome by converting inputs into outputs. Processes are measurable, repeatable, and should be continuously improved to enhance efficiency, quality, and overall performance within an organisation [14]. Processes can be categorised into three types: main processes, which directly create value for customers; supporting processes, which assist main processes without directly adding customer value; and management processes, which focus on planning, control, and improvement. Additionally, processes can be grouped based on their complexity and details. Tasks combine to form activities, and activities form sub-processes, and sub-processes then constitute a process. This grouping helps with better communication and mapping [15].

The figure below provides a simple illustration of a process. Here, the input consists of tree logs, the process involves various activities that transform the logs into the desired output (notebooks).

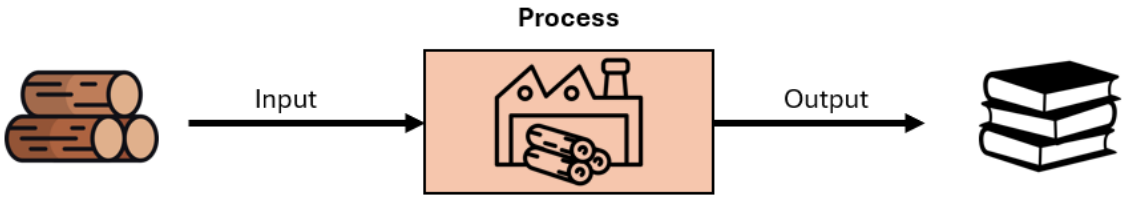

Figure 3: Illustration of simple process.

Process Mapping

Process mapping is a structured approach used to visually document and analyse workflows within an organisation. It provides a clear representation of how tasks, activities, and decisions flow within a process, making it easier to identify inefficiencies, redundancies, and

opportunities for improvement. By breaking down a process into its individual components, organisations can enhance efficiency, quality, and overall performance [16].
At its core, process mapping serves several key purposes. By visualising how a process works, employees gain a clearer understanding of their roles and responsibilities, which enhances overall clarity. It also helps identify bottlenecks by highlighting inefficiencies or delays that may hinder productivity. Additionally, process mapping plays a crucial role in standardising workflows, allowing organisations to establish consistent procedures and reduce variability in outputs. Furthermore, it supports continuous improvement, serving as a foundational tool in methodologies like Lean, Six Sigma, and TQM [14].

There are several types of process maps, each designed for a specific purpose. Flowcharts are the most common, using standardised symbols to represent each step in a process [16]. Swimlane diagrams illustrate interactions between different departments or roles, making it easier to understand cross-functional workflows [17]. Value stream maps, often used in Lean methodology, help visualise the flow of materials and information throughout a process [14]. SIPOC provide a high-level overview by identifying key elements such as suppliers, inputs, processes, outputs, and customers [18,19]. While each of these mapping techniques offers valuable insights, this study will focus specifically on flowcharts.

Developing a process map involves several key steps to ensure clarity and effectiveness. The first step is to define the process by clearly stating its objectives and scope. Once the purpose is established, the next step is to identify key activities by breaking down the process into tasks and decision points [14,16]. After identifying these activities, they must be arranged in a logical sequence to ensure a smooth workflow. It is also important to determine the inputs and outputs of each step, as this helps in understanding what goes into the process and what results come out of it. Once the structure is clear, a diagramming tool can be used to visualise the process in a clear and organised manner. Finally, the process should be analysed for inefficiencies, and improvements should be recommended to enhance performance [17,19].

2.2 Statistical Process Control

Basing decisions on facts is a fundamental cornerstone of TQM. Making decisions based on data and objective evidence is essential for improving quality, minimising defects, and reducing waste. Relying on accurate and reliable information, rather than intuition or gut feeling, enables companies to identify meaningful insights that drive continuous improvement initiatives. This approach typically involves data collection, analysis, and interpretation [13].

One of the key methodologies supporting fact-based decision-making in TQM is Statistical Quality Control (SQC), which provides structured approaches to monitor, regulate, and enhance process performance. SQC comprises three primary methods: Statistical Process Control (SPC), acceptance sampling, and the design of experiments. While acceptance sampling helps assess product quality by inspecting a subset of items from a production batch and design of experiments refines processes by identifying and optimising critical control factors, SPC is a proactive approach focused on maintaining process stability through

continuous monitoring of key variables. SPC stands out as a powerful tool for achieving process stability and ensuring manufacturing consistency [20].

SPC is built on strong principles, is straightforward to implement, and applies across different manufacturing processes. It is important to note that SPC is not just a set of technical methods, it fosters a culture of continuous improvement, especially when management actively participates. At its core, SPC relies on seven essential tools: histograms, check sheets, pareto charts, cause-and-effect diagrams, defect concentration diagrams, scatter diagrams, and control charts [1]. A more detailed explanation of the tools is represented in Table 1.

Table 1: Description of seven core SPC tools.

Tools	Description
Histograms	Histograms are graphical representations of data distribution, showing how often each range of values occurs in a dataset. They help identify the spread and central tendency of data, making it easier to detect patterns or irregularities.
Check sheets	Check sheets are simple, structured forms used for data collection. They are particularly helpful for tracking the frequency of specific events or defects. This tool helps identify common problems or trends over time, often serving as the first step in more detailed analysis.
Pareto charts	Pareto charts are bar charts that display the frequency or impact of problems, ordered from most frequent to least frequent. Based on the 80/20 rule, Pareto charts help prioritise which issues to address first, focusing on the most significant problems.
Cause-and-effect diagrams	A cause-and-effect diagram, also known as a fishbone diagram, is a tool used to identify the potential causes of a problem. When an issue or defect is found in a process, this diagram helps break down and organise the possible reasons behind it. The diagram visually maps out different categories of causes, such as people, equipment, methods, or materials, and connects them to the central problem. By using this tool, teams can systematically explore all the factors that might contribute to the issue, even when the causes aren't immediately obvious. This helps in finding the root causes and addressing them effectively. The cause-and-effect diagram is often used in conjunction with Root Cause Analysis (RCA), particularly the "5 Whys" method. This approach involves repeatedly asking “Why?”, typically five times, to drill down to the fundamental cause of a problem [21]. However, while the five-question approach is a commonly accepted guideline, in practice, the number of iterations may vary depending on how quickly the root cause is identified, it may take fewer or more than five times [22].
Defect concentration diagrams	Defect concentration diagrams help visualise where defects are most concentrated within a process. By mapping defects, organisations can focus on areas that need the most attention, thus improving overall quality.
Scatter diagrams	Scatter diagrams display the relationship between two variables. By plotting data points on a graph, scatter diagrams help identify correlations.
Control charts	Control charts are the most advanced SPC tool. They are used to monitor a process over time and detect variations that are either common or special causes. By analysing control charts, organisations can take immediate action when processes go out of control, ensuring consistent quality and stability in production.

2.2.1 Histograms

Histograms are graphical representations of data distribution, showing how often each range of values occurs in a dataset. They help identify the spread and central tendency of data, making it easier to detect patterns or irregularities. Histograms show data distribution, variation, and patterns. They help spot skewness, gaps, and outliers. Additionally, histograms are key in quality control for understanding process behaviour, thus very instrumental in data-driven decision-making [1,21].

The data is presented using a histogram, where the range of values is divided into intervals known as bins. These bins are used to visualise the distribution of the data, as shown in figure 4. It is generally recommended to use between 5 and 20 bins to ensure a meaningful representation. Using too few or too many bins can result in a histogram that fails to reveal useful or informative patterns. A common rule of thumb is to use the square root of the total number of observations to determine the number of bins, which often works well in practice, as noted by Montgomery [1]. In a histogram, the horizontal axis represents the observed values grouped into bin ranges, while the vertical axis shows the frequency, how many observations fall within each bin [1].

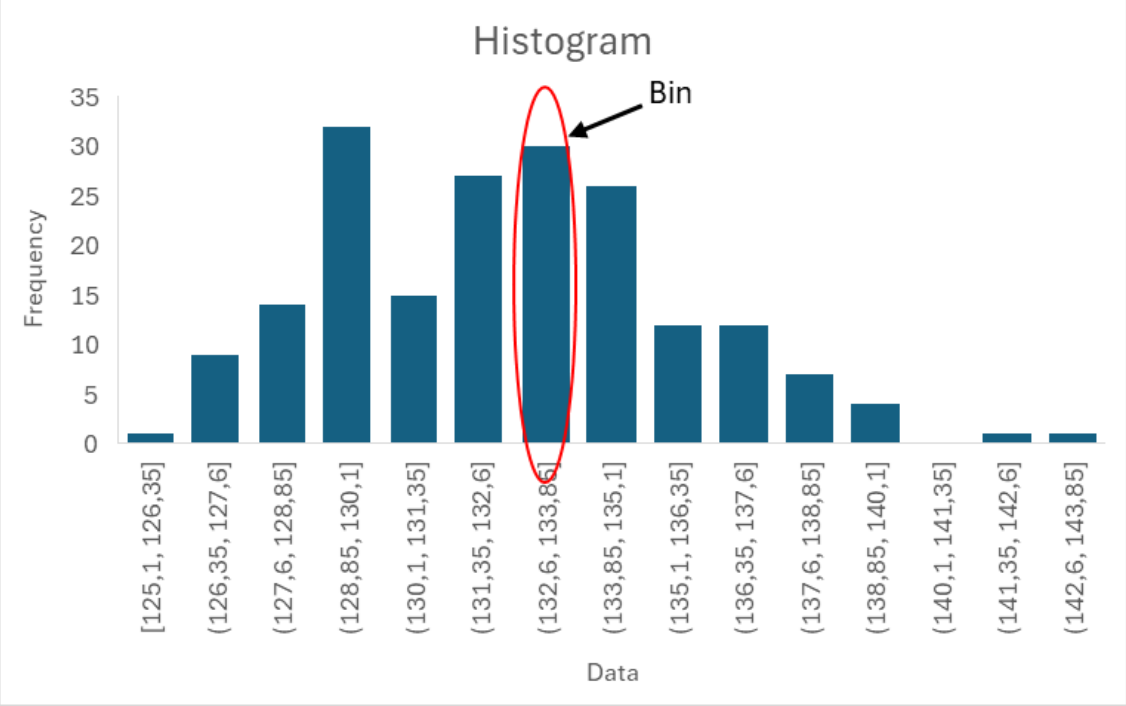

Figure 4: Illustration of a histogram

2.2.2 Control Charts

One of the most important tools in SPC is the Shewhart control chart, developed in the 1920s by Walter A. Shewhart at Bell Telephone Laboratories. This chart is grounded in fundamental statistical concepts and remains a cornerstone of process monitoring [1]. SPC charts are an advanced type of time series plot that help in analysing process stability and identifying the nature of variation present in a system [21].

Control charts are essential tools for monitoring process behaviour. They help identify patterns, trends, and shifts in a process, allowing corrective actions to be taken before issues such as defects occur (see Figure 5) [21]. In any process, some level of variation is inevitable. The primary purpose of control charts is to monitor and manage this variation, ensuring that it remains within acceptable limits. By detecting abnormalities early, organisations can implement corrective measures to maintain process stability and improve overall quality [1].

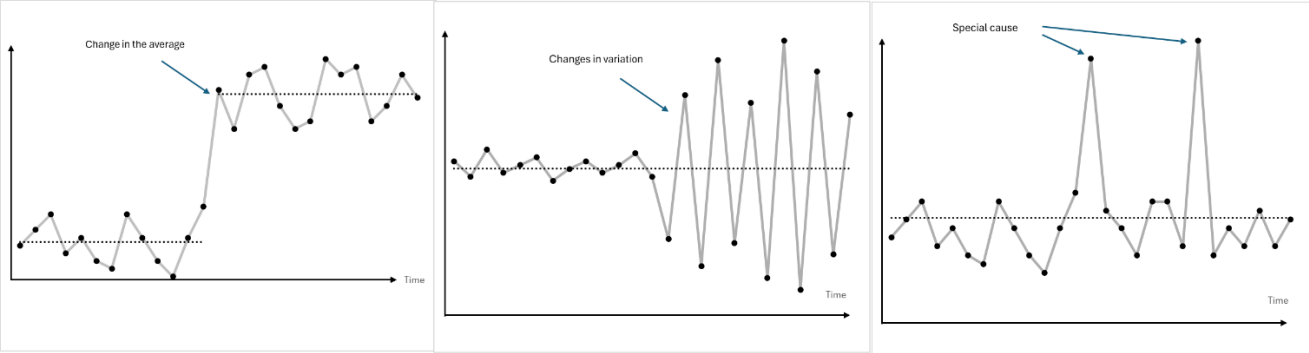

Figure 5: Illustration of three different changes in a process.

To explain control charts, an illustration is provided in Figure 6. This example follows a cookie production process in a company where monitoring the diameter of the cookies is a critical quality parameter. As shown in the Figure 6, the diameter of a cookie is measured at regular intervals, every four minutes, and plotted on the control chart. The chart visually represents the changes in diameter over time, forming a chronological time series. The standard deviation (sigma values) represents the natural variation within the process and helps in defining control limits. The figure shows instances of special cause variation, indicating the need to investigate the root causes behind them. The remaining points represent common cause variation, which are natural in a process.

According to Bergman and Klefsjö [13], control charts are constructed with control limits set at three times the standard deviation (±3σ) from the process mean. These limits are widely used and commonly used in industries. These are known as the Upper Control Limit (UCL) and Lower Control Limit (LCL). These control limits represent the "voice of the process (VOP)", meaning they are derived from the actual process behaviour. In contrast, tolerance limits represent the "voice of the customer (VOC)", as they define the acceptable range of variation based on customer requirements. To establish control limits, specific formulas are used depending on the type of control chart being constructed, the sample size, etc. These formulas serve as a starting point for calculating UCL, LCL, and the Centre Line (CL). For a

more detailed explanation of these calculations, the authors refer to Montgomery [1] as well as Bergman and Klefsjö [13].

Figure 6 illustrates the presence of both common cause and special cause variations. Common cause variation is the natural fluctuation inherent in the process, while special cause variation indicates an unexpected shift or disturbance that needs investigation [1]. The main goal of a control chart in SPC is to monitor and control these variations, ensuring the process remains stable and within acceptable limits. A stable process means that the values remain within the control limits with no unusual patterns or trends [13]. By continuously tracking this data, the company can quickly detect deviations and implement corrective actions, ensuring consistent product quality and minimising defects.

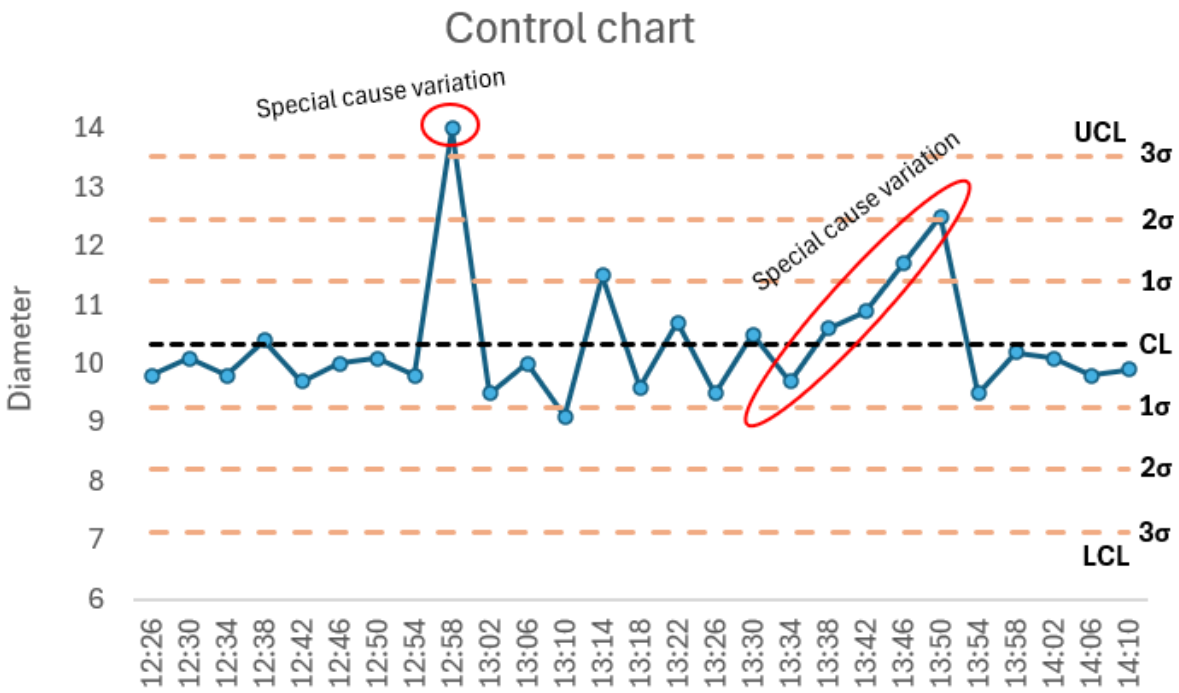

Figure 6: Illustration of cookies diameter variations.

Corrective actions in a process are determined by how variations behave over time. Typically, special cause variations follow a set of predefined rules, known as the Western Electric Rules. When these rules are violated, corrective actions must be taken to address the underlying issue. According to Bergman and Klefsjö [13], the most common signals indicating special cause variations include:

- Rule 1: A single point falls outside the 3-sigma control limits.
- Rule 2: Two out of three consecutive points fall outside the 2-sigma limits on the same side of the centreline but remain within the control limits.
- Rule 3: Four out of five consecutive points fall on the same side of the centreline outside the 1-sigma limit.
- Rule 4: Eight consecutive points lie on the same side of the centreline.

Bergman and Klefsjö [13] also highlight that additional Western Electric Rules exist beyond those listed above. However, applying too many rules increases the risk of false alarms, leading to unnecessary corrective actions.

Different types of Control Charts

The choice of control chart depends largely on the type of quality parameter being monitored. The first step is to determine whether the data is variable (numerical measurements like weight or volume) or attribute-based (such as number of defects). Sample size and how frequently samples are collected also influence the selection of the appropriate chart [1]. Since this study focuses on fat content, which is a numerical measurement, only control charts for variable data are described.

Table 2 provides an overview of the different types of control charts for variable data, along with a brief description of each. For more detailed information, the authors refer to Montgomery's book [1].

Table 2: Control charts for variable data.

Control charts	Description
I-chart & MR-chart	The Individual chart (I-chart) is useful when the sample size is 1, meaning that a single measurement is taken at each point in time. It is often paired with the Moving Range Chart (MR-chart), which tracks the range between consecutive observations (i.e., the difference between the current value and the previous value). However, Montgomery [1] notes that some experts advise against using the MR-Chart, as it does not always provide meaningful insights into shifts in the process. If an MR-Chart is used, it should be interpreted with caution to avoid misleading conclusions.
X-bar & R-chart	The $\bar{X}$ (X-bar) and R chart, where $\bar{X}$ represents the sample mean and R stands for the range is typically used when the sample size is between 2 and 9. The $\bar{X}$ chart tracks the average value of the process, while the R chart monitors the range within each sample [1].
X-bar & S-chart	The $\bar{X}$ and S chart, where S stands for standard deviation is used when the sample size is 10 or more, or when the sample size varies from one subgroup to another. Like the previous chart, $\bar{X}$ monitors the process mean, while the S chart tracks the standard deviation to measure variability more accurately, especially for larger samples [1].
CUSUM	Cumulative Sum Control Charts (CUSUM) are advanced tools used in SPC to detect small shifts or gradual trends in process data. Unlike traditional control charts, CUSUM charts accumulate deviations from the target over time, making them highly sensitive to even minor changes in the process [1].
EWMA	Exponentially Weighted Moving Average (EWMA) charts are also charts are advanced tools in SPC and are used when detects small shifts or trends in the data, serves as the same purpose of CUSUM [1].

Constructing the control charts relies on that the data gathered firstly is normal distributed. We refer to [1] for more information about normal distribution. The reason behind the normal distribution is to ensure that the constructed control limits are reliable and trustworthy. In case of data that are not normal distribution, there is other actions that can be considered, such as

transforming the data to become normal distributed, this is usually more advanced and will not be described further [21].

2.3 Previous Studies on SPC in Food Industry

Although SPC has proven highly effective in manufacturing industries, its adaptation in the food industry is relatively low. A notable indication of this was observed in a research paper by Dora et al. [23], which presented a quantitative survey involving 35 food companies that examined various quality control methods. The results revealed that 25 companies relied on visual inspection, 8 used acceptance sampling, and only 5 companies implemented SPC as a quality control method.

The slower adoption of SPC in the food industry can be attributed to several key challenges. One major challenge is the variability of raw materials, which is influenced by uncontrollable factors such as weather conditions, seasonal changes, and potential pest infestations. These environmental factors directly impact the composition of food ingredients such as milk, fruits, and grains leading to natural fluctuations in their properties [24].

In addition to material variability, other barriers include a lack of top management commitment, resistance to change, insufficient knowledge, a shortage of practical implementation guidelines, and limited industry experience with SPC. These factors have collectively contributed to the slower adoption of SPC in the food industry [2].

Despite these challenges, in recent years, the application of SPC in the food industry, has gained increasing attention. A study by Lim et al. [25], indicated that the increasing attention toward the application of SPC in the food industry, can be attributed to the growing globalisation of the industry and the resultant competitive pressures. Even though SPC is not a mandatory requirement, as companies strive to maintain market share, SPC has emerged as a strategic tool for ensuring product consistency, meeting stringent international quality standards, and facilitating market expansion. The study also found that companies using SPC performed better operationally than those that didn’t. They experienced lower waste, fewer defects, and reduced rework, giving them a clear advantage in efficiency and overall process control.

Minimal efforts, however, have been made to integrate these techniques effectively. Some case studies have demonstrated the potential and effectiveness of SPC in food and dairy processing. A 2014 study conducted in southern Minas Gerais, Brazil examined the implementation of SPC in the filling process of 200g butter pots. The study aimed to assess whether the products met specification limits and legislative requirements. The findings revealed that the company was unintentionally overfilling, sending more than 4.47% of output per batch as extra to customers [26].

One research conducted in Serbia in 2015 investigated the use of multivariate SPC for two cheese variants, focusing on critical quality parameters such as pH, fat content, and protein

content. The study concluded that there were marked variations in most of the parameters [27].
Another study also conducted in Serbia in 2014, analysed the application of SPC in food packaging processes across five dairy producers and two confectionery manufacturers. The research assessed how effectively these processes complied with regulatory standards. As a result, the study showed that some companies have overfilling in the packaging compared to underfilling packaging [28].

Despite these examples the food industry's integration of SPC remains limited, highlighting the need for greater awareness, investment, and practical implementation to enhance process efficiency and quality assurance. As SPC continues to demonstrate its effectiveness in ensuring consistency and compliance, its adoption within the food and dairy sectors could play a crucial role in improving overall product quality and operational efficiency.

2.4 Quality Function Deployment

Quality Function Deployment (QFD) was developed in the late 1960s by Yoji Akao and Shigeru Mizuno in Japan. QFD can be defined as “a system for translating customer requirements into appropriate company requirements at each stage from research and product development to engineering and manufacturing to marketing, sales and distribution” [13, p.124]. Essentially, QFD is a systematic product development process designed to ensure customer satisfaction by translating customer needs and requirements into specific product characteristics [13].

One of the most widely used tools in QFD is the House of Quality. This tool consists of several key elements, such as customer needs and importance, product characteristics, a relationship matrix, a correlation matrix, and a competitive assessment (see Figure 7).

- Customer needs and importance (often referred to as the “Whats”) represent customer expectations and requirements, ranked based on their level of importance.
- Product characteristics (often referred to as the “Hows”) define the technical features and attributes needed to meet customer expectations.
- Relationship matrix illustrates the connection between product characteristics and customer needs, showing how well each product feature addresses specific customer requirements.
- Correlation matrix evaluates how different product characteristics interact with one another, identifying whether they support or conflict with each other.
- Competitive assessment compares how well the designed product meets customer needs relative to competitors, helping identify areas of competitive advantage or improvement.

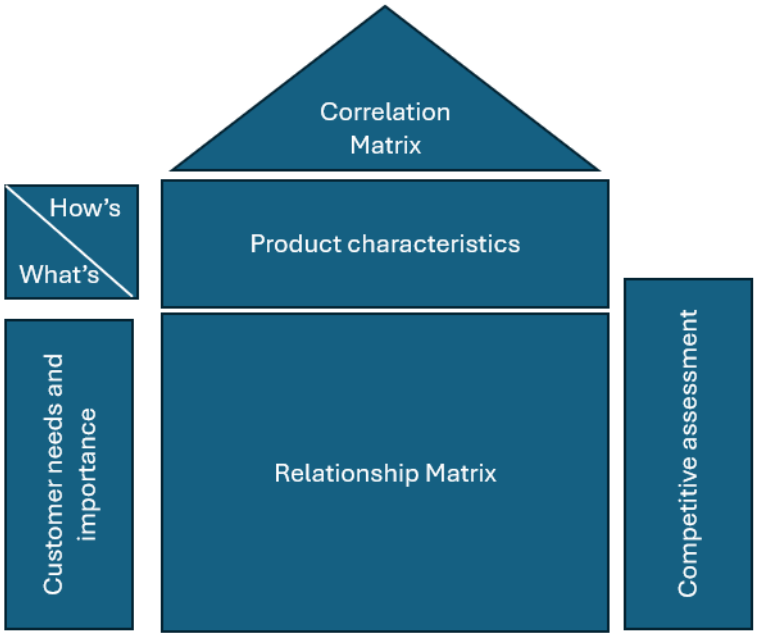

Figure 7: The House of Quality illustration.

By using the House of Quality, companies can systematically align their product development efforts with customer expectations, ultimately improving product quality and market success [13]. In this study, the principles of QFD, particularly the structure of the house of quality - were adapted to support process prioritisation in relation to research question 1, which seeks to identify the process step(s) in dairy production most suitable for SPC integration. Specifically, the relationship matrix concept from QFD was reinterpreted in the form of a prioritisation matrix, where production process steps were assessed against a set of predefined criteria. This adaptation enabled a systematic, data-driven comparison helping ensure that the selected process steps are those most likely to impact fat content consistency and, by extension, customer satisfaction.

2.5 Measurement System Analysis

Measurement System Analysis (MSA) ensures that a measurement system is reliable by assessing both its accuracy and precision. Accuracy is determined by evaluating bias, linearity, and stability, which indicate how close measurements are to the true value. Precision, however, is the focus of a gauge repeatability and reproducibility (Gauge R&R) study, which examines variability within the measurement system. Repeatability assesses variation when the same operator measures the same part multiple times, while reproducibility evaluates variation when different operators measure the same part. Resolution, another key factor, refers to the smallest detectable change a measurement system can identify. If resolution is too low, small variations in the process may go unnoticed, impacting data reliability [1]. In the study, the MSA played a key role in evaluating the data provided by the case company, specifically in determining whether the variation originated from the process itself or from the measurement system.

3. Method

With the theoretical background presented, this chapter describes the research strategy - the blueprint for carrying out the study to ensure that each step is organised and aligned with the study's objectives. The methods employed by the authors in collecting and analysing data relevant to this study are equally described.

3.1 Case Study

The case study method is preferred when research aims to explore phenomena within their real-life context, especially in situations where the boundaries between the phenomenon and its context are not clearly defined. Yin [29] argues that case studies are particularly valuable when the researcher seeks to answer 'how' and 'why' questions, as these types of inquiries require an in-depth understanding of the subject matter rather than just statistical correlations. Unlike experiments, which manipulate variables in controlled settings, or surveys, which often provide broad but superficial insights, case studies allow researchers to examine contemporary events in detail, incorporating multiple sources of evidence such as interviews, observations, and documents. Case studies can contribute to the development of best practices [29].

Since this study explores the integration of SPC in dairy production, an area where SPC adoption has been relatively slow as observed in the literature, it employs an exploratory case study. This is particularly suitable as it allows for a deep investigation into how SPC can be effectively implemented in dairy operations, considering industry-specific challenges and nuances.

3.2 Overall Research Design

The study follows a structured research approach developed by the authors to effectively address the research questions. This approach is illustrated in figure 8. Four key components are captured: a literature study, current state visualisation, process prioritisation, and lastly, the development of a roadmap for SPC integration.

For RQ1, the first three steps, literature study, current state visualisation, and process prioritisation were essential, while for RQ2, the focus was primarily on the synthesis of multiple literature leading to the development of a customised SPC integration roadmap for dairy production.

The current state visualisation includes three main steps: data collection, data analysis, and measurement system analysis. Process prioritisation was conducted using a prioritisation matrix. Each step of this research design will be described in detail in the following sections.

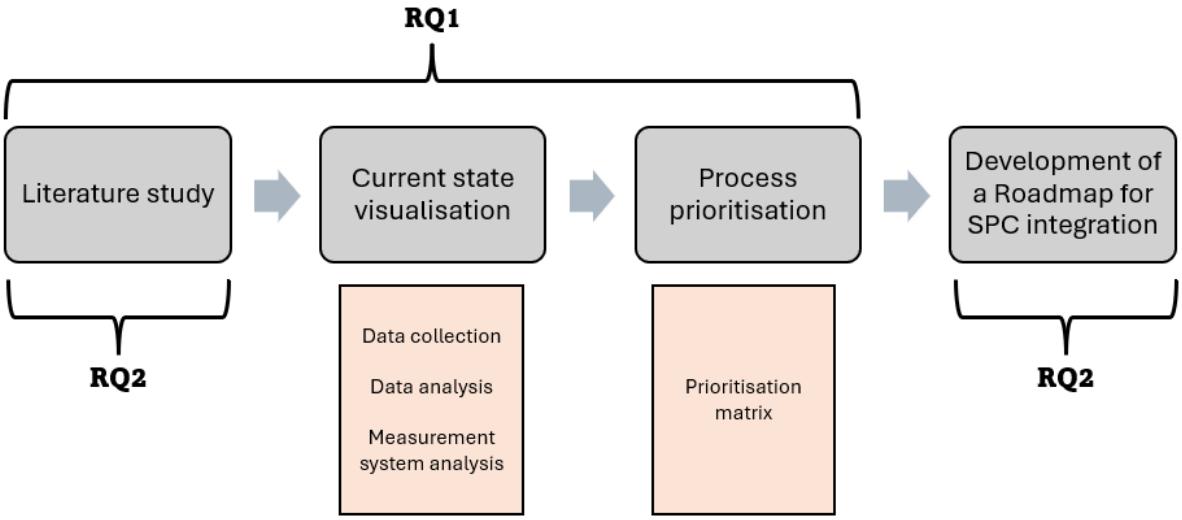

Figure 8: Overall research design developed by the authors.

3.2.1 Literature Study

A literature study involves gathering data produced by other researchers, such as existing studies, theories, and scholarly work on a specific topic. It is a crucial method for gaining insights, expanding knowledge, and deepening the understanding of a research subject. By analysing previous research, a literature study helps identify gaps in existing knowledge, highlight trends, and lay the foundation for new findings in the field [30].

The literature study was a crucial part of this thesis, aimed at identifying relevant theories and research on the topic. As mentioned earlier, the application of SPC in the dairy industry is still an emerging research area, unlike its well-established use in manufacturing. Given this, it was necessary to explore the available literature to gain a deeper understanding and find studies related to this thesis.

The literature study was conducted using two main databases: Unisearch and Google Scholar. These served as the primary tools for identifying relevant research. The literature study was based solely on full-text availability articles. The keywords listed below were used in the search.

- Statistical Process Control (SPC)
- Dairy
- Framework
- Roadmap
- Food Industry
- Implementation
- Integration
- Fat content

These keywords were combined using “AND” or “OR” to generate the most relevant literature possible. Since the RQ’s address different aspects of the study, the search strategy

was adapted accordingly. For instance, for RQ1, terms such as "framework" and "roadmap" were excluded.

Regarding RQ1, none of the reviewed articles specifically addressed where SPC can be implemented within a production setting in dairy operation as outlined in this thesis. However, for RQ2, some relevant studies were found discussing roadmaps for SPC integration in food industry. Despite these findings, it can be concluded that research on SPC integration in the dairy industry is still limited compared to its application in traditional manufacturing. This remains an evolving research area with ongoing studies.

3.2.2 Current State Visualisation

The current state visualisation includes several key steps, which are outlined in this section: data collection, data analysis, and measurement system analysis.

Data Collection

Data collection is a fundamental tool in conducting research. “By definition, data collection is defined as the process of gathering, evaluating and analysing precise understandings for research using typical authenticated methods.” [31, p.6]. Data collection plays a crucial role in ensuring that research findings are accurate, reliable, and meaningful. It is the backbone of any research process, regardless of the field, as it determines the quality and credibility of the results.

The approach to data collection may vary based on the area of study, the nature of the research, and the type of information required. There are various methods for collecting data, such as interviews, observations, database research, and reviewing existing literature, among others. Each method serves a unique purpose and is chosen based on the research objectives, the nature of the study, and the type of data required [31].

Data collection was crucial to enable a comprehensive data analysis to understand the current state of the case company with respect to SPC and to gain knowledge about the critical quality parameter - fat content - to monitor and control. Primary data were collected by the authors through interviews with a manager, engineer and an operator. The authors also had access to secondary data - data already collated and stored. This data had already been compiled in different databases and could be exported for statistical analysis to be conducted. The researchers were given access to data related to the fat content of all the products made at the case company.

Process Mapping – Understanding the current process

Process mapping is a structured method used to visually capture and analyse workflows through a process. It offers a clear overview of tasks, activities, and decision points, helping to pinpoint inefficiencies, overlaps, and areas for improvement [16]. In the context of this study,

process mapping played a key role in understanding and visualising the production flow, supporting the identification of where SPC could be most effectively applied in relation to the RQ1.

This step was taken to visualise the production process from the raw material intake to storage of finished goods set to be delivered to the customers. Understanding the current process at Arla Foods is essential for evaluating where SPC should be integrated. Process mapping is conducted to identify the steps involved from raw milk to final dairy product. This mapping was endorsed by the supervisor at the dairy, who also provided flowcharts detailing their production process. It is important to note that this supervisor - the operations engineering specialist - is conversant with the entire production process at the dairy, from raw material intake to the final product, and a key participant in all root cause investigations of incidents of quality problems at the dairy. Production process maps were created digitally on *draw.io.* These maps are presented in the *4.1.2 Process Mapping*. This process mapping provided valuable insights into the production process steps at the dairy, which will play a key role in the prioritisation process for identifying the most suitable process step(s) for SPC integration.

Interviews – Understanding fat content as a quality parameter and the current process

Interviews are a key qualitative study approach used to gather in-depth insights from participants. They can be structured, semi-structured, or unstructured. Structured interviews follow a fixed set of questions, ensuring consistency across responses. Semi-structured interviews use a guide but allow flexibility for further exploration. Unstructured interviews are open-ended, allowing free-flowing discussions. The choice depends on the study's objectives, with semi-structured interviews being common for balancing depth and consistency. Interviews help capture experiences, perceptions, and challenges directly from participants, making them valuable for case studies [29,32].

For this thesis, unstructured interviews were conducted to gain insights into two key areas: the importance of the fat content quality parameter in dairy products and an in-depth understanding of Arla's production process from raw materials to finished goods storage (FGS).

Interviews were held with various stakeholders at Arla Foods, with an operator, manager, and engineer, to explore why fat content (percentage) is a critical quality parameter for the company. The goal was to assess its significance in dairy operations and how it impacts product quality. Additionally, unstructured interviews were used to map out the production process, as this was essential for identifying potential areas for SPC integration. Understanding the different steps in production was crucial for determining where SPC could be applied effectively (connected to RQ1).

The unstructured approach was chosen to allow open discussions, ensuring a more comprehensive understanding of both the quality parameter and the production workflow. Table 3 provides an overview of the stakeholders involved in the interview process, including

their respective roles, the date of the interview, and the topics discussed. Due to confidentiality, the names of the interviewees are not disclosed.

During the interviews, field notes were taken by the authors to capture the insights shared by the stakeholders. Recordings and transcriptions were not used, as the primary aim of the interviews was to gain insight into the quality parameter - fat content, as well as to understand the various process steps involved in the production process, while also creating a more relaxed environment that encouraged employees to speak openly and comfortably.

Table 3: Interview guide overview.

Date	Role	Subject discussed
14/01/2025	Production Manager	Project scope, fat content
14/01/2025	Operations Engineer Specialist	Project scope, fat content
20/01/2025	Operations Engineer Specialist	Process mapping
21/01/2025	Operations Engineer Specialist	Process mapping
22/01/2025	Operations Engineer Specialist	Process mapping
23/01/2025	Operations Engineer Specialist	Process mapping
28/01/2025	Operator	Process mapping, fat content

Data Extraction from Database

To enable statistical analysis, data extraction from a database was necessary to apply various analytical methods and derive meaningful interpretations and results. This process involved exporting data from Arla's enterprise resource planning (ERP) system into an Excel format for further analysis. For this thesis, Excel and Minitab software was used for data analysis.

At Arla, data collection follows a structured process. Operators manually enter data into a data entry system, which is then stored within the ERP system. This stored data can later be exported into different file formats, such as Excel, for further examination and analysis. The exported data, as illustrated in Table 4, includes several key elements. First, the quality parameter being analysed is identified. Next, the specific product (various dairy product names) is recorded, followed by the dates when the results were captured. Lastly, the dataset includes the measured result values. Since, the data had already been collated and stored by the company, there was no need for extensive new data collection.

The duration of the data received spanned between from 2024-01-01 to 2025-02-06, and the various statistical analyses were conducted based on this dataset.

Table 4: Data extraction from database overview.

Quality Parameter	Product	Result Date	Result values

The company provided historical data on fat content values from two production process steps: **standardisation** and **hydrolysis,** for more information about these process steps, see

4.1.2 Process Mapping. At present, the fat contents of dairy products produced at the case company are measured at two stages in the production process, the standardisation and hydrolysis steps. The dairy products are still semi-finished at these two process steps. For certain dairy products, the fat content is measured at the standardisation step, and for others, at the hydrolysis step. In addition to these earlier mentioned process steps, the fat content is also measured after all the process steps are completed and the dairy products are ready for storage in the finished goods cold storage. The sample collection typically involves an operator getting up onto the silo and scooping out a small portion of the product into a smaller container (just one container of approximately 10cl) to be taken to the laboratory for the fat measurements. This essentially represents a sample size of one for each production batch.

Data Analysis - Fat content measurements from database

The data analysis essentially involved statistical investigation on the quality parameter - fat content, analysing historical data related to fat content measurements, spanning approximately one year (from 2024 until 2025). Different statistical analysis was used, such as descriptive statistics, individual value plot and histograms to visualise and quantify the current level of fat giveaway associated with each product at the dairy. The primary reason for using these tools was for ease of visualisation of the current state with respect to fat giveaway. Minitab and Excel were utilised for descriptive statistics, individual value plots and histograms.

Descriptive Statistics

Descriptive statistics summarise and organise data to make it easier to understand. Key components include measures of central tendency (mean, median, mode) and measures of variability (range, variance, standard deviation). These statistics help provide a clear summary of data characteristics, such as the distribution, spread, and central values [21].

Descriptive statistics played a crucial role in visualising the current state of fat content across different dairy products. Key statistical measures such as total count, mean, standard deviation (StDev), maximum, and minimum (range) values provided valuable insights into the variation and consistency of fat content in each product.

Individual Value Plots

Individual value plots are graphical representations that display each data point within a dataset on an X-Y axis graph. The purpose of these plots is to visualise individual data points, making it easier to identify patterns, detect deviations, spot outliers, and draw meaningful conclusions [21].

The individual value plots were essential for the data analysis, providing a clear visualisation of each dairy product's fat content distribution. This enabled a deeper understanding of the variation within different products and helped identify which dairy products consistently

exhibited higher fat giveaway in relation to the target value. By analysing these plots, valuable insights were gained regarding the process performance.

Histograms

The description of histograms can be found in *2.2.1 Histograms.* In this study, histograms were employed to visualise the distribution of fat content in each dairy product, along with the insertion of tolerance limits: the Lower Tolerance Limit (LTL) and the Upper Tolerance Limit (UTL). This approach enabled a clear assessment of how well each dairy product met customer requirements, referred to voice of the customer (VOC). By analysing the histograms alongside the tolerance limits, valuable insights were gained regarding the process capability and how consistently each product adhered to specifications. Additionally, this visualisation helped identify potential defects, such as instances where fat content exceeded or fell below the defined tolerance range.

Measurement System Analysis

As mentioned in the *Chapter 2 Theoretical Background*, a process consists of two types of variation. Variation from the process itself and variation from the measurement system. For this thesis, the MSA was performed to ensure that the data provided (data extracted from database) by the company was consistent and reliable. This analysis was crucial for verifying that the observed variation was primarily due to the process rather than inaccuracies in the measurement system.

Data collection method - MSA

Data collection for the MSA was conducted on 7th April, 2025. The case company operates two fat measurement machines located at different production sites, and both were included in the analysis. For Machine A, a total of 8 samples were collected, and for Machine B, 10 samples were taken at various intervals and measured using the respective machines. Since the product was not lactose-free, each sample pair was drawn from the standardisation tank for the specific product base, with a 3-5minute interval between samples. Due to confidentiality agreements, the name of the product base is not disclosed. Each sample was measured twice (two replicates) on both machines, and the fat content values were recorded accordingly.

Data analysis method - MSA

The MSA analysis was conducted using Minitab software. A paired t-test was performed for both Machine A and Machine B to evaluate the measurement system. The reason for using the paired t-test was to assess whether there were significant differences between replicated measurements taken under the same conditions. By comparing repeated samples, the analysis aimed to evaluate the consistency and repeatability of the measurement system.

3.2.3 Process Prioritisation

Process prioritisation in the study involved an unbiased and objective approach to identifying the most suitable production process step(s) for integrating SPC to effectively monitor and control the fat content of dairy products.

Prioritisation Matrix

A prioritisation matrix is a structured tool that systematically compares different alternatives based on multiple criteria, making it highly relevant for objective decision-making. By systematically comparing different process steps against carefully decided criteria, it ensures that decisions are data-driven rather than based on intuition [21].

The prioritisation matrix serves as an important decision-making tool, helping to determine which process step(s) that should be prioritised for SPC integration by assessing each step against selected criteria. This minimises the risk of focusing on "non-essential" process steps and ensures that resources are directed where they are most needed. The insights gathered from the process through process mapping were helpful in this prioritisation matrix.

The prioritisation matrix deployed for this study was inspired by the house of quality – a QFD tool. The relationship matrix in the QFD illustrates the connection between product characteristics and customer needs, showing how well each product feature addresses specific customer requirements. In this study, an adapted version of the relationship matrix was done where different production process steps were assessed based on predefined criteria. The prioritisation matrix was chosen for its structured approach, allowing objective comparison of multiple factors using predefined criteria. It offers a transparent method to identify the most impactful options, making it suitable for complex production evaluations.

A representation of the prioritisation matrix can be seen in figure 9. The prioritisation matrix followed a stepwise approach. Firstly, the evaluation criteria were generated and represented as columns on the matrix. The different process steps to be assessed against the criteria were then represented as rows on the matrix. Each criterion was evaluated for every production process step based on weighted scales, weak (1), medium (3), and high (9). More detailed explanation of how each criterion were evaluated for each process step and the scoring system are found in *4.2.1 Prioritisation Matrix*.

Evaluation Criteria / Process Steps	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Total Score
Process Step 1					
Process Step 2					
Process Step 3					
●					
●					
●					
●					
Process Step n					

▲ = Weak (1)
● = Medium (3)
◯ = High (9)

Figure 9: Prioritisation matrix overview

Generation of the Criteria

In the development of a prioritisation matrix, the generation of evaluation criteria is a critical step that ensures the decision-making process is both structured and objective. The authors generated evaluation criteria through stakeholder analysis - identifying key stakeholders and understanding their concerns.

Through interviews, the authors gathered insights into the most important factors to consider for SPC integration. This process ensured that the evaluation criteria accurately reflected stakeholder priorities, making the decision-making framework more relevant and comprehensive.

3.2.4 Roadmap for SPC Integration

Integrating SPC into operations requires a systematic and practical roadmap, especially in industries that are less mature in adopting such quality control techniques. Lim et al. [4] emphasise that one of the main barriers to SPC implementation in the food industry is the absence of clear, applicable guidelines on how SPC should be integrated into operational processes. Their study also points to a general shortcoming in current research, where the methodological aspects of SPC are often discussed, but little attention is paid to practical implementation strategies tailored for the food industry [4].

Further reinforcing this point, Lim et al. [25] in another study argue that the lack of structured and actionable guidelines presents a major challenge for companies attempting to implement SPC effectively in the food industry. Does et al. [33] support this by stating that the existing literature heavily focuses on either the statistical tools themselves or on organisational aspects of change management, while largely neglecting the practical implementation dimension. In a systematic review on SPC integration within the food industry, Lim et al. [2] identify one of the key barriers as the absence of practical manuals or frameworks specifically designed for

food manufacturers. They highlight the lack of concrete, step-by-step guidance tailored to real production environments, which results in uncertainty regarding how to begin and sustain SPC initiatives. The authors argue that this gap implies a broader need for well-structured, industry-specific implementation guidelines [2].

The authors also stress that each industry comes with its own structural and organisational challenges, which can complicate the adoption of one-size-fits-all SPC strategies. These circumstances highlight the urgent need for a tailored, systematic approach, ideally one grounded in real-world case studies. Such guidelines should outline not only the tools and techniques of SPC but also clarify who within the organisation should be responsible, where the process should start, when key steps should occur, and how the implementation should unfold in practice [2].

Development of the Conceptual Roadmap for SPC Integration

To address these gaps, a comprehensive literature study was conducted to identify and analyse key research on the integration of SPC. This review provided a solid theoretical foundation, which was then complemented by process-specific insights gathered through interviews from the case company. By combining these sources, relevant concepts were synthesised and used to develop a practical, structured roadmap tailored specifically to the needs of the dairy sector. The aim is to bridge the gap between theory and practice by offering the kind of systematic and hands-on guidance that existing literature has consistently highlighted as lacking. This work contributes to a more confident, effective, and industry-relevant adoption of SPC within dairy manufacturing settings. Figure 10 shows a conceptual diagram capturing the steps taken by the authors in developing the roadmap.

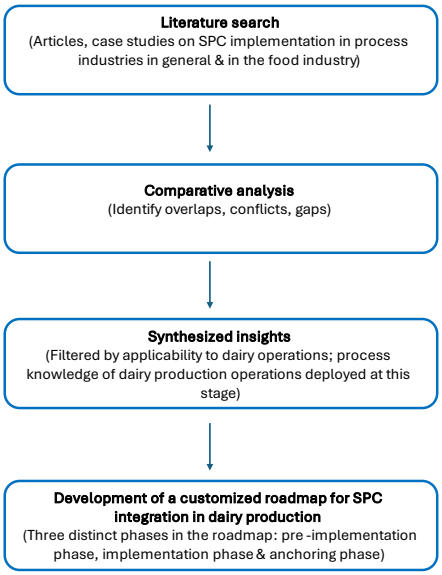

Figure 10: A conceptual diagram capturing the steps taken by the authors in developing the roadmap for SPC integration in dairy operations.

The first step was the literature search. The databases used by the authors for literature search were Unisearch and Google Scholar. Similar to the method presented in *3.2.1 Literature Study,* but with more focus on keywords like SPC, Dairy, Dairy Production, Framework, Roadmap, Food Industry, Implementation, Integration combined with "AND" or "OR".

The next step was the comparative analysis of the selected literatures. This analysis involved identifying concepts that re-appear in most of the literatures, concepts that were missing in one literature but captured in some others and some conflicting views in the various literatures. The purpose of this step was to distil the most relevant and consistent insights, understand and try to reconcile discrepancies, to ultimately ensure a comprehensive and balanced foundation for the development of a context-specific and practically applicable roadmap for integrating SPC into dairy production operations.

The third step, an output from the second step, involved the collection of the insights that were consistent across the various literatures and assessing their applicability to dairy operations. This assessment by the authors was enhanced with the help of the process knowledge acquired at the case company.

The last step involved the development of a stepwise roadmap for the integration of SPC in dairy operations. The roadmap features the steps needed in the pre-implementation, the implementation and the anchoring phases of the integration process.

3.3 Research Quality

Ensuring high research quality has been a central consideration throughout this study. Consistent with the principles of service action research, efforts were made to design a project that is both practically relevant and academically rigorous. The aim was not only to contribute to the existing body of knowledge but also to generate insights that could be meaningfully applied within the case company. To this end, quality criteria specific to action research were carefully considered, particularly those outlined by Elg et al. [34], dialogic validity, outcome validity, catalytic and democratic validity.

In terms of dialogic validity, emphasis was placed on fostering open dialogue and collaborative reflection throughout the research process. Interviews with stakeholders at Arla Foods provided rich insights and contributed to a shared understanding of challenges in production, particularly regarding fat content variation. The process mapping conducted as part of the current state visualisation was developed in close collaboration with case company personnel, ensuring that it accurately reflected real-world operations. Ongoing interaction and feedback loops helped ensure that the research remained grounded, iterative, and relevant to the practical context.

Outcome validity - which relates to whether a study results in practical improvements or actionable outcomes - was also addressed. The study produced a three-phase roadmap for SPC integration, tailored specifically to Arla's production environment. This roadmap offers

clear, structured steps for implementing SPC, and is adaptable to similar settings across the dairy industry. Moreover, the identification of the standardisation and hydrolysis stages as the most promising targets for SPC application provides Arla with a concrete, evidence-based foundation for operational improvement. These contributions reflect the study's capacity to drive meaningful change, thereby fulfilling the aims of outcome validity.

Catalytic validity - a criterion that refers to the extent to which research stimulates learning, reflection, or change among participants, not just offering conclusions but sparking transformation in thinking or behaviour was also ensured. The study acted as a catalyst for organisational learning at Arla, helping the company understand how and where SPC can be applied, particularly in a food industry context where such practices are still emerging. Moreso, by engaging employees in interviews and revealing gaps between current practices and potential SPC applications, the research encouraged reflection on existing production processes, especially in relation to quality control and fat giveaway. The resulting roadmap provides a transformational structure that enables Arla not only to act but also to think differently about process monitoring and quality assurance.

Democratic validity focuses on inclusiveness and the meaningful involvement of stakeholders in the research process, ensuring that those directly affected by the outcomes are actively engaged in shaping the study. In this thesis, employees at Arla were not treated as passive subjects but as valuable contributors whose insights helped shape the direction and content of the research. Their involvement through interviews provided first-hand perspectives on the current production processes, particularly in relation to quality control and fat content variation. This allowed the researchers to ground their findings in the practical realities of the organisation. By incorporating employee experiences and operational knowledge, the study ensured that the issues explored were genuinely relevant and reflective of actual conditions within the dairy facility.

However, some limitations should be acknowledged. While steps were taken to ensure practical relevance, the theoretical generalisability of the findings may be constrained by the single-case design. Although feedback from stakeholders was gathered throughout the study, involving a wider range of departments and teams in a more structured way could have provided even deeper and more diverse insights. By integrating both academic rigor and practical engagement, and by reflecting critically on the research process, this study aligns with contemporary views on high-quality service action research. Future research could build on this foundation by incorporating cross-validation across multiple case settings.

3.4 Ethical Considerations

Ethical considerations play a crucial role in the quality and credibility of research, as there are clear expectations and responsibilities placed on the researcher. To ensure that the research is both trustworthy and robust, researchers must be aware of and adhere to ethical principles throughout the entire research process [35]. The Swedish Research Council outlines eight general principles of good research practice, for example, that researchers must be truthful about their findings, take responsibility to avoid causing harm to individuals, and maintain structure and transparency in how the research is conducted [35].

In line with these principles, this study has followed several ethical practices. Process mapping and data extraction were conducted with the consent of the case company, ensuring that any sensitive operational information was handled confidentially. Interview participants were anonymised to protect their identities, and all data used for analysis, including database extractions and measurement system evaluations was managed responsibly, remaining strictly within the scope of this study.

To ensure objectivity and reduce bias, the prioritisation matrix was developed using clear and justifiable criteria. Moreover, elements such as the process mapping and prioritisation matrix were validated by a representative from Arla Foods to strengthen the quality and relevance of the results. Lastly, to prevent the publication of any information that could potentially harm the company or be misinterpreted, Arla Foods will review and approve the final version of the thesis before publication.

4. Findings

This chapter presents the findings from the case company, based on the research methods detailed in the previous chapter. It includes results from interviews, process mapping, fat content data analysis, and measurement system analysis. Furthermore, the economic impact of fat giveaway is examined, along with the outcomes of the process prioritisation.

4.1 Current State Visualisation of Case Company

The current state visualisation is crucial as it provides a comprehensive understanding of the existing production conditions and serves as a foundation for identifying improvement opportunities. The current state visualisation is made up of several key components. It begins with the findings from the interviews, followed by process mapping and a description of the process steps, along with visualisations of three different products produced at the dairy. This is followed by the results of the data analysis, descriptive statistics, an individual value plot, and a histogram. The final components include the results from the measurement system analysis. Each of these key components are described in more detail in the following sections.

4.1.1 Interview Findings – Understanding the process flow and fat content as a critical parameter

The interviews with key stakeholders, namely the production manager, the operations engineer specialist, and an operator, provided valuable insights that contributed to two key outcomes:

1. They reinforced that fat content (%) in the product is a critical parameter that must be closely monitored for effective SPC integration. Stakeholders highlighted the financial and operational consequences of fat variability, confirming the need for tighter control.
2. The insights derived from the interviews were instrumental in helping the researchers develop a detailed process mapping of the production facility. These insights clarified how fat content variability originated and propagated, enabling a structured approach to optimising the production process.

Fat Content as a Critical Parameter for SPC Integration

The stakeholders interviewed emphasised that fat content (%) must be controlled within tight limits due to its direct financial and operational impact. The integration of SPC into the production system was identified as essential to mitigate the risks associated with fat variability.

Production Manager's Perspective: The production manager highlighted the cost implications of excessive fat giveaway, particularly in cream form. Additionally, the production manager

pointed out that the absence of real-time SPC monitoring meant that corrective actions were often delayed, exacerbating fat giveaway issues.

Operations Engineer Specialist's Perspective: The operations engineer emphasised SPC integration as being key to enabling predictive adjustments that would potentially minimise the fat giveaway issues encountered.

Operator's Perspective: The operator pointed out that the lack of real-time monitoring meant adjustments were often reactive rather than proactive, leading to product inconsistencies.

4.1.2 Process Mapping – Overview of the current state

Figure 11 below displays the process maps for various dairy products, both with lactose (regular) and without lactose (lactose free). The production process is divided into three broad product categories, ESL (Extended shelf life) production, yogurt production, and fermented cooking products production. A more detailed, step-by-step explanation of each process step, along with an overview of the products produced at each stage is provided in the next sections.

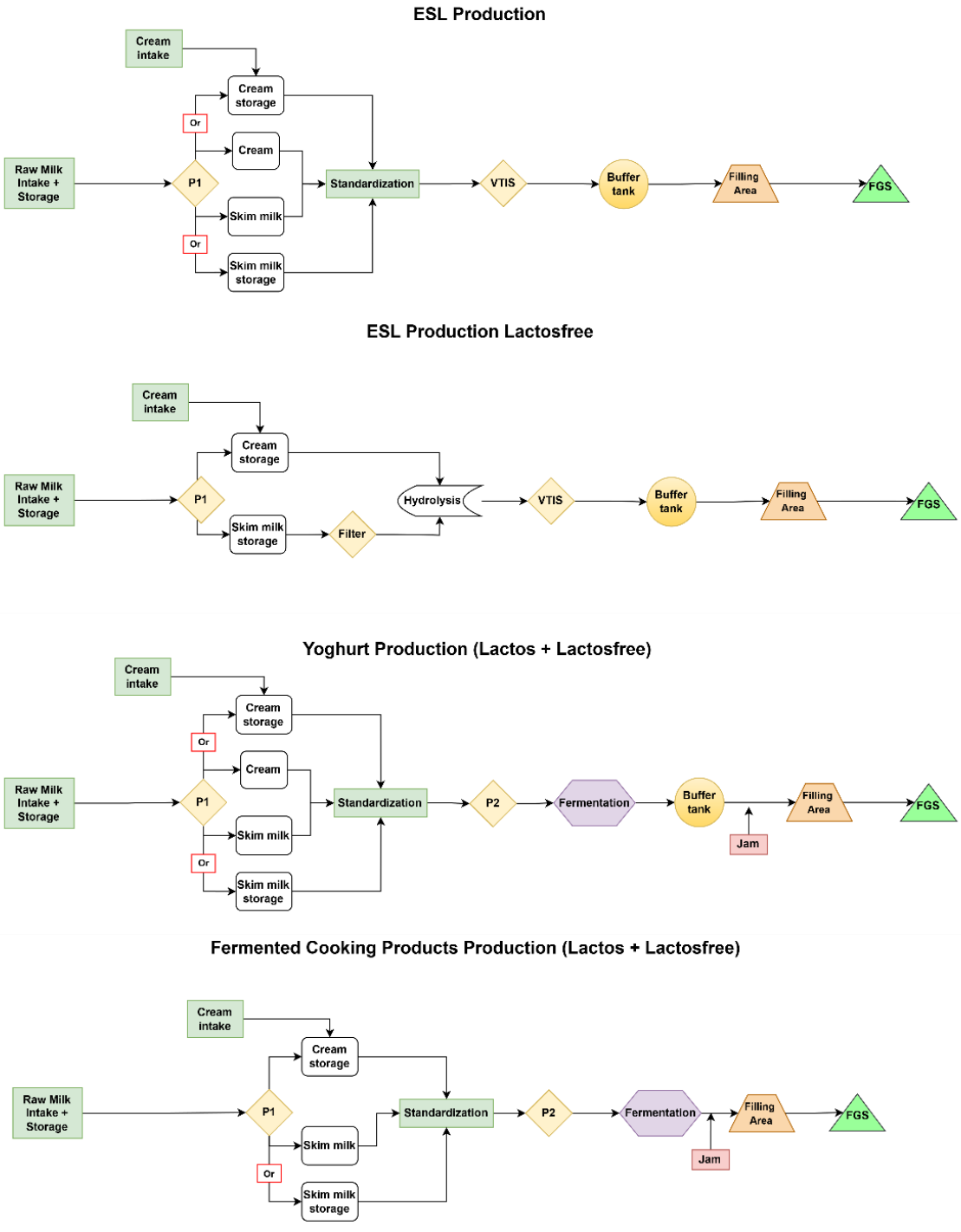

Figure 11: Process maps of dairy production.

Table 5 below describes the various process steps involved in dairy production at the case company.

Table 5: Detailed description of each process step.

Process step	Description
Raw milk intake + Storage	Trucks carrying milk from farms enter the facility, where the milk is received at the dairy. It is then transported through pipes that cool it down before being stored in designated storage tanks.
Pasteurisation 1 (P1)	The raw milk is then transported to the pasteurisation stage, where it is heated at a certain temperature, and a separation of the milk into cream and skim milk occurs. Both cream and skim milk are then either stored in silos (storage tanks) or transferred to the standardisation tanks.
Cream storage	Pasteurised cream is stored in dedicated silos.
Skim milk storage	Pasteurised skim milk is stored in the dedicated silos.
Cream intake	Cream intake refers to receiving extra cream from other dairies (Arla-owned dairy production facilities) for augmentation.
Standardisation	Pasteurised raw milk or milk from both the cream and skim milk storages are fed into the standardisation tanks. Depending on the product being produced, different amounts of cream and skim milk are added to achieve the desired fat composition in the final product. Standardisation involves mixing cream and skim milk while incorporating additives such as various powders and sugar. The desired fat content of the final product that gets to the customer is achieved at this process step.
Filter	The process filters out lactose from the skim milk using an ultrafiltration unit and the normal filtration, effectively removing lactose from the skim milk.
Hydrolysis	Lactose free products are the only dairy products that go through this process step. Here, the filtered skim milk is mixed with cream in a silo. Enzymes are then introduced into the silos to initiate the chemical reactions that result in the product being lactose-free.
Pasteurisation 2 (P2)	The second pasteurisation stage involves heating the standardised mixture to a certain temperature. After this second pasteurisation, the mixture is transferred to fermentation tanks for further processing.
VTIS	Milk is heated, a process known as direct heating, where it is held at a specific temperature for a certain time duration to meet legislative requirements.
Fermentation	Fermentation is the process where milk is transformed into yogurt. A culture is added in the silos containing the standardised milk to induce the fermentation process. For lactose free products, enzymes are also added into the silos.
Buffer tank	The semi-finished products are transported to storages (buffer tanks) almost ready to be filled into various containers in the filling area. where jam is introduced before filling area. Between the buffer tank and the filling area, jam could be added depending on the specific product. This jam addition provides different flavour profiles, such as strawberry or vanilla, giving different taste for the product.
Filling Area	Different filling machines are used to fill the finished products into containers (tetra packs, buckets, cups, etc) of various sizes, and sealed.
Finish Goods Storage (FGS)	The finished goods are transported to a finished goods storage area, where the products are cold-stored and prepared for transport.

Three different products - Arla Latte Art 2.6%, Vanilla Yogurt 2%, and lactose free Crème Fraiche 32% are illustrated in figure 12 below. They offer insights into how each product is produced with different additives (ingredients), such as skim milk powder, vitamin D, culture, sugar, protein powder, flavour (vanilla) added at various process steps. The products are included for visualisation purposes only and have no impact on the results of the research.

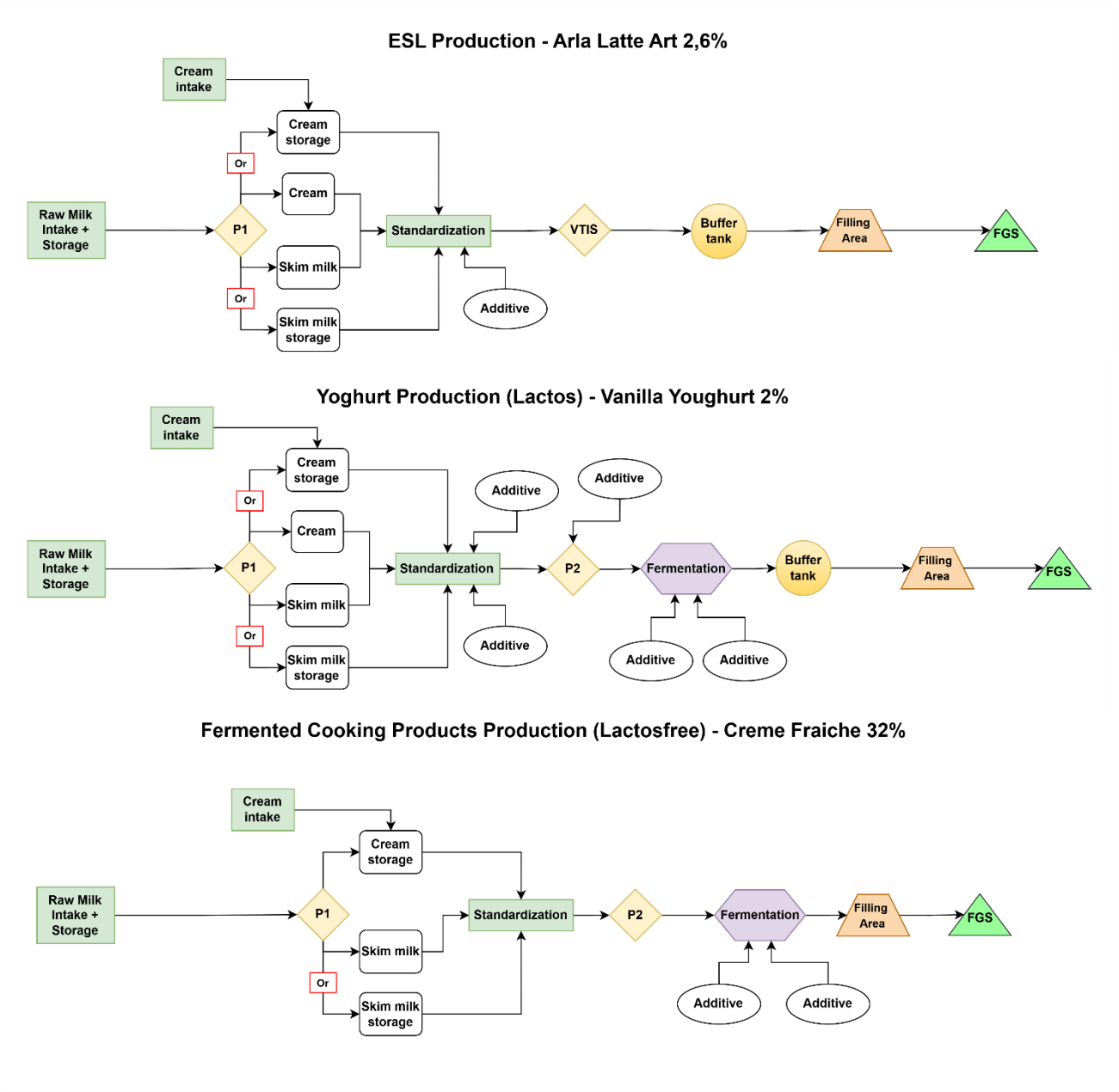

Figure 12: Three different dairy products produced at each product category.

4.1.3 Data Analysis - Fat content measurements from database

The data analysis was carried out using fat content data extracted from the company's database, focusing on the standardisation and hydrolysis stages. The data includes fat content measurements from samples taken during these process steps. A base (referred to as "BAS") is a fat-standardised, semi-finished mixture of cream, skim milk, and additives (such as sugar and powdered ingredients). These bases are stored in either the standardisation or hydrolysis silos, depending on the product, before being pumped to the next processing station.

Each base can be used to produce different container sizes, with each size assigned a unique article number. For example, crème fraiche with 32% fat content may be packaged in various formats:

- One article number may represent a 5-dl package
- Another, a 2-dl package
- While others might be in 2kg, 5kg or 10kg buckets

Despite the different article numbers, these all originate from the same base. A single base can correspond to as many as nine different article numbers. Taking this into account, a total of 69 unique bases were identified and included in the analysis.

The results of the fat content data analysis are illustrated through descriptive statistics, individual value plots, and histograms. While full results across all products are omitted for confidentiality reasons, one representative product, denoted as ***Bas A*** also for confidentially, with a fat content of 32% is presented in detail to illustrate the analytical approach. The following sections display the key findings for this product: the descriptive statistics, individual value plot, and histogram.

Descriptive Statistics

The descriptive statistics for ***Bas A*** are shown below in Table 6. The data reveals that the average fat content for this base is 32.67%, based on an analysis of 352 data points. This indicates that the company is, on average, giving away more fat than the target value of 32%. The fat content in this dataset ranges from 30.76% to 33.79%, with a standard deviation of 0.315.

Table 6: Results from Descriptive Statistics for Bas A.

Descriptive statistics	
Product	**Bas A**
Total Count	352
Mean	32,6716
StDev	0,314532
Minimum	30,76
Maximum	33,79

Individual Value Plot

The individual value plot for ***Bas A*** is presented below in figure 13. As shown in the figure, the fat content for this base frequently exceeds the target value. This indicates that the company is consistently delivering more fat (cream) than what is stated on the product label. Such over-delivery leads to unnecessary product giveaway in fat, resulting in increased production costs for the company.

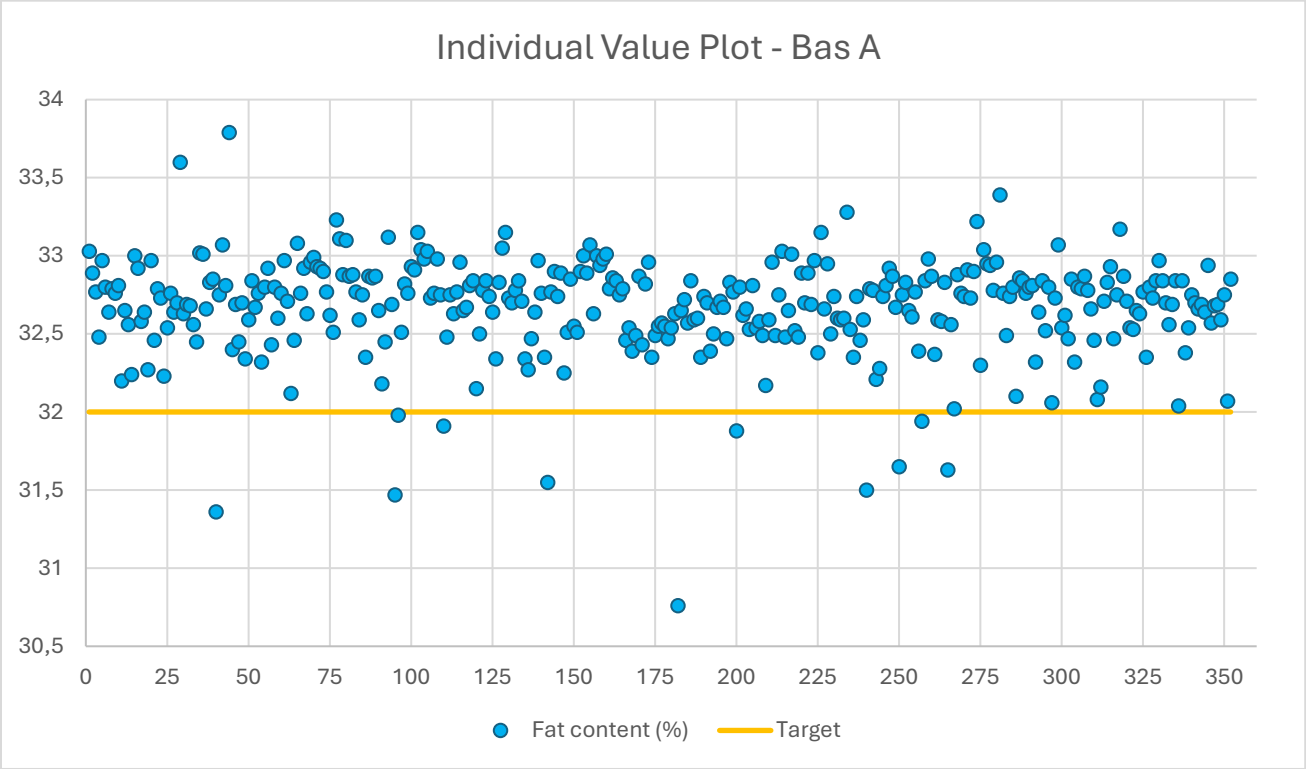

Figure 13: Results from Individual Value Plot for Bas A.

Histogram

The histogram for ***Bas A*** is shown below in Figure 14. As illustrated, the fat content distribution is skewed to the right in comparison to target value, meaning that the fat content frequently exceeds the target value. This confirms the earlier observation that the company often delivers more fat than intended.

Despite this, the histogram also shows that the product consistently meets customer requirements, even with a few outliers on the higher end. While such outliers are sometimes referred to as defects, in this case, they do not result in noticeable differences in product characteristics such as taste or texture. Therefore, these deviations are generally considered acceptable and do not justify scrapping the product. However, it's important to clarify what would constitute an actual defect. For example, if a product is labelled as containing 3% fat but is found to have 10% fat during production, the deviation is significant enough to mislead the customer and affect product quality. In such cases, the unit would be classified as defects and should be discarded.

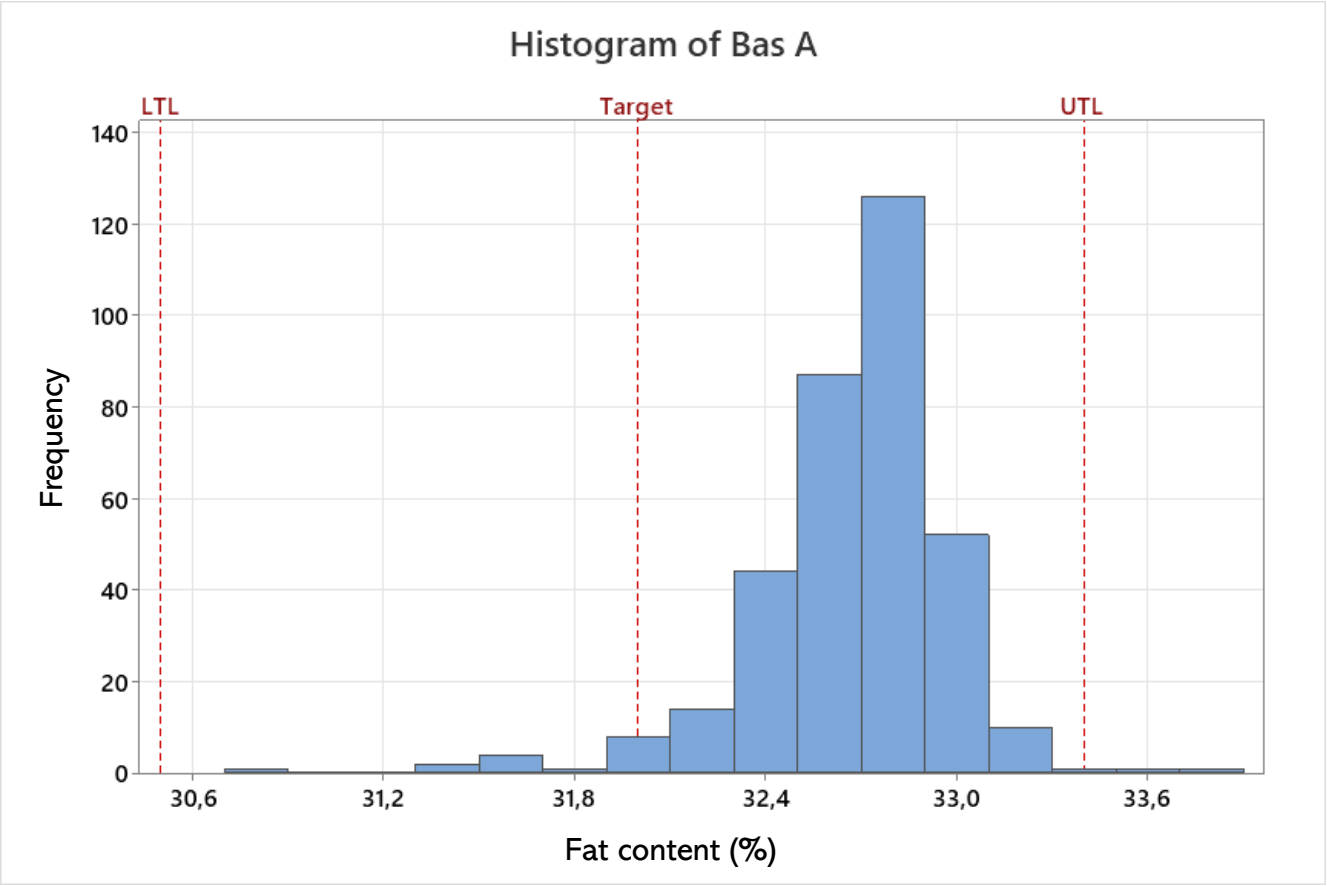

Figure 14: Results from Histogram for Bas A.

4.1.4 Economic Impact of Fat Giveaway

The result from the descriptive statistics for the select product (Bas A) indicates a yearly average of 32.6716% fat which translates to a surplus of 0.6716% from the target value of 32%. This surplus can be estimated in financial terms to fully understand the cost implications. The total cost of the fat surplus measured in SEK was calculated by multiplying the fat surplus (0,6716%) by the quantity of Bas A produced yearly in kg/year, and then multiplying this product by the cost of cream in SEK/kg. This value is approximated at 2.8 MSEK, meaning an additional cost of 2.8 MSEK can be attributed directly to the excessive fat giveaway. This loss highlights the financial impact of process variation and underscores the importance of tighter control.

4.1.5 Measurement System Analysis

The results from the measurement system analysis are presented in figure 15. The paired t-test showed that the measurement system is accurate and reliable for both machines, as the p-values were greater than 0.05. This indicates a failure to reject the null hypothesis, meaning there is no statistically significant difference between the mean values of replicate 1 and replicate 2 for each machine. As a result, the observed variation is attributed primarily to the process itself rather than to measurement inaccuracies. This confirms that the historical data provided by the case company can be considered trustworthy, thereby validating the data analysis presented in *4.1.3 Data Analysis - Fat content measurements from database.*

Paired T-Test : Machine A

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Replicate 1 (Vit)	8	0.48625	0.00518	0.00183
Replicate 2 (Vit)	8	0.48750	0.00463	0.00164

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference ≠ 0
T-Value	-0.55
p-value	0.598

Paired T-Test : Machine B

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Replicate 1 (Frukt)	10	0.49200	0.00789	0.00249
Replicate 2 (Frukt)	10	0.49500	0.00707	0.00224

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference ≠ 0
T-Value	-0.76
p-value	0.468

Figure 15: Results from the Paired T-Test for Machine A and B.

4.2 Process Prioritisation

The process prioritisation is supported by prioritisation matrix, this tool is used to evaluate which production step in the dairy process is most suitable for SPC integration. This is described in the following section.

4.2.1 Prioritisation Matrix

The prioritisation matrix consists of four key steps. First, the criteria for evaluation are defined (represented as columns in the matrix). Next, the relevant process steps are identified (represented as rows). In the third step, each process step is evaluated against the criteria using a weighted scoring system. Finally, a total score is calculated for each process step to help draw meaningful conclusions. Description of each step is explained further.

Generation of the Criteria

Four different criteria were developed, and are explained below:

1. Measurement Feasibility: Is it feasible/practicable to (continuously) measure the fat content at this process step?
    - Explanation: Since SPC involves continuous measurements, is it feasible to take measurements continuously at this step.

2. Process Criticality: How critical is it to monitor the fat content at this process step with respect to legislation (to avoid major non-compliance)?
    - Explanation: A process step with strict legislations is preferred and considered more for SPC integration to avoid major non-compliance

3. Impact on Fat Content Variability: Does this process step contribute to a marked variation in fat percentage in the product?
    - Explanation: A process step that directly introduces variation in the fat content of the dairy product is given more consideration for SPC integration.

4. Economic Impact: Will integrating SPC at this process step help achieve cost savings related to fat (cream usage) while maintaining the desired fat percentage in the final product.
    - Explanation: Since SPC is about reducing variations and saving costs, will SPC at this process step help achieve it.

Evaluation process

Each criterion was evaluated for every production process step based on weighted scales. An illustration of the weighting is presented below.

1: Weak connection of the criteria to the identified process step.
3: Moderate connection of the criteria to the identified process step.
9: High connection of the criteria to the identified process step.

According to Park et al. [36], the relationship matrix in the House of Quality is typically assigned values of either 1, 3, 9 or 1, 5, 9. These are among the commonly used relationship weights, which is why they were selected for use in this study. It is also worth noting that Park et al. [36] analysed thirty QFD applications and found that none of them provided any justification for choosing specific scales such as 1, 3, 9; 1, 5, 9; 1, 3, 5; 1, 2, 4; or 1, 6, 9.

The choice of using the scores 1, 3, and 9 by the authors is not only based on established practices, but also on the benefits these specific values bring to the evaluation process. First, using distinct scores like 1, 3, and 9 pushes evaluators to clearly differentiate between process steps, rather than choosing vague middle values. Second, the larger gaps between the numbers encourage evaluators to think more carefully before assigning a score. Lastly, this type of scale creates a more consistent understanding among evaluators and reduces confusion, especially when compared to broader scales like 1-5 or 1-10.

After each process step were assigned a score, the total score is calculated by adding up its scores across all evaluation criteria. The process step(s) with the highest score(s) is/are identified as being the most suitable areas for SPC integration. To validate this, the matrix was evaluated and validated by a representative (Operations Engineer Specialist) from Arla Foods. This validation consolidated the findings from the prioritisation matrix.

The outcome of the prioritisation matrix identified two process steps with the highest scores (see Figure 16). The process steps that received the highest points were **standardisation** and **hydrolysis**, which are the two process steps in dairy production that would potentially benefit most from the integration of SPC, particularly in relation to controlling fat content to maintain product consistency, supporting the findings for RQ1.

Process steps	Process Criticality	Impact on Fat Content Variability	Measurement Feasibility	Economic Impact	Total Score
Raw Milk Intake + Storage	▲	▲	○	▲	12
Pasteurization (P1)	▲	●	●	○	16
Filtration	▲	▲	●	▲	6
Standardization	○	○	○	○	36
Hydrolysis	○	○	○	○	36
VTIS	▲	▲	▲	▲	4
Pasteurization (P2)	●	▲	▲	▲	6
Fermentation	●	▲	▲	▲	6
Buffer tanks (product storage before filling)	●	▲	○	▲	14
Filling Area	○	●	○	▲	22
Finished Goods Storage (FGS)	○	▲	○	▲	20
Cream Intake + Storage	○	▲	○	○	28
Skim Milk Storage	○	▲	○	▲	20
		▲ Weak (1) ● Medium (3) ○ High (9)			

Figure 16: Results of prioritisation matrix.

To summarise the findings, a prioritisation matrix was used to evaluate each process step based on predefined criteria to determine which step(s) in dairy production would most benefit from the integration of SPC, particularly for controlling fat content to ensure product consistency. The results indicated that the **standardisation** and **hydrolysis** steps are the most relevant. Notably, data analysis revealed a significant fat giveaway associated with ***Bas A***, where most values exceeded the target. This discrepancy was estimated to result in an average annual financial loss of 2.8 million SEK. Despite this, the histogram shows that ***Bas A*** consistently meets customer requirements. The next chapter then presents the developed roadmap for SPC integration which were inspired by literature studies and the findings from the case company.

5. Roadmap for SPC Integration

This chapter presents a roadmap for integrating SPC into the dairy industry, which is particularly crucial for addressing RQ2. Developed through a synthesis of relevant literature, the roadmap is structured into three key phases: pre-implementation, implementation, and anchoring. Some steps in the roadmap are illustrated within the company context, and each phase is explained in detail in the following sections.

Developing a clear and structured roadmap is essential for the successful integration of SPC into dairy operations. The roadmap presented in this thesis was designed in response to the limitations identified in existing SPC implementation frameworks within the dairy industry. It builds on insights from previous research and is further strengthened by process-specific knowledge gained through interviews with representatives from the case company. The roadmap considers both organisational and practical aspects for a successful integration of SPC, ensuring a holistic and practical approach.

As illustrated in figure 17, the roadmap is divided into three main phases: the Pre-Implementation Phase, the Implementation Phase, and the Anchoring Phase. Each phase is described in detail in the following sections, providing a clear and actionable step-by-step guide tailored to the needs of dairy operations. It is worth noting that the roadmap for SPC integration will not provide a comprehensive description of all steps within each phase. However, the following section offers an overview of the key elements that should be addressed under each step.

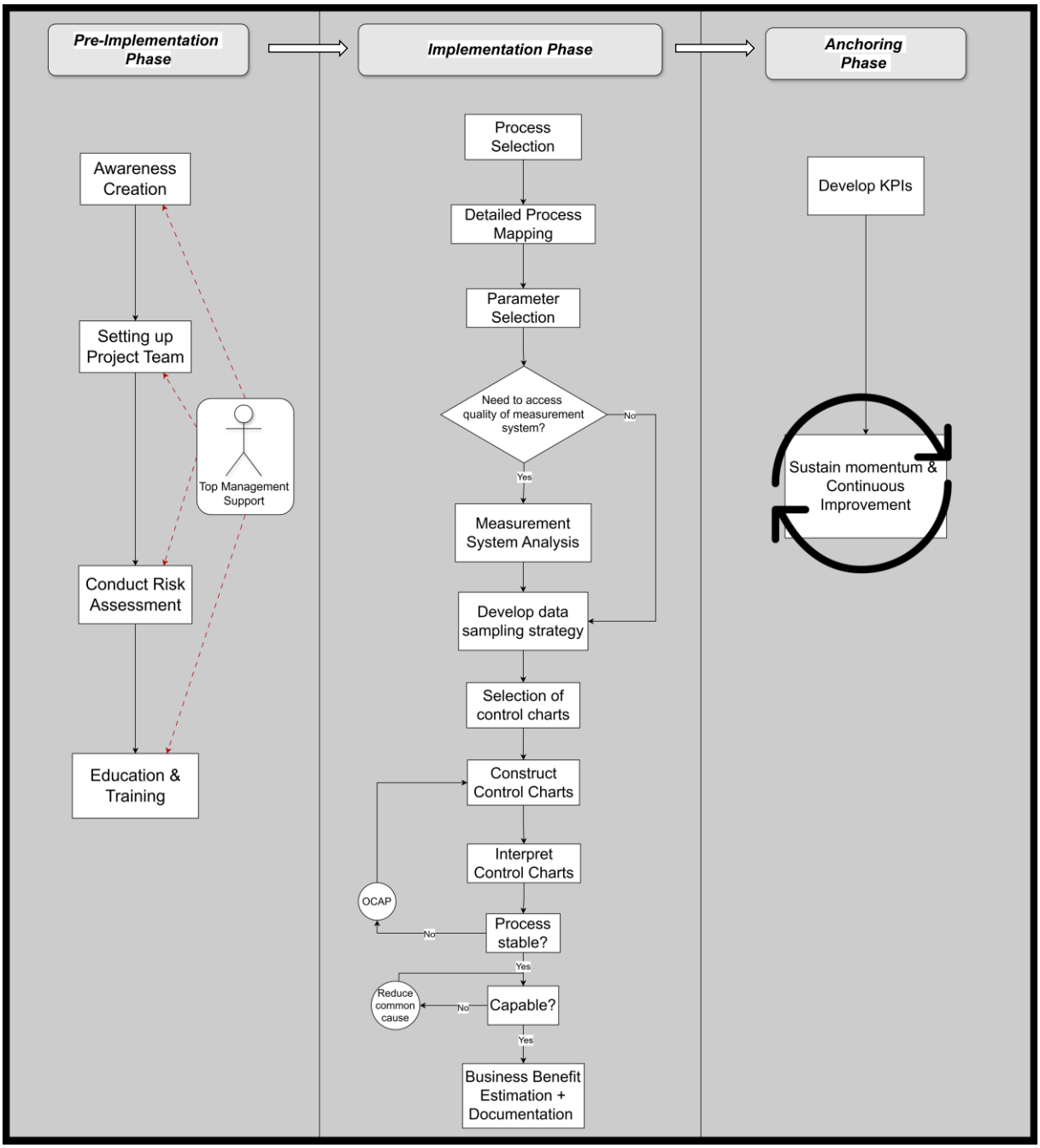

Figure 17: Conceptual roadmap for SPC integration in dairy operations.

5.1 Pre-implementation Phase

The pre-implementation phase plays a critical role in the successful integration of SPC, as it outlines the necessary preparations before the actual implementation begins. In the developed roadmap, this phase consists of four key steps: creating awareness, establishing a project team, conducting a risk assessment, and providing education and training. Each of these steps is described in detail in the following sections.

Awareness Creation

Creating awareness is one of the most critical components in the successful integration of SPC. It marks the true starting point of the implementation journey and lays the foundation for all subsequent phases. At this early stage, it is essential that top management is not only made aware of SPC, but also fully convinced of its benefits, particularly its potential to improve operational efficiency and positively impact the company in the long term. Gaining top management buy-in at the outset is vital, as their support and commitment will drive the initiative forward and influence its success and sustenance across the organisation [4,33].

Top management must be the first to clearly understand what is required of them in terms of leadership, resource allocation, and ongoing support. A strong and visible commitment from leadership sends a clear signal that SPC integration is a strategic priority, not just a technical project. It is also during this phase that the organisation's vision for SPC should be articulated and communicated from the top down, ensuring that all employees are aligned with the purpose and direction of the initiative [4,33].

The importance of leadership commitment at this stage cannot be overstated [33]. As Antony and Taner [37] note, one of the most common reasons for SPC implementation failure is a lack of top management involvement. This observation is echoed across several studies [2-4, 25, 33, 38-41], all of which highlight the foundational role that leadership plays in shaping a culture capable of sustaining quality improvement.

In parallel, this phase must also address the issue of resistance to change, a challenge commonly faced in SPC implementation. Resistance may stem from fear of the unknown, scepticism toward statistical tools, or discomfort with new training requirements. As Antony and Taner [37, p. 481] emphasised, "The management should be prepared to address any resistance to change that might be present within the organisation, plus any fear of training or reluctance to embrace the technique SPC and its tools." Recognising and proactively managing these concerns from the start will strengthen the groundwork for a smoother and more effective implementation process.

Setting up Project Team

Setting up a project team involves forming one or several groups that will actively work with the use and implementation of SPC, these are often referred to as SPC action teams. It is essential that these teams are cross-functional, involving individuals from different departments. Each team member brings unique knowledge and perspectives, which are invaluable for ensuring a successful SPC integration. Typical roles within these teams might include process engineers, operators, quality engineers, supervisors, and an SPC expert (who may be brought in externally) [4,33,37]. Throughout this phase, it is crucial that top management provides consistent support and plays an active role in guiding the process [37].

This phase also includes the formation of a responsible unit or team tasked with initiating and overseeing the project, commonly known as the SPC steering committee. This group serves as a process action team, accountable for managing the project from initiation to completion. Team members may include a quality manager, operations manager, production manager, SPC facilitator (possibly external), process manager, and quality improvement manager, among others [4,33]. As with the action teams, top management involvement is critical. Their visible support sets the tone for the initiative and reinforces its importance across the organisation.

Conduct Risk Assessment

Conducting a project risk assessment is a critical step in identifying, evaluating, and mitigating potential issues before they arise. It allows for proactive planning to prevent disruptions and supports a smoother implementation process [21]. In the context of SPC integration, risk assessment should address both the “process” aspect, relating to the technical implementation of SPC and the “project” aspect, which includes management, coordination, and execution. The aim is to minimise uncertainties and increase awareness of possible risks that could impact the success of the initiative. A well-established method for conducting such an analysis is Failure Mode and Effect Analysis (FMEA), as described by Brook [21]. The risk assessment can be conducted by the SPC steering committee, as they hold the overall responsibility for the project's planning and execution. Their cross-functional composition allows them to identify potential risks from multiple perspectives, whether operational, technical, or organisational. This proactive approach ensures that mitigation strategies are in place before challenges arise, ultimately increasing the likelihood of a successful SPC implementation.

Notably, none of the reviewed research articles [2-4, 25, 33, 37-41] emphasised the importance of a comprehensive risk assessment prior to project initiation, highlighting a significant gap in the existing literature. A case study conducted by Kishk and Ukaga [42], at a company referred to as “Case A,” examined the impact of effective risk management on project success. The study revealed that the project experienced a cost overrun of $135 million due to the failure to act on identified risks and implement appropriate mitigation measures. The authors concluded that, had the organisation proactively addressed these risks, it could have avoided the overrun entirely and saved the full amount. This case study clearly illustrates the importance of conducting a thorough project risk assessment. Implementing SPC is a significant investment, and without proper risk management, it can become unnecessarily costly and vulnerable to failure.

Education & Training

This step involves educating all individuals who will be involved in, or impacted by, the use of SPC, particularly those who will apply it in their day-to-day operations. The training should aim to build awareness of SPC, communicate its potential benefits, address resistance to change, and foster the in-house expertise needed to sustain the implementation over time.

Moreover, it plays a key role in establishing a culture of continuous learning and improvement within the organisation [4,33].

An SPC facilitator is especially vital during this phase. Their role is to guide the organisation in understanding how SPC should be applied in practice, explaining not just the tools, but the mindset and processes behind them. As Lim et al. [4] emphasis, the transfer of knowledge within the organisation is crucial. In industries such as food and dairy, where statistical expertise is often limited, actively maintaining and developing internal competence is essential for long-term success.

Top management involvement is essential to ensure the necessary support is in place and to help address any challenges or unexpected issues that may arise during the process. It is also important that top management remains fully aware of the time and budget requirements associated with the implementation, as their commitment and oversight are key to the project's success [4].

5.2 Implementation Phase

The implementation phase represents the core of the SPC integration process, where planned actions are put into practice to ensure successful adoption. This phase outlines the concrete steps required to move from planning to execution. The following section explains the steps in a chronological sequence to be followed in the implementation phase of the roadmap.

Process selection

Process selection is a critical step in the effective implementation of SPC. It involves choosing which process or part of the production line to focus on first, based on its importance, impact on product quality, and potential for improvement. Lim et al. [4] highlighted that focusing on the most critical processes can lead to significant and measurable improvements. While applying SPC across all operations is ideal in theory, they noted the practical necessity of narrowing the focus to one process area at a time. To guide this, they advocate for using well-defined, objective, and measurable criteria that support a fair and data-driven selection process. Antony and Taner [37] reinforced this view by pointing out that applying SPC across every manufacturing process simultaneously is often unrealistic due to time and cost constraints. Their work further underscores the importance of prioritisation as a practical and strategic starting point for implementation.

Lim et al. [38] expanded this discussion by arguing that beyond critical success factors (CSFs), a company’s readiness plays a pivotal role in successful SPC adoption. They developed a framework of nine readiness dimensions through a systematic review, highlighting process prioritisation as one of the “vital few” elements that form the foundation of SPC readiness. While readiness on its own may not guarantee success, it increases the likelihood of effective implementation by ensuring resources and attention are directed where they are most needed. Similarly, Goh and Xie [43] emphasised the value of targeting specific

subprocesses instead of attempting to implement SPC across an entire production system. Recognising the limitations posed by human and economic resources, they proposed that selection should be based on two key dimensions: technical criticality - how important the process is to product quality - and statistical criticality - how stable and capable the process is. They also highlighted the Analytic Hierarchy Process (AHP) as a structured decision-making tool that helps prioritise subprocesses in an objective and systematic manner, ensuring efforts are focused where they will have the greatest impact.

A review of existing literature clearly shows a strong consensus: process selection is widely recognised as one of the most crucial steps in SPC implementation. Across various studies, researchers have consistently emphasised that identifying and prioritising the right processes lays the foundation for meaningful results. Without a clear selection strategy, organisations risk spreading resources too thin, diluting impact, or applying SPC in areas that do not significantly influence product quality or performance

Standardisation and Hydrolysis Processes – Case company

At the case company, the standardisation and hydrolysis processes were selected as the most suitable processes for the initial application of SPC. This selection was carried out using a prioritisation matrix, which allowed for a structured comparison of several process areas based on a set of defined criteria. The use of a prioritisation matrix conferred objectivity to the decision-making process. The prioritisation process is detailed in the section *4.2.1 Prioritisation Matrix*.

Detailed Process Mapping

After selecting which process(es) to focus on, the next step is to build a thorough understanding of how the process actually works. This is where detailed process mapping becomes essential. At its core, process mapping involves laying out each step of the selected process - from inputs and activities to decision points and outputs - to gain a complete and accurate picture of its flow. It serves as a fundamental tool for process improvement and supports SPC by offering clarity on where to measure, what to control, and where variation may occur [21,44].

Oakland [45] stressed that when planning or improving any process - whether in manufacturing, administration, or management - clearly visualising each step allows everyone involved to understand it, making it easier to identify inefficiencies or areas for improvement. A well-constructed process map also supports shared understanding across departments - particularly engineering, quality, and production - which is critical when implementing SPC. Most importantly, it lays the groundwork for identifying key quality characteristics and determining where and how data should be collected. Bunney and Dale [44] further noted that involving the people who work directly with the process is crucial during mapping, as their insights often reveal how the process functions in practice - not just how it appears on paper.

Similarly, Elg et al. [46] emphasised the importance of engaging end-users and operators during SPC implementation. In the study, the importance of involving operators and other end-users throughout the development and rollout of the SPC system is emphasised. While their study didn't explicitly focus on process mapping, their approach of involving those closest to the process aligns with the same principle: to improve any process meaningfully, it must first be thoroughly understood. Their method, based on practical insight and real use, mirrors the purpose of process mapping - to provide a realistic understanding of how things operate.

Does et al. [33] recommend that, to gain a comprehensive view, it is important to zoom into the process and break it down into clearly defined and numbered steps, each representing a distinct transformation. Visual tools such as flowcharts are useful in this context, not only for communication but also for identifying where problems may exist. This structured visualisation becomes the foundation for targeted improvements and control.

A review of existing literature strongly supports the use of detailed process mapping as a critical early step in any process improvement initiative, particularly SPC. Across various studies, authors consistently highlight the value of mapping in uncovering hidden inefficiencies and providing clarity on the process in consideration.

Parameter Selection

The selection of a critical process parameter is a pivotal step in the implementation phase of the SPC roadmap, as it lays the foundation for meaningful and targeted process monitoring. This step focuses on identifying a measurable variable that reliably reflects how well the process is performing and can be used to assess stability over time.

Objectively identifying and prioritising the right parameter can be challenging, particularly in complex production environments. To support this decision-making, Lim et al. [4] recommend the use of structured tools such as cause-and-effect analysis, design of experiments, pareto analysis, and multi-vari charts. These tools help teams move beyond subjective judgment, enabling a more systematic and data-driven approach to determine which parameters should be monitored for ongoing control and improvement.

Selecting fat content as the critical process parameter – Case company

At the case company, operating within the dairy production sector, **fat content** was selected as the critical process parameter for SPC implementation. In dairy processing, fat content is a vital quality characteristic that has a direct impact on product consistency, texture, and compliance with regulatory standards. For products such as milk, cream, and yogurt, the percentage of fat must remain within a defined range to meet both legal requirements and consumer expectations. Fat content, being both measurable and closely tied to product quality, serves as a reliable indicator of process stability and is therefore a suitable parameter for SPC monitoring in this setting.

Measurement System Analysis (MSA)

Just like any process, measurement itself can have variation, and it's important to understand how much of that variation comes from the measurement system. Measurement system analysis essentially checks if a measurement system is reliable enough for process improvement work. The key characteristics of the measuring device (gauge) that are evaluated are: resolution, bias, and precision. Resolution is about how finely a measurement tool can detect differences. For a gauge to be useful, it should be able to show enough variation to reflect what's really happening in the process. A general rule is that it should have at least 10 distinct readings within the tolerance range. Bias refers to accuracy. It assesses whether the measurement consistently hits the true value. If a system has bias, it means there's a consistent error in one direction (too high or too low), which needs to be corrected or accounted for. Precision looks at consistency - how much the measurements vary when repeated under the same conditions. It's broken down into repeatability (variation from the device itself) and reproducibility (variation from different users or setups). A good measurement system should have low variation in both. A measurement system is considered acceptable if its variation is small compared to the total process variation. If the system isn't capable, it's best to fix that first before starting any SPC work [21].

Measurement system analysis – Case Company

To ensure the reliability of fat content measurements - identified as the critical process parameter for monitoring process stability - a MSA was carried out, focusing specifically on assessing the measurement consistency using a **paired t-test**. The analysis aimed to determine whether the measurement device consistently produces stable results under repeated use. The results are shown in *4.1.5 Measurements System Analysis*.

Develop Data Sampling Strategy

Once a critical process parameter has been selected and the measurement system has been verified as capable, the next step is to establish a clear strategy for collecting data on that parameter. This involves determining how and how often measurements should be taken. A well-thought-out sampling strategy ensures that the data collected is both meaningful and consistent, allowing teams to effectively monitor the process over time. This ongoing measurement is essential for detecting shifts, trends, or unusual variation, and is at the core of assessing the stability and control of the process in SPC implementation [1,4].

Selection of Control Charts

After establishing a data sampling plan, the next step in SPC implementation is choosing the appropriate type of control chart for monitoring the selected process parameter. The choice of chart depends largely on the type of data being collected - whether it's variable data (like measurements on a continuous scale) or attribute data (such as counts of defects or

defectives). It also depends on factors such as sample size, frequency of data collection, and whether the focus is on individuals, subgroups, or proportions [1,4].

For instance, $\bar{X}$ and R charts are commonly used when monitoring the mean and range of subgroups with continuous data, while p-charts or c-charts are more suitable for attribute data like proportions or counts of defects. The right chart helps visualise how the process behaves over time and makes it easier to detect unusual patterns or shifts that may indicate problems. Selecting the wrong type of control chart can lead to misinterpretation of data, potentially causing unnecessary adjustments or missed signals. Therefore, this step is crucial for ensuring that the SPC tool works as intended - providing early warnings and guiding process control decisions. According to Montgomery [1], aligning the type of control chart with the nature of the data and process conditions is essential for accurate monitoring and effective quality control.

The selection of different types of control charts is illustrated in Appendix, figure 18, with inspiration drawn from [1, 4]. As previously discussed, choosing the appropriate control chart is critical to avoid false alarm signals and to clearly distinguish between Phase I (initial analysis and baseline establishment) and Phase II (ongoing monitoring and control) [1, 4]. For a more detailed explanation of the phases and the step-by-step guidance on how to select suitable control charts for a given process, the authors refer to [1].

Construct Control Charts

Once the process parameter, data collection plan, and appropriate chart type have been determined, the next step is to construct the control chart. This involves plotting the collected data over time to visualise how the process behaves, with calculated control limits indicating the expected range of normal variation [1]. The choice of software for creating and maintaining the chart can be decided by the SPC team, based on availability and ease of use.

Interpret Control Charts

This involves looking for patterns, trends, or points that fall outside the control limits. A stable process will show random variation within the limits, while any points outside the limits - or non-random patterns within them - may signal that something in the process has changed [1]. It’s important to react appropriately: not every fluctuation requires action, but signs of special cause variation should be investigated. Interpreting the chart correctly helps avoid unnecessary adjustments while ensuring that real issues are addressed promptly. This step is key to making SPC a useful tool for ongoing process control rather than just a data-gathering exercise**.**

An essential part of effective SPC implementation is having a clear out-of-control action plan (OCAP) in place to guide the response when special-cause variation is detected in the process. According to Lim et. al [4] noted that the lack of structured responses to out-of-control signals is a common challenge in food industry settings, often leading to delayed corrective actions or

inconsistent handling of process deviations. A well-defined OCAP helps operators and quality personnel react quickly and appropriately by outlining specific steps to follow when a control chart indicates an abnormal pattern - such as a point outside control limits or a non-random trend within limits. Montgomery [1] emphasises that the goal of an OCAP is not only to bring the process back under control but also to understand and eliminate the root cause of the variation to prevent recurrence. A typical plan might include stopping the process, notifying the appropriate personnel, documenting the incident, conducting a root cause analysis (e.g., using the 5 Whys or Fishbone Diagram), and implementing corrective and preventive actions. Importantly, the plan should be standardised, documented, and well-communicated to all relevant staff to ensure consistency in response. This level of preparedness strengthens the overall effectiveness of SPC and supports a proactive quality culture.

Process Capability Evaluation

Once a process has been brought under statistical control, the next step is to assess its capability - that is, to determine how well the process can consistently produce output that meets specification limits. This involves comparing the natural variability of the process to the allowable range defined by customer or regulatory requirements. Key metrics such as C_p and C_{pk} are commonly used for this purpose, providing a numerical indication of whether the process is capable and centred within the specification limits. According to Montgomery [1], a capable process not only remains stable over time but also produces results that fall comfortably within the required tolerances. Assessing process capability is essential because a process can be statistically stable yet still incapable of meeting quality expectations. This step provides valuable insight into whether improvements are needed and helps set realistic targets for quality performance. If the process is not capable, the appropriate action is to reduce common cause variation and then reassess the control charts [37].

Business Benefit Estimation & Documentation

One of the key motivations for introducing SPC in a production environment is its potential to reduce waste, minimise process variation, and improve overall efficiency. By detecting issues early and responding to them before they escalate, SPC helps prevent defective products, reduce rework and scrap rates, and maintain consistent product quality [1]. Implementing SPC is not only a technical quality initiative - it also has clear business implications. Over time, these improvements contribute to cost savings, better resource utilisation, and increased customer satisfaction. In industries like dairy production, where margins can be tight and quality expectations are high, even small gains in process control can lead to meaningful business benefits. To fully realise these benefits - and to be able to measure them - proper documentation is essential. This includes documenting each step of the SPC implementation, from process selection and control chart setup to data sampling strategies, corrective actions, and outcomes. Clear records not only help in tracking progress and demonstrating impact, but they also support knowledge transfer, training, and continuous improvement efforts.

In regulated industries, well-maintained documentation ensures traceability and compliance with quality standards. QMSs stress the importance of documented information in quality management systems for traceability, consistency, and improvement [47]. Without proper documentation, valuable lessons may be lost, and the sustainability of the SPC program may be compromised. Therefore, the business case for SPC should be supported not only by the expected performance improvements, but also by a commitment to systematic and transparent documentation practices.

5.2.1 Pilot Test

As emphasized in prior studies, implementing SPC gradually - beginning with a well-planned pilot test - can prevent common pitfalls associated with rushed deployment and improve the chances of long-term success [37]. Before fully rolling out SPC across production, conducting a pilot test is a valuable step in ensuring the system works effectively in a real-world setting. A well-executed pilot not only helps to identify practical challenges early on but also provides an opportunity to fine-tune the approach based on real process conditions. One key outcome of the pilot should be a clear communication of the results - what worked, what didn't, and what adjustments are needed - so that all stakeholders are aligned moving forward. It also creates a chance to develop and formalise standard operating procedures (SOPs) for how SPC will be applied and maintained. This ensures consistency and provides a reference for training and future implementation. Additionally, the pilot helps verify that there is compatibility between existing digital quality management (QM) systems and the new SPC system, avoiding future integration issues and ensuring data flows smoothly between platforms. Overall, a pilot phase reduces risk and sets a solid foundation for broader application.

5.3 Anchoring Phase

The anchoring phase plays a crucial role in the successful integration of SPC, as it focuses on the activities necessary to embed the implementation and ensure long-term sustainability. In the developed roadmap, this phase consists of two key steps: developing key performance indicators (KPIs) and sustaining momentum & continuous improvement. Each of these steps is described in detail in the following sections.

Sustainability or maintaining an SPC implementation over time is just as important as the earlier phases. Lim et al. [2] highlight that, within the food industry, sustaining SPC practices remains one of the most challenging aspects of the entire implementation process, and they emphasise the need for further research in this area.

Develop KPIs

Key performance indicators (KPIs) are critical success factors that reflect the organisation's ability to meet its objectives. They are measurable values used to track the performance of key processes over time and serve as a foundation for identifying improvement areas. KPIs

play a central role in monitoring the effectiveness of SPC efforts, ensuring that performance targets are met and that improvements are sustained across operations [48].

Developing KPIs that reflect and monitor the performance of selected processes is essential for ensuring the continued progress of SPC implementation [4]. One practical example of a KPI in SPC implementation is the measurement of product defects. In dairy production, where quality and consistency are critical, tracking the number and type of defects provides direct insight into process performance.

Sustain Momentum & Continuous Improvement

Sustaining momentum refers to the continuous effort required to ensure that SPC implementation remains effective and long-lasting. It involves keeping the initiative alive beyond the initial rollout, embedding it into daily operations and the organisation's culture. Key activities include maintaining in-house SPC expertise, facilitating regular knowledge exchange, retraining personnel, and actively motivating employees and continuously improving. Establishing a learning-oriented culture within the organisation is equally essential. This can be fostered through collective learning, a clear and shared vision, personal development, and encouraging reflective thinking and adaptive behaviours across all levels [4].

Sustaining momentum also involves implementing reward systems that recognise and celebrate achievements related to SPC efforts. By acknowledging employees' contributions and showing genuine appreciation, organisations can foster continued motivation and strengthen commitment to the SPC journey. Recognising and rewarding success not only boosts morale but also helps retain knowledge and in-house expertise over time. Moreover, a well-structured reward system can drive employees to actively work toward achieving the company's KPIs. Continued support and visible engagement from top management remain essential in this phase to ensure long-term success [4].

Continuous improvement goes hand in hand with sustaining momentum. This includes regularly re-training staff, offering ongoing education, conducting improvement activities, and continuously reinforcing awareness throughout the organisation [4]. For a company to truly embed SPC into its operations, it must adopt a mindset of constant development across all areas. SPC implementation is not a one-time event, it is a long-term commitment that requires persistent effort and a culture that embraces growth and learning. By actively nurturing these aspects, the company ensures that SPC does not become a one-time project, but a sustained, continuous and evolving process of improvement.

6. Discussion & Conclusion

The discussion chapter examines the results and findings in relation to the research questions. It also includes a reflection on the chosen methodology, provides suggestions for the case company, and highlights research gaps along with recommendations for future studies.

6.1 What process step(s) in dairy production would benefit most from the integration of SPC, particularly in relation to controlling fat content to maintain product consistency?

The first research question aimed to identify which process step(s) in dairy production would benefit most from the integration of SPC, with a focus on maintaining fat content consistency. To address this systematically, a prioritisation matrix was developed based on four key evaluation criteria: Measurement Feasibility, Process Criticality, Impact on Fat Content Variability, and Economic Impact. These criteria were carefully chosen to ensure a comprehensive and practical assessment of each process step's suitability for SPC integration.

Measurement feasibility assessed whether it was practicable to obtain continuous or frequent fat content measurements at a given step, recognising that SPC relies on real-time or near real-time data for effective monitoring. Process criticality evaluated the importance of fat content control at each step in relation to legislative compliance, acknowledging that failure to meet regulatory standards could result in significant non-conformances. Impact on fat content variability considered whether a particular process step was a significant source of fat content variation, thus identifying points where controlling variability would have the greatest effect. Finally, economic impact addressed whether SPC implementation could drive cost efficiencies, particularly regarding the usage of cream and the ability to maintain desired fat specifications without unnecessary wastage.

Applying this prioritisation matrix, the study identified **standardisation** and **hydrolysis** as the two process steps most suitable for SPC integration. These two steps received the highest scores in the evaluation process, as presented in the prioritisation matrix (see Figure 16). Standardisation, by its nature, directly adjusts the fat content to meet specific product requirements. Variations at this stage can significantly influence final product consistency, making it both a critical and economically impactful step. Hydrolysis was similarly prioritised based on its evaluation against the four defined criteria. Although hydrolysis is primarily recognised for its role in enzymatic modification of dairy components, the process also met important thresholds in terms of measurement feasibility, process criticality, potential impact on fat content variability, and economic significance. The results align well with the central goals of SPC, which emphasise reducing variability at critical control points where measurement is feasible, regulatory requirements are stringent, and economic benefits can be realised. Importantly, the prioritisation matrix not only ranked the process steps but also

provided a transparent and replicable framework grounded in both theoretical soundness and industrial practicality.

Nevertheless, it is acknowledged that the outcomes are influenced by the selected criteria and the weights assigned during evaluation. Alternative contexts, different operational realities, or evolving technological capabilities could lead to different prioritisations. Therefore, while the findings strongly support the focus on standardisation and hydrolysis, further empirical validation through pilot SPC implementations would strengthen these conclusions and refine the approach for broader application. Additionally, it is important to recognise that the findings of this study are specific to the production environment and operational realities under investigation. Factors such as the particular dairy products manufactured, the process technologies in place, and the regulatory landscape all influenced the prioritisation outcomes. Therefore, while the methodology applied - particularly the use of the prioritisation matrix with the four defined criteria - offers a structured and replicable framework, the results themselves should not be assumed to be universally applicable without adaptation. Other dairy facilities, especially those with different product lines, automation levels, or regulatory pressures, might identify different process steps as most suitable for SPC integration. As such, the prioritisation matrix should be seen as a flexible tool, one that can be tailored to specific production contexts to guide decision-making on where SPC would deliver the greatest impact.

Critical reflection on process prioritisation method

While the use of a prioritisation matrix provided a structured and transparent framework for identifying suitable process steps for SPC integration, a closer examination reveals potential bias embedded in the evaluation, particularly in relation to the "*Measurement Feasibility*" criterion. In the matrix, the standardisation and hydrolysis process steps received the highest weightings under this criterion. This outcome, however, appears to be slightly influenced by the current operational practices at the case company, where fat content measurements are already being conducted at these stages.

Although the criterion was meant to evaluate how practical it would be to implement continuous measurement systems, in this case, it may have unintentionally supported the existing way of doing things. That is, the presence of existing measurements may have skewed the evaluation in favour of those steps, rather than offering an objective assessment of measurement feasibility across all relevant process steps. This creates a concern that the process may be going in circles - supporting current practices instead of objectively finding the best points in the process to apply SPC based on technical needs and quality goals

To strengthen the robustness of future prioritisation efforts, it may be beneficial to decouple the evaluation of feasibility from current practices and instead assess potential based on engineering and operational capability, even if measurement systems are not currently in place. This approach would help to uncover overlooked opportunities and ensure that prioritisation is driven by process control needs rather than convenience.

6.2 What actionable steps in a roadmap can be taken to integrate SPC into dairy operations?

The second research question sought to identify actionable steps that could guide the integration of SPC into dairy operations. In response to this, a structured and phased roadmap was developed, which is designed to guide the dairy industry through the complex process of SPC implementation (see Figure 17). This roadmap is divided into three primary phases: **pre-implementation**, **implementation**, and **anchoring**. Each phase encompasses specific steps aimed at addressing the organisational, technical, and cultural challenges associated with integrating SPC. The roadmap is intended to provide a clear, systematic, and sustainable approach, ensuring not only the adoption of SPC tools but also their long-term success and alignment with organisational goals. Each of these phases and their respective steps are described in detail in sections 5.1 to 5.3.

The pre-implementation phase serves as the foundational stage of the SPC integration process. Its critical role cannot be overstated, as it sets the groundwork necessary for the subsequent phases. The implementation phase is where plans turn into action, driving the successful integration of SPC. One of the key elements of the implementation phase is the iterative nature of the process. The roadmap encourages continuous learning and adaptation through feedback loops, ensuring that the SPC system evolves in response to real-world performance. It also emphasises the importance of pilot testing as an integral part of this phase. The pilot study allows the organisation to test SPC methods in a controlled environment before a full-scale rollout. It helps identify potential issues early on, enables fine-tuning of the approach, and allows for the development of SOPs. The pilot also verifies that SPC systems are compatible with existing digital quality management (QM) systems, ensuring smooth data integration. This step reduces risk and provides a solid foundation for scaling up SPC across the operation. The anchoring phase focuses on embedding SPC practices into the organisation's daily operations and culture. It ensures that SPC is not merely an isolated project but becomes a sustainable part of the company's long-term strategy. The two primary steps in this phase - developing key performance indicators (KPIs) and sustaining momentum through continuous improvement - are critical for maintaining the long-term success of SPC. By establishing relevant KPIs, the organisation can measure the effectiveness of the SPC system, monitor progress, and make necessary adjustments. Sustaining momentum and fostering a culture of continuous improvement are vital to ensure that the SPC system remains relevant and effective, even as production processes evolve and new challenges emerge. The anchoring phase also emphasise the importance of ongoing training and support to reinforce the importance of SPC within the organisation. Without these efforts, the integration may lose momentum, and initial benefits may diminish over time.

While the roadmap provides a clear and structured approach to SPC integration, it is important to recognise that its implementation will vary depending on the specific context of each dairy facility. Organisational size, technological maturity, workforce capabilities, and

market demands may necessitate adjustments to the timeline or steps involved. The roadmap is intended as a flexible guide, adaptable to different contexts, rather than a rigid framework. Additionally, it is essential to consider that the roadmap could be further refined by integrating actionable strategies to address resistance to change and creating a more robust feedback mechanism between phases. Feedback loops from pilot studies and initial implementations could be used to continuously update the roadmap, ensuring that it remains effective and responsive to technological advancements, evolving market needs, and lessons learned from earlier stages of implementation.

Limitations of the MSA illustration at the case company

The MSA conducted in this study does come with certain limitations. Typically, an MSA includes a Gauge R&R study, which captures both the variation caused by the measurement equipment (repeatability) and the variation between different operators (reproducibility). In a standard Gauge R&R, measurements from multiple operators using the same equipment are compared to identify any inconsistencies.

However, in this case, the company utilises two automated measurement machines that independently monitor fat content. Because the machines display the measurement values automatically, operator influence is minimal to non-existent. As a result, the reproducibility aspect related to operator variation is not relevant in this context. Therefore, a traditional Gauge R&R was not conducted. Instead, the MSA focused on evaluating the consistency and accuracy of the machines themselves by comparing replicate measurements, which was considered sufficient for the scope and conditions of this study.

Fat Content as the monitored parameter at the case company

While fat content was selected as the critical process parameter for monitoring process stability, this decision was largely based on its strong link to product quality and regulatory compliance. However, the selection process was not entirely data-driven and could be considered somewhat subjective. Several other process parameters - such as protein content, pH level, vitamin D content, lactose content and viscosity - also play significant roles in product quality and could have been valid candidates for monitoring, see Table 7. A more rigorous and objective approach, such as the use of designed experiments, would have allowed for a systematic evaluation of these variables to determine which one(s) most strongly influence overall process performance or product quality. Relying solely on expert judgment or practical familiarity may lead to overlooking variables whose impact is less obvious but still critical. However, at the case company, some of these alternative parameters presented practical challenges related to measurement or interpretation, which are outlined below.

Table 7: Other quality parameters and their associated limitations.

Parameter	Limitation
Protein content	Yearly average is set (set every 5yrs).
pH	The pH value obtained in a silo is influenced by the fermentation duration time. However, there was no available data connecting the pH values recorded to the corresponding fermentation duration.
Vitamin D	Added only to products up to 3% fat. Sent out to be measured at another lab.
Viscosity	Not measured regularly in the dairy.
Lactose content	Limited to lactose-free products.

6.3 Methods Discussion

The methodological approach adopted in this study was carefully designed to address the research objectives in a structured and practical manner. The choice of an exploratory case study as the overarching research strategy was appropriate given the aim to explore the relatively underdeveloped area of SPC integration within dairy operations. As highlighted by Yin [29], case studies are particularly valuable when seeking to answer "how" and "why" questions in real-world settings where boundaries are not sharply defined. This approach allowed for a deep, context-specific understanding of the production processes at the case company and the practical challenges involved in implementing SPC.

The overall research design - comprising literature study, current state visualisation, process prioritisation, and roadmap development - provided a systematic way of addressing both research questions. The literature study was essential in grounding the study in existing theories and practices, while also revealing the significant gaps in research related to SPC in dairy production. However, one limitation worth noting is that the literature study relied heavily on available full-text articles, potentially excluding relevant but less accessible sources. This may have somewhat constrained the breadth of perspectives considered, although it ensured the credibility and depth of the sources used.

The current state visualisation, which included process mapping, data collection, statistical data analysis, and MSA, offered valuable insights into the operational realities at the case company. The combination of primary data from interviews and secondary data from the company's database enriched the analysis. Nevertheless, the reliance on unstructured interviews, while allowing for flexibility and deeper insights, introduced some degree of subjectivity. Since interviews were not audio-recorded and transcribed, but rather summarised through field notes, there is a risk that certain nuances may have been lost. Future studies could consider more structured data capturing methods without compromising the open dialogue needed for exploratory case research.

The use of statistical tools such as descriptive statistics, individual value plots, and histograms was appropriate for analysing fat content variability. Conducting an MSA further strengthened the reliability of the data by ensuring that measurement variation did not significantly distort the observed process variation. The application of the paired t-test in evaluating the consistency of the fat content measurement systems added rigor to the analysis, even though only two machines and a relatively small sample size were included. The process prioritisation using a prioritisation matrix introduced a structured decision-making approach that minimised subjective bias when identifying critical process steps for SPC integration. The matrix was thoughtfully designed, with stakeholder input, which made the evaluation criteria both comprehensive and aligned with organisational priorities. However, it is acknowledged that some level of subjective judgment was unavoidable when scoring process steps against the criteria. Despite these challenges, the prioritisation matrix provided a transparent and replicable method for setting integration priorities.

Finally, the development of the SPC roadmap was a crucial contribution of the study. The roadmap was constructed through a careful synthesis of insights from the literature and practical knowledge from the case company, ensuring that it was both evidence-based and industry-relevant. The inclusion of a pilot study phase within the roadmap was a notable strength, allowing real-world validation before full-scale implementation. However, one limitation is that the roadmap, while structured and detailed, may require further adaptation depending on the unique operational, technological, and organisational contexts of other dairy facilities.

In summary, the methods used in this thesis were robust and appropriate for the research questions posed. Nonetheless, some limitations related to sample size, interview technique, and the generalisability of the roadmap are recognised. These reflections offer valuable guidance for future research aiming to build on the findings and extend SPC integration strategies in the dairy and broader food manufacturing sectors.

6.3.1 Ensuring Quality of Research

To ensure the quality of this research, several steps were taken throughout the project. From the beginning, the goal was to design a study that was both useful for the case company and solid from an academic standpoint. The quality criteria commonly associated with action research - such as dialogic, outcome, catalytic, and democratic validity - were considered and guided the research process.

One of the ways the research quality was strengthened was through early and active collaboration with the case company. Early in the project, discussions were held with staff at Arla to better understand the challenges they were facing, especially related to fat content variation. These conversations were not just about gathering background information, they also played a major role in shaping the research questions themselves. Rather than coming into the study with fully pre-defined questions, the researchers listened to the concerns raised

by Arla and used those insights to form research questions that were truly relevant to their needs.

Once the research questions were clear and agreed upon, the rest of the project became more focused. It gave the study a clear sense of direction and made it easier to plan and carry out each stage - from collecting data and mapping processes, to analysing results and developing the roadmap. Having input from the case company early on helped ensure that the research stayed practical and aligned with the realities of their operations. It also helped keep the work grounded and ensured that the outcomes would be useful, not just theoretical.

6.3.2 Study Limitations

Highlighting the limitations of a study is essential to acknowledge factors that may have constrained the research and to provide direction for future work. In this master's thesis, several limitations have been identified that are important to reflect upon. These insights help frame opportunities for continued research and development.

One key limitation was the lack of existing research identifying where SPC can be most effectively applied within a dairy production setting. This reflects a broader gap in SPC literature, where there is limited focus on dairy operations and insufficient studies outlining the specific production areas most suitable for SPC integration. As a result, more targeted research is needed to clearly define critical points of application in both dairy production and the wider food industry. Understanding the optimal conditions and locations for SPC implementation remains an important area for future exploration. Another limitation was the scarcity of literature addressing SPC implementation strategies tailored to the dairy industry. While a few studies touch on roadmap development and SPC integration within general food production, none specifically address the unique context, challenges, and requirements of dairy operations. This underscores a significant gap in academic research and suggests a need for more focused studies that consider the specific dynamics of the dairy sector.

Even more broadly, the food industry as a whole remains underrepresented in SPC literature when compared to traditional manufacturing industries. Although there have been efforts to apply SPC within food production, these are relatively limited in scope. SPC implementation in the food sector is still developing, and further research is needed to establish practical, industry-specific strategies.

This thesis contributes to closing that gap by attempting to tailor an SPC roadmap to dairy operations. However, the findings also emphasise the need for continued academic inquiry and practical innovation to support effective SPC integration in food and dairy production environments.

6.3 Suggestions for Case Company

This section presents recommendations on control chart selection and data sampling strategy, both of which are key elements within the implementation phase of the SPC integration roadmap. It is also recommended that the case company proceed with the remaining steps of the roadmap following the guidance provided in *Chapter 5 Roadmap for SPC Integration*.

Control Chart Recommendation for the Case Company

Since fat content, expressed as a percentage is a continuous variable, a control chart designed for monitoring variable data is most appropriate. According to Lim et al. [4], $\bar{X}$ and R charts are among the most commonly used control charts in the food industry. This type of chart is particularly suitable when data is collected in subgroups with a sample size between 2 to 9. However, if measurements are collected individually, which is currently the practice at the case company, an Individuals (I) and Moving Range (MR) chart would be a more appropriate alternative. Selecting the correct type of control chart is essential for accurately detecting process shifts or trends and plays a key role in supporting consistent, data-driven decision-making to maintain process stability.

Developing Data Sampling Strategy for the Case Company

It is recommended that more samples be taken during the process, with the first sample taken at the beginning, just shortly after the mixture of various raw materials is introduced. More samples would then be collected just before the contents are released to the next downstream processes. This approach enables the company to verify that the fat content remains stable throughout the process and helps detect any unwanted variation within the production batch. By establishing this sampling routine, the company can improve monitoring precision and enhance control over product consistency. This recommendation is based on the authors' understanding of the process and is therefore presented as a suggestion rather than a definitive requirement. It aims to provide a practical starting point for the case company to begin applying SPC methods in a manageable and meaningful way. As the company gains more experience with data collection and chart interpretation, the sampling strategy can be adjusted or expanded based on real process behaviour, operational constraints, and production goals.

In summary, this study set out to explore how SPC can be effectively integrated into dairy production, with a focus on controlling fat content to ensure consistent product quality. By applying a structured prioritisation method and developing a tailored roadmap, it was possible to identify key process steps - **standardisation** and **hydrolysis** - where SPC would offer the most value. The study also presented a practical approach for guiding implementation, from early preparation through to long-term integration. While the findings are specific to the case company, the methodology and roadmap offer a flexible foundation that other dairy producers can adapt to their own needs. Ultimately, this research highlights the potential of SPC to bring greater control, efficiency, and confidence to dairy operations - provided it is approached thoughtfully, with attention to both technical and organisational realities.

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9. Appendix

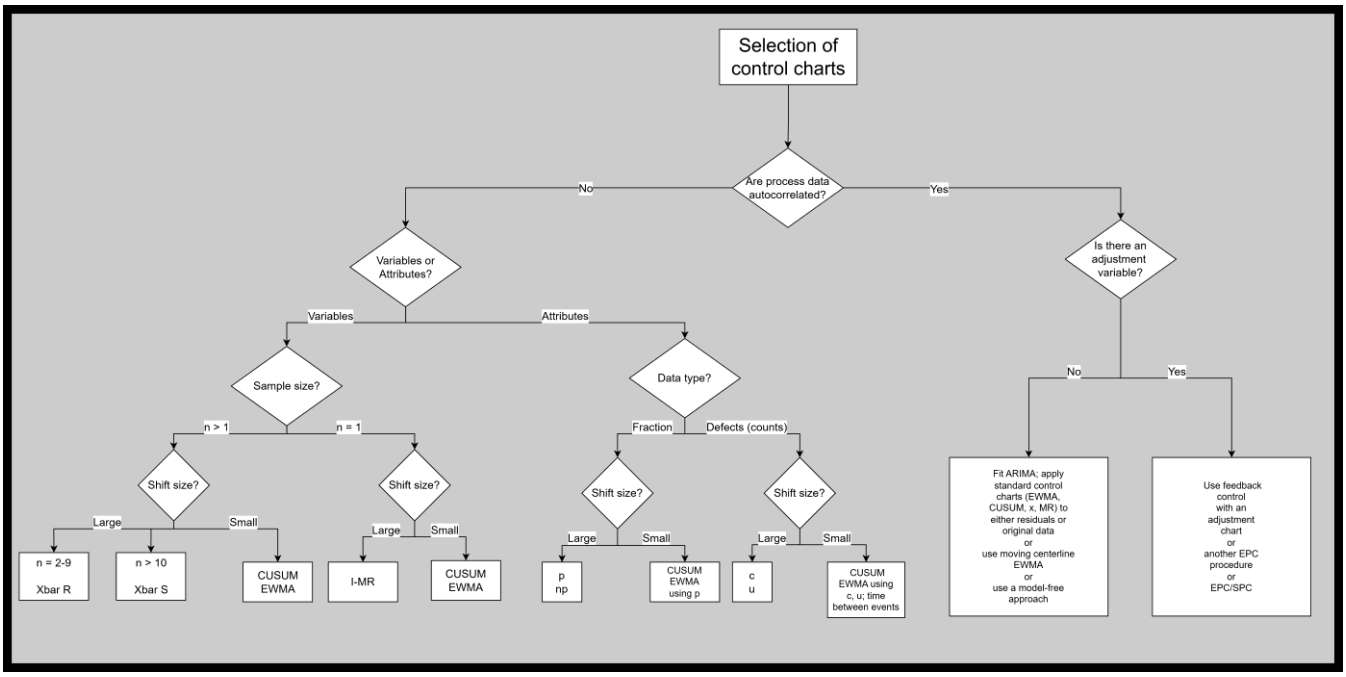

Figure 18: Selection of control charts flow, inspirations taken from [1,4].