CATÓLICA
ESCOLA SUPERIOR DE BIOTECNOLOGIA
PORTO

IMPROVEMENT AND OPTIMIZATION IN THE PACKAGING LINES OF THE FROZEN FISH COMPANY MARCABO Lda.

By

Valeria Ilian Montero Enriquez

September 2022

CATÓLICA
ESCOLA SUPERIOR DE BIOTECNOLOGIA
PORTO

IMPROVEMENT AND OPTIMIZATION IN THE PACKAGING LINES OF THE FROZEN FISH COMPANY MARCABO Lda.

Training Placement Report /Thesis presented to Escola Superior de Biotecnologia of the Universidade Católica Portuguesa to fulfill the requirements of

Master of Science degree in Food Engineering

By

Valeria Ilian Montero Enriquez

Supervisor (Company): João Peixoto (M.Sc.)

Tutor (University): Teresa Maria Ribeiro da Silva Brandão (Ph.D.)

September 2022

Resumo

Na indústria alimentar, a importância de assegurar a máxima qualidade possível de produtos acabados tornou-se cada vez mais um dos principais objetivos das organizações que operam neste sector, mas usar ferramentas para obter um produto melhor com uma boa qualidade é um desafio.

Neste desafio utilizou-se uma metodologia designada por “Six Sigma”, que tem como objetivo reduzir os produtos defeituosos. Esta metodologia foi aplicada durante 21 dias a produtos congelados e embalados (todos eles peixes e cefalópodes), com o objetivo de aumentar a qualidade. Três linhas de produção foram o alvo, designadas como linhas "Cefalópodes", "Ensacadora" e "Higienização". O ciclo DMAIC (Definir, Medir, Analisar, Melhorar e Controlar) foi aplicado e apoiado por ferramentas e técnicas de qualidade ao longo de todas as suas fases.

O nível “Sigma” obtido na fase de Medida foi de 4,57 para a linha "Cefalópodes", 3,37 para a linha "Ensacadora" e 4,05 para a linha "Higienização". O nível “Sigma” ideal seria igual a 6, o que corresponde a 3,4 produtos não conformes (neste caso com um bom sistema de embalagem/procedimento de controlo acima do considerado aceitável) em um milhão de produtos. No entanto, nesta primeira abordagem, seria irrealista atingir o nível 6 na escala de “Sigma” devido à sua sensibilidade e constrangimentos, esperando-se que pelo menos o nível 5 fosse atingido. No entanto, a produção na empresa aumentou, embora tivesse sido difícil acompanhar os produtos e aumentar o “Sigma”.

Na fase de Análise, as causas mais prováveis do problema foram analisadas, tendo sido selecionadas ações na fase de Melhoria. As causas identificadas tiveram origem principalmente nas linhas de produção onde as soluções/melhorias consistem na reestruturação dos planos de produção, qualidade e manutenção para alcançar um ciclo de produção mais eficiente sem atrasos nas linhas. Estas soluções revelaram-se as mais adequadas, aproximando-se dos pontos críticos do problema e aumentando o nível de “Sigma”. Na fase de Controlo, procurou-se reunir medidas e sugestões para que as possíveis melhorias pudessem ser implementadas de forma contínua e que as ações possam ser implementadas no futuro para estabilizar os processos o máximo possível.

Palavras-chave: Metodologia “Six Sigma”, DMAIC, controlo de qualidade

Abstract

In the food industry, the importance of ensuring the maximum possible quality of finished products has increasingly become one of the key objectives in organizations operating in this sector but using the tools to get a better product with good quality is a challenge.

For this challenge, it was used a methodology called Six Sigma, which has the objective of reducing defective products. This methodology was applied for 21 days to packed frozen products (all of them fish and cephalopods) aiming at increasing quality. Three production lines were the target, designated as “Cefalópodes”, “Ensacadora” and “Higienização” lines. The DMAIC (Define, Measure, Analyze, Improve and Control) cycle was applied and supported by tools and quality techniques throughout all its phases.

The Sigma level obtained in the Measure phase was 4.57 for “Cefalópodes” line, 3.37 for “Ensacadora” line and 4.05 for “Higienização” line. The ideal Sigma level would be equal to 6, which corresponds to 3.4 non-compliant products (in this case with a good packaging system/control procedure above the one considered acceptable) in one million products. However, in this first approach, it would be unrealistic to reach level 6 on the Sigma scale due to its sensitivity and constraints, so it was pointed out to reach at least level 5. Nevertheless, the production in the company increased although it was difficult to follow the products and increase the Sigma level.

In the Analyze phase, the most probable causes of the problem were analyzed, and actions were selected in the Improve phase. The identified causes had origin mainly in the production lines where solutions/improvements consist in restructuring the production, quality, and maintenance plans to attain a more efficient production cycle without delays in the lines. These solutions proved to be the most appropriate ones, approaching the critical points of the problem, and increasing the Sigma level. In the Control phase, we sought to gather measures and suggestions so that possible improvements can be implemented continuously and that actions can be implemented in the future to stabilize the processes as much as possible.

Keywords: Six Sigma methodology, DMAIC cycle, quality control

Acknowledgements

A stage that changed my life ends, everything began when it was most necessary, it was two years of great effort and struggle, starting with a dream and now it is more a reality. I wanted to live the experience of living somewhere else, risking, and leaving everything behind. COVID came closing the doors of my opportunities, and when I had no option to continue in this country, the idea of studying came and opened the door I was asking for.

But this was not easy, I had to strive to learn a language that I had been learning little, adapt to people who had a line of study, unlike me who had not studied for years, but as Paulo Coelho said in his book The Alchemist "When you really want a thing, the whole universe conspires to help you get it", and that's what happened. I had long nights of study and not sleeping, being the cause the work and study, always on weekends I saw the recorded classes to understand the subject, continue studying, do projects in zoom, professional practices at a temperature that I am not used to, and then, with perseverance and discipline I got work to learn the experience to the fullest.

But did I do this alone? Never. And that is why, I would like to thank through this section my most sincere thanks to the people who were with me on this path.

First of all, to God for giving me light before the question of what I would do in Portugal, always being with me. Then there is a main scaffold in my life, which is my mother, being an unconditional support to fulfill this goal in a moral and economic way. That, even though he didn't like it being far away and less so during the pandemic, he knew the ability I must accomplish things and always trusted me to the end. I will always thank you for this.

I want to thank the people I love most in this wonderful country, they are my project team Vera, Inés C. and Inés S. who never left me in the moments I needed most, from understanding the subject, as well as personal help to continue being here and thus achieve my goal. They will always be in my heart, thank you for never leaving me.

Thirdly, I would like to thank my manager Gustavo Borges and team leader Lauro Lapa, who gave me their support to finish this process, even though I faced problems such as fatigue and physical exhaustion from working and studying. I will always keep in mind that on the road to success you meet people who help and care about people to work in an efficient way. Thank you.

I would like to thank my tutors that help me through this. One is Engº João Peixoto, he first accepted me in Mar Cabo and helped me along the way of learning and carrying out the project, as well as in the thesis. And to my other tutor, Engª Teresa Brandão, who listened to me when I had health problems, she always supported me to continue and her help was incredible in the thesis. Thank you very much to both.

Also, I would like to thanks to the company Mar Cabo Lda. that let me do the internship in there. All the people were supportive and always helping me to achieve this goal.

And finally, I want to thank on behalf of the school Professor Cristina, who although she always had many things, I always look for a way to help me finish the master's degree.

Always grateful for life, for the challenges that show who we are and the wonderful people you are.

Infinite Thanks!

Contents

Tables Index

Figures Index

List of Symbols and Abbreviations

A_3 - Constant for calculation of control limits

B_3 - Constant for calculation of control limits

B_4 - Constant for calculation of control limits

C_i - Criterion i

D - Distribution D of Lilliefors

F - Fisher distribution

F_0 - Statistic based on Fisher distribution

H_0 - Null hypothesis

H_1 - Alternative hypothesis

K - number of classes

n - Number of sample data

N - Total number of observations

O_j - Option j

p - Probability

S - Standard deviation of the sample

Sp^2 - Sample pooled variance

t - time or t-Student distribution

t_0 - Statistic based on t-Student distribution

X_i - Sample data for point (i= 1, 2, 3… n)

$\bar{X}$ - sample average (mean)

Z - Standard Normal distribution

Z_0 - Statistic based on Standard Normal distribution

α - Significance level

Δ_0 - Difference between two populations means

μ - Population mean

ν - degrees of freedom

σ - Population standard deviation

ω - Statistic related to a given quality

Abbreviations

6M - Manpower, Methods, Medium, Machinery, Materials and Measurements

ARL - Average Run Length

CTQ - Critical-To-Quality

DFSS - Design for Six Sigma

DMAIC - Define, Measure, Analyze, Improve and Control

DPMO - Defects Per Million Opportunities

FMEA - Failure Mode and Effects Analysis.

GFSI - Global Food Safety Initiative

GMP - General Manufacturing Practice

HACCP - Hazard Analysis and Critical Control Point

IFS - International Food Standard

ISO - International Organization for Standardization

LC - Mean value for the variable to control

LIC - Lower Control Limit

LSC - Upper Control Limit

LSS - Lean Six Sigma

QMS - Quality Management Systems

SIPOC - Supplier, Input, Process, Output e Customer

SQF - Safe Quality Food

TQM - Total Quality Management

IFS - International Food Standard

ISO - International Organization for Standardization

1. Introduction

This project focused on a methodology currently used to reduce errors that occur in packaging lines of frozen products produced in Mar Cabo Lda., for improvement and optimization of the processes. In this section, the fish industry is described and quality management systems for continuous improvement are approached.

1.1. The Fish Industry

Marine ecosystems, and in particular fisheries, have been and are an important source of protein for direct human consumption and for animal feed; on the other hand, they support an important economic activity that generates jobs and income, particularly in developing countries, where it is estimated that no less than 100 million people live from or are related to fishing activities (Bifani, 2007).

Portugal has the highest per capita consumption of fish in the European Union. The contribution of fishing activity to the Gross Domestic Product (GDP) is less than 1%. Fishing provides around 15 000 jobs, and employment has been progressively reduced since the beginning of the nineties. Currently, in Portugal, the fisheries sector provides 0.6% of total employment. Fishing activity is concentrated in small coastal communities, where it is a very important socio-economic factor. Of the thirty regions most dependent on fishing in the European Union, two are located in Portugal (Algarve and Azores).

The Portuguese fishing industry is quite large and diversified. Fishing vessels are classified according to the area in which they operate; they can be divided into local fishing vessels, coastal fishing vessels and long-distance fishing vessels.

The local fleet consists mainly of small traditional vessels, covering, in 2004, 87% of the total fishing fleet and representing 8% of the total tonnage. These vessels are generally equipped to use more than one fishing method, such as hooks, gillnets, and traps, and constitute the so-called multipurpose segment of the fleet. The capture yield is low but reasonable income levels are achieved by the high commercial value of the species caught: octopus, black sablefish, conger eel, pout, hake, and anglerfish are examples. This fishing industry accounts for 37% of total catches (FAO, 2004).

According to national fisheries statistics carried out by the National Institute of Statistics (INE) and General Directorate of Natural Resources, Security and Maritime Services (DGRM), the Portuguese fleet captured 163 837 tons of fish in 2019, an increase of 13.1% compared to 2018.

Of the total caught in the year of analysis, 110 454 tones correspond to fresh or chilled fish, which corresponds to the value of EUR 262 233 thousand (INE, 2020).

In 2019 the Processing Industry of Fisheries and Aquaculture reached a total production of 233,000 tons (220,000 tons in 2018), distributed by the following segments (Figure 1): frozen, dried and salted, and preparations and canned products. Total sales represented 95% of domestic production (94% in 2018). The production of 2019 corresponded to an increase of 6.0% compared to the previous year, distributed by: dried and salted (+15.2%), preparations and canned fish (+3.0%), and frozen (+2.8%). Regarding the production structure, the frozen group is the most representative one with 51.1% of the total production (52.7% in 2018). The dried and salted products represent 27.7%, with an increase when compared to the previous year (25.5% in 2018) and finally the group of preparations and canned fish with 21.2% (21.8% in 2018).

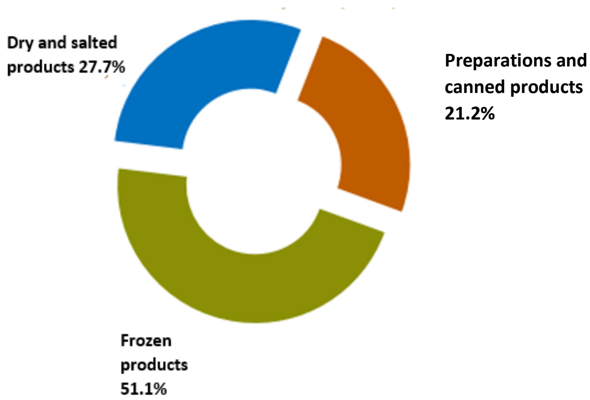

Figure 1. Segments of the processing industry of fishery products (2019).

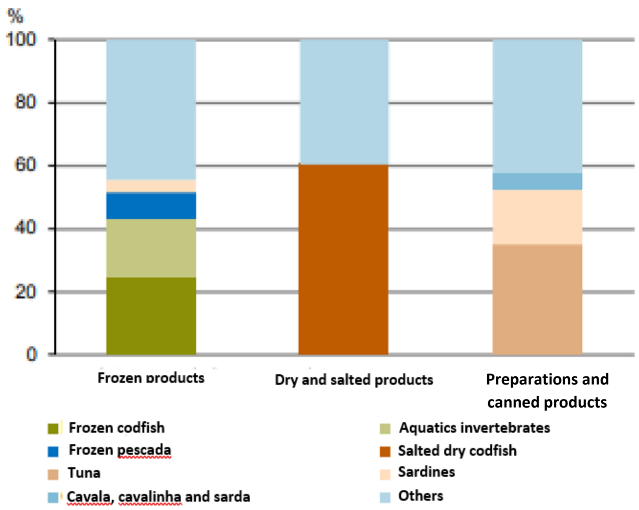

Figure 2. Quantities produced by the processing industry of fishery products (2019).

In 2019 the processing industry of fishery products earned EUR 1 172 million, reflecting an increase of 9.8% compared to the previous year's results. The increase in total sales was due to a higher appreciation of the dried and salted (+20.3%) and frozen products (+11.2%) subsectors, resulting in increases of EUR 57 million and EUR 55 million, respectively. Concerning the amount of sales value in 2019 (Figure 3), frozen products remained the most important group, with 46.4% of the total sales value (45.8% in 2018), followed by dried and salted with 29.0% (26.5% in 2018), thus surpassing the preparations and canned products which did not exceed 24.6% of sales (27.7% in 2018). The changes in the value of sales are in Figure 4.

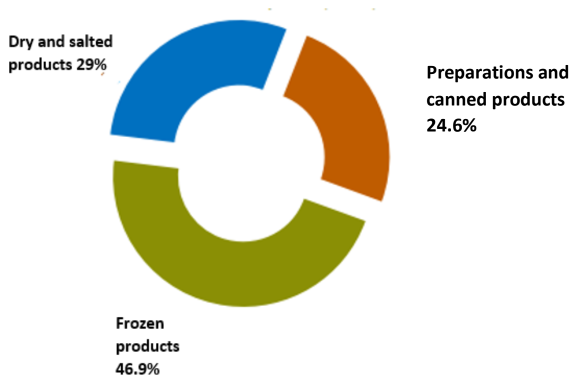

Figure 3. Amount of sales of the fish processing industry (2019).

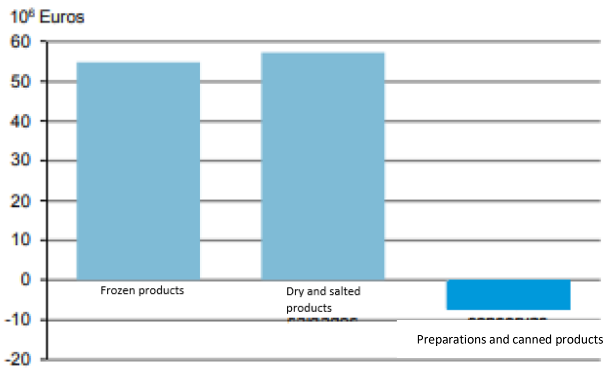

Figure 4. Changes in the value of sales of the fish processing industry.

The reduction of costs related to production is one of the main objectives of companies. The reduction of defects or non-compliant products means being able to offer more products to the customers, investing the same resources, and being more productive. In this way, a food company to continue to succeed in the market must be open to constant improvements.

Speaking specifically about the fishing process, being a product of high perishability, which manages to guarantee security and quality throughout the distribution chain paying special attention to handling, transport and storage offering a product of excellent quality which is beneficial for customers (Dudbridge, 2011).

Nowadays, presenting a good product that is mainly for the company that offers it, obtains recognition in the market, but above all it generates reliability on the part of consumers that will be reflected in an economic benefit, obtained through the fulfillment of their operational goals and delivery times, generated by the increase in productivity; thus, guaranteeing permanence in the market satisfying the needs and requirements of stakeholders. These objectives are achieved through the implementation and execution of projects or methodologies that lead to continuous improvement, which allows companies to create a culture of development, growth and strengthening of processes.

1.2. The Frozen Food Industry

Currently, freezing has been established and recognized as the outstanding method for preserving the natural qualities of perishable products, particularly for meats, including fish (Zhan et al., 2017; Fikiin, 2007). As a result, the frozen food industry has become a substantial part of the global economy and the well-being of the population. At the same time, the high reputation of freezing techniques as the safest and which allow for greater preservation of the nutritional value of products should not create the misperception of total food security and thus lead to negligence and lack of diligence in the management of the frozen food supply chain. Although freezing food drastically reduces putrefaction phenomena, physical and biochemical reactions can occur and be accentuated if adequate processing and handling conditions are not implemented (Fikiin, 2007).

The lack of adequate procedures in companies operating in the frozen food industry can lead to the premature detriment of the quality attributes of their products and can potentially be dangerous for consumers if bacteriological reactions are given in food. Nevertheless, it is proposed to conduct a study in a company that operates in the frozen food sector to verify and possibly improve its production processes.

1.3. Food Quality Control

Food quality control refers to the use of technological, physical, chemical, microbiological, nutritional, and sensory parameters to define acceptable tolerance limits for the consumer, while at the same time minimizing costs for the producer. Quality control also involves maintaining product quality within the 9 parameters defined as initially acceptable. These quality factors are dependent on specific attributes, especially sensory properties (namely taste, color, aroma, and texture), quantitative properties (such as the percentage of sugar, protein, and fiber), and other attributes such as peroxides, monocarboxylic acids and enzymes (Adamson, 2004).

The most important objective for food quality is to ensure consumer protection. To ensure the standardization of procedures related to the food industry, food laws and regulations cover related activities affecting marketing, production, labeling, additives used in products, dietary supplements, compliance and GMP (General Manufacturing Practice), the use of tools such as HACCP (Hazard Analysis and Critical Control Point), and the inspection of factories and import and export activities (Adamson, 2004). The most important factors in the quality of processed foods are the safety and reliability of the same, followed by taste and price. The need for food quality control stems from the losses that food companies suffer if they are involved in defective products. This evidence also largely affects the image and reputation of companies.

1.4. Quality Management Systems in the Food Industry

The food supply chain describes the path of food products throughout the industrial procedure, from their production to their distribution. The food supply chain is generally defined in five stages: the supply of raw materials, the production and processing of products, packaging, storage and transportation, sale, and consumption (Grunert, 2005).

To ensure safety and quality for the consumer, the existence of quality management systems in each sector of activity in the food industry is indispensable and the number of organizations in the food industry that use Quality Management Systems (QMS) has been increasing (Orris et al, 2000).

The quality management systems to be highlighted in the food industry are as follows (Baert et al., 2005):

1. GFSI (Global Food Safety Initiative) - The mission of this initiative is to continuously progress food safety management systems to gain consumer confidence in the safe delivery of food;
2. IFS (International Food Standard) - In 1999 an association of German retailers (BDH - Bundesvereininung Deutscher Handelsverbände) began to develop a standard in which suppliers would be controlled by labelling their products (nutrition declarations), trying to create a single form of cross-cutting assessment and control across all organizations. Its content is based on the structure of ISO 9001:2000, and ifs is fundamentally a list of requirements that food industries must meet to be certified;
3. SQF 2000 (Safe Quality Food) - This standard is based on the requirements defined in codex Alimentarius and ISO 9000. Due to divergences in size, processes and products and the impracticality of being used a single standard for all companies in the food industry;
4. HACCP - The initiative to develop a standard to certify the HACCP system has been introduced in the Dutch food processing industry. The first version was introduced in 1996, with the name 'Criteria for the evaluation of a HACCP operation system'. Six years later it was renamed 'Requirements for HACCP-based food safety system'. It is based on the 7 basic principles and the 12 steps of the HACCP, which are the following (FAO, 1998);
5. ISO (International Organization for Standardization): ISO 15161:2001 – 'Guidelines for the application of ISO 9001:2000 in the food and beverage industry'. This standard provides a practical framework for coordinating different requirements and standards in a single standard, including good production practices, and requirements for the implementation of HACCP and a quality management system.

1.5. Continuous Improvement

Continuous improvement is in a close relationship with Lean Manufacturing since both imply a continuous search for improvements in all areas of the organization. Continuous improvement must have the participation and commitment of all members of the organization: managers and line workers. According to Marin-Garcia et al. (2008),"continuous improvement is defined as small incremental changes in production processes or work practices that allow to improve some performance indicator". They add that continuous improvement is based on the Deming cycle, composed of four phases, which are indicated in the Figure 5.

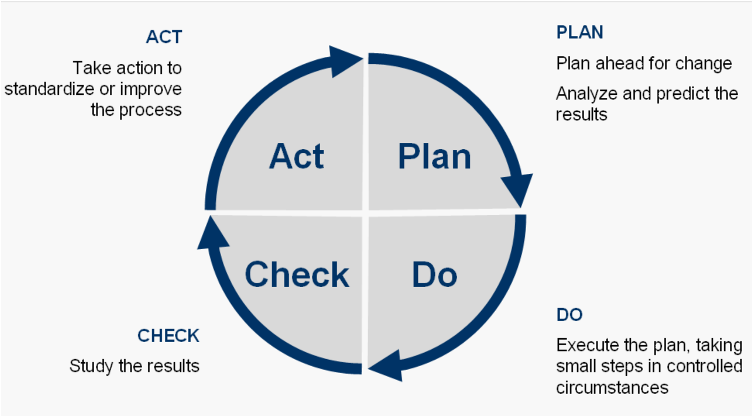

Figure 5. Deming cycle (Marin-Garcia et al., 2008).

Continuous improvement more than a tool is a philosophy that must be integrated into the company and must have the support of the workers so that it can be carried out and maintained over time, in addition this philosophy is based on the fact that there will always be something to improve in the company no matter how small it is, either in the area of manufacturing or in the service area, which is where the research takes place.

2. Six Sigma

2.1. Definition

Six Sigma had its origin in the year 1988 in the company MOTOROLA. The purpose and objective of this program was to reduce the variations that occur in the processes to achieve 3.4 DPMO defects (parts per millions of opportunities). This reduction of defects could be achieved by using different statistical methods such as ANOVA, control graphs, designs of experiments, regression and other statistical tools. There was also no shortage of process management techniques.

Six Sigma uses statistical tools for the characterization and study of processes. The objective of the Six Sigma methodology is to reduce variability, so that the process is always within the limits set by customer requirements.

The letter Sigma is used in statistics for the calculation of the standard deviation of a population. An estimator of Sigma based on sample standard deviation is given by the following equation:

$$S = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}} \qquad (1)$$

In the above, the letters refer to:

S - standard deviation of the sample

X_i - sample data for point (i= 1, 2, 3… n)

$\bar{X}$ - sample average (mean)

n - number of sample data

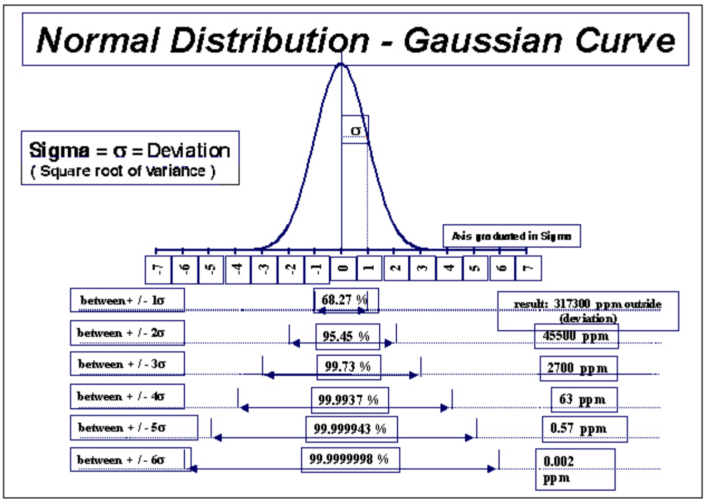

Figure 6. Gaussian curve.

Getting 3.4 defects in a million opportunities is an ambitious but achievable goal. The efficiency of a process can be classified based on its Sigma level (Normal distribution; Figure 6):

1. 1Sigma = 690,000 DPMO = 31% efficiency
2. 2Sigma = 308,538 DPMO = 69% efficiency
3. 3Sigma = 66,807 DPMO = 93.3% efficiency
4. 4Sigma = 6,210 DPMO = 99.38% efficiency
5. 5Sigma = 233 DPMO = 99.977% efficiency
6. 6Sigma = 3.4 DPMO = 99.99966% efficiency

The percentages were obtained assuming a deviation from the nominal value of 1.5 Sigma.

Among the benefits obtained from Six Sigma are improvements in profitability and productivity. An important difference from other methodologies is customer orientation.

Six Sigma has evolved since its application merely as a quality tool to be included within the key values of some companies, as part of its philosophy of action. Although it was born in companies in the industrial sector, it has been successfully applied in the service sector today. Six Sigma has been influenced by the success of other tools, such as lean manufacturing, with which it shares some objectives and it is complementary, generating a new methodology known as Lean Six Sigma (LSS).

In a study on the impact of various quality management techniques and tools all implemented in the same business organization, the company found that Six Sigma had the greatest impact compared to other methodologies, such as Failure Mode and Effects Analysis (FMEA) and Total Quality Management (TQM), among others (Dusharme, 2003).

2.2. Six Sigma Team

One of the main objectives of this methodology is to achieve a high degree of efficiency and effectiveness in each of the processes, in this way attaining the expectations and needs of the client, translated into the satisfaction of each of them. Each of the Sigma project leaders play an important role in the continuous improvement of processes, such as: the Board of Directors, champion, responsible for implementation, black belt, green belt, and master black belt.

2.3. Phases of the Six Sigma Methodology

The Six Sigma methodology proposes a work strategy, known as DMAIC - Define, Measure, Analyze, Improve, Control – a structured troubleshooting existing procedure (Figure 7). For the design of new products and processes, instead of DMAIC, which applies to products and processes already in production, in this case can be applied the Cycle DMADV - Define, Measure, Analyze, Design, Verify. The DMADV cycle is an integral part of the DFSS (Design for Six Sigma) approach (McCarty et al., 2004).

1. **Define** is the initial phase of the Six Sigma methodology, where the most important problem, objectives, team, and processes of the project are defined.

   It seeks to describe the specific problem, identify the objective of the project and its exact scope, which can be broken down and organized using a Project Charter, as well as determine the key customers of the process to be optimized as well as their CTQs (Critical-To-Quality). Its purpose is to ensure that the project gains acceptance by the company (John et al., 2015).

2. **Measure** - in this phase information is collected on the possible causes that affect the process and its performance, as well as it is evaluated the capabilities and the current sigma of the process.

   After data collection, the current performance of the process is measured. To ensure a reliable measurement of the performance, valid metrics should be chosen for the conformity of its outputs, which allow to apply actions that directly affects the performance to the proposed goal (McCarty et al., 2004). At the conclusion of this phase, Project Charter should be reviewed and, if necessary, updated with new targets and restrictions that will be identified in the project.

3. **Analyze** - the root causes that affect the current performance of the process and the error rate generated by it are analyzed to subsequently propose a redesign of the process or product according to the results.

   After identifying the potential causes that affect the process in its current state, a process of selecting them follows, aiming to identify the process so that the gap between the current performance and the goal defined in the Define or Measure phase is possible, depending on whether project charter was revised. For this evaluation, it is crucial to apply statistical tools that suit the problem under analysis (Pyzdek, 2003). At the end of this phase, the output should be a list of potential causes of the problem, bridging with the next phase, where solutions are developed that allow the resolution or mitigation of the problem.

4. **Improve** - in this stage of identifying the possible characteristics within the process that can be improved, solutions are proposed to mitigate or eliminate the causes that originate problems in the processes and thus attain the expectations and needs of the client.

   It is important to note that, in addition to the analysis of the effects that solutions may have on improving the process, an analysis of costs versus benefits should be carried out, not forgetting that it is the implementation of changes to the structure and procedures of a company, and that a solution that presents very high costs confers greater risks.

5. **Control** - a control plan of the new process is elaborated to maintain the Sigma achieved.

   To ensure process stability, comparations between the initial and current results of this phase should be made using statistical tools for monitoring (Pyzdek, 2003).

Figure 7. DMAIC cycle.

2.4. Quality Tools

The tools that will be explained below are characterized by being visual and simple, where simple statistical methods are used, which can detect and solve the problems that arise in the company. The use of the tools will depend on the goal that is intended.

By applying the tools in organizations and using them correctly, they allow the resolution of 95% of the problems of the workplaces, leaving only 5% of the cases in which other more complex tools are needed (Ishikawa, 1994).

The use of these tools and techniques is done in a structured way, based on the connection of each phase of the DMAIC cycle and considering the main objective that is intended to be achieved in each of the phases. The following topics present some of the tools and techniques used throughout the DMAIC cycle.

2.5. Project Charter

This document represents a written statement, developed, and coordinated by the customer, the organization that provides the product or service, and other key stakeholders, who authorize a project, and ensures that the resources and management commitments necessary to achieve success are provided.

The following elements should be listed in a project charter: the name of the project; brief description of the problem; scope of the project; objectives; roles and responsibilities of team members; dates and milestones to be fulfilled; the results to be achieved with the completion of the project; restrictions and assumptions; performance measurement parameters.

The execution of this document should be carried out as soon as the selection of the project to be carried out is complete. This document helps the team to carry out the project within the established time, meeting the defined budget, and according to specifications (McKeever, 2006).

2.6. Supplier, Input, Process, Output e Customer (SIPOC)

SIPOC is a diagram that allows you to expand the information provided by process maps to identify stakeholders within the operation. This tool identifies all variables that affect the performance of the process and then prioritize them, so that the team can focus on its field of implementation of actions. The SIPOC diagram is a tool that returns a complete supply chain reference, to better understand the process itself and its relationships (McKeever, 2006).

2.7. Gantt Diagram

The Gantt diagram is a tool that allows to define the beginning, end, and durations of all tasks that constitute a project. It is essentially a horizontally oriented bar chart, in which the horizontal axis corresponds to the time and vertical axis to a collection of related activities, machines, employees, or other resources. Bars are used as a form of representation of duration and start and end times of activities.

2.8. Critical-To-Quality (CTQ)

The first phase of the DMAIC cycle is the team's learning about what parameters are truly important to customers. The tools and techniques used to define CTQs are the following (Pyzdek, 2003):

- Technique of critical incidents
- Letters; Complaints
- Internet chat chats, forums
- Publishing reviews

2.9. Process Flowchart

This tool provides a visual representation of the entire process that is the object of analysis, thus allowing to (John et al, 2015):

- Facilitate the understanding of the entire procedure
- Harmonize the understanding of the process by the entire project team
- Clarify the individual steps of the process
- Establish the basis for advanced process analysis
- Identify the potential for optimization and improvement in the process(s)
- Clarify the complexity of the process

2.10. Data Collection Plan

The data collection plan describes the various factors to be considered in the data collection process for the Measure phase of the DMAIC cycle, i.e. (John et al., 2015):

- What data to collect (data definition)
- How the collection is carried out (operational definition)
- When the collection is carried out (frequency)

In the construction of the data collection plan, the customer is firstly asked about the quality requirements to be satisfied, both expressed and latent. Next, the team members jointly decide which or what data to collect that allow the evaluation of the current state of the project quantitatively, starting from a qualitative evaluation (Pyzdek, 2003).

2.11. Hypothesis Test

Hypothesis testing is a statistical inference method that allows verifying whether a given hypothesis made about a given parameter of a population (or several populations) should be rejected or not, based on the results obtained from one or more samples.

The hypothesis that is intended to be tested is the Null Hypothesis (H_0) which always contains an equality in its formulation. The veracity of the Null Hypothesis is assumed throughout the test, until there is statistical evidence to reject it, a rejection that is based on a test statistically appropriate to the case in analysis.

The Alternative Hypothesis (H_1) is an alternative statement to the Null Hypothesis, and always contains an inequality in its formulation; depending on the case, the hypothesis test will be bilateral (≠), or unilateral (< or >). In Figure 8, a unilateral test on the right is shown. The reject zone is defined by the set of test statistic values that lead to the rejection of H_0. The corresponding non-rejection zone may be unilateral or bilateral, depending on the case in question. Considering two populations with normal distributions, independent and with means μ_1 and μ_2, known variances σ_1^2 and σ_2^2 , the hypothesis to be tested to verify whether the difference of the two means is equal to one Δ_0 value is formulated by:

$$H_0: \mu_1 - \mu_2 = \Delta_0 \tag{2}$$

$$H_1: \mu_1 - \mu_2 \neq \Delta_0 \tag{3}$$

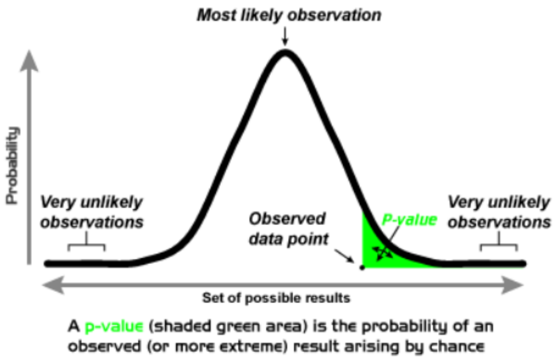

Figure 8. One-sided test (right).

Thus, by collecting two samples with sizes n_1 and n_2 with means $\bar{X}_1$ and $\bar{X}_2$, the statistic associated to the test will be based on the standard Normal distribution:

$$Z_0 = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} = \frac{(\bar{X}_1 - \bar{X}_2) - \Delta_0}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} \tag{4}$$

The null hypothesis is rejected when $|Z_0| > Z_{\alpha/2}$, being α the significance level assumed.

If the two populations have unknown and different variances, calculations can be done by assuming samples variances instead. The statistic of this test will be based on t-Student distribution:

$$t_0 = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} = \frac{(\bar{X}_1 - \bar{X}_2) - \Delta_0}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \tag{5}$$

If the variances are not significantly different, a combined (pooled) variance can be used and calculated by:

$$Sp^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \tag{6}$$

The null hypothesis is rejected when $| t_0 |> t_{\alpha/2,\nu}$ being ν the degrees of freedom that can be calculated by:

$$v = \frac{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)^2}{\frac{\left(\frac{S_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{S_2^2}{n_1}\right)^2}{n_2 - 1}} \tag{7}$$

Considering two Normal populations with variances $\sigma_1^2$and σ_2^2, and intending to verify if they are not significantly different, the hypotheses to be tested are:

$$\mathrm{H}_0: \sigma_1^2 = \sigma_2^2 \tag{8}$$

$$\mathrm{H}_1: \sigma_1^2 \neq \sigma_2^2 \tag{9}$$

The statistic is based on the F-distribution given by:

$$F_0 = \frac{S_1^2}{S_2^2} \tag{10}$$

The null hypothesis is rejected when $| F_0 |> F_{\alpha/2},\nu_1,\nu_2$.

2.12. Control Chart

A control chart is a graph that demonstrates the evolution over time (t) of a statistic (ω) referring to a given quality characteristic. This graph is represented by the points relative to the pair (t, ω), being LC the mean value for the in-control process, LIC the lower control limit and LSC the upper control limit.

If one or more points are outside the interval [LIC, LSC], it is inferring that the process is out of statistical control. In cases where the points present a special or systematic tendency and not a random behavior, although there are no points outside the range [LIC, LSC], it may indicate the existence of special causes; in this case, the reason for its presence should be investigated and corrective actions taken.

The construction of a control chart is an iterative process, where initially the process parameters are unknown (Phase I), and a second phase, in which the parameters have been previously estimated (Phase II). Phase I corresponds to process control, while Phase II corresponds to process monitoring. If the values of the ω statistic follow a Normal $N(\mu_{\omega}, \sigma_{\omega}^2)$ distribution, the action limits and the centerline of a Shewhart control chart (Figure 9) are given by:

$$LSC_{\omega} = \mu_{\omega} + 3\sigma_{\omega}^2 \quad (11)$$

$$LC_{\omega} = \mu_{\omega} \quad (12)$$

$$LIC_{\omega} = \mu_{\omega} - 3\sigma_{\omega}^2 \quad (13)$$

This means that Shewhart's control limits are located at $\pm 3\sigma\omega$ from the center line. Assuming that ω is normally distributed, this means that the probability of a point being between the control limits is 99.73%.
According to Shewhart's principles, where a point is outside the control limits, it is assumed that it is due to special causes of variation, in example, that point does not belong to the distribution of the statistics being controlled, corresponding to a risk α equal to 0.27% of a point belonging to the distribution of ω being outside the control limits. This probability is called type I error, producer risk, or significance level. Thus, from 370 out of 370 points there will be on average a false alarm, assuming erroneously that the value of ω does not belong to the distribution that is being controlled. The value 370 is called ARL (Average Run Length), which is the average point number on a control chart before a point does not belong to the range [LIC, LSC] - out-of-control situation.

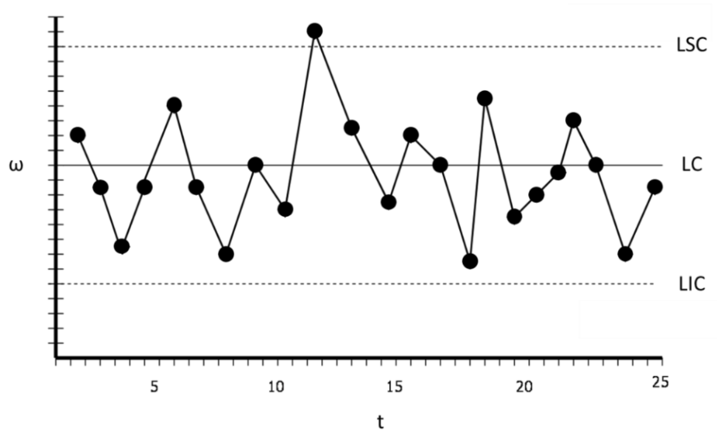

Figure 9. Control chart.

In Phase I of the implementation, whose objective is to verify the stability of the process, the steps are as follows:

1. Quality feature selection.
2. Development of a control plan consisting of the sample size, sampling frequency, measuring equipment and measurement method.
3. Selection of the type of letter according to the sample statistics to be controlled.
4. Collection of m samples of dimension n for a certain period of time, making a total of m. n = N units (N ≥ 100).
5. Calculation of the statistics to be controlled for each sample.
6. Determination of control limits and axis.
7. Verification of the existence of special causes of variation.
8. Elimination (if necessary) of the points indicating the existence of special causes of variation.
9. Determination of revised limits and the axis.
10. Construction of the revised control chart.
11. Verification that the case has only common causes of variation.

In Phase II, considering that the characteristic, control plan and type of chart have already been defined, the steps are:

1. Represent on the chart the CONTROL limits LIC, LSC and the LC center line defined in Phase I.
2. Collect sample i, determine the statistic ω_i and represent the value on the chart.

3. Check that the value is due to a special cause of variation.
4. If an out-of-control situation is identified, identify the cause, and implement corrective actions.
5. Collect the sample $i + 1$, calculate ω_{i+1}, representing in the graph the respective value.
6. Proceed sequentially in accordance with paragraphs 3, 4 and 5.

Data collection is a particularly important step in the implementation of control charts. If it is not carried out properly, there is a risk that all the conclusions drawn by its application are incorrect by indicating situations that are not actually happening.

There are two types of traditional control cards: variable control charts and attribute control charts.

Within variable control charts, they should be used where the control of characteristics measured on a continuous scale is economically feasible, and these have the following advantages (ISO 7870-2, 2013):

- There are many processes and products with measurable characteristics on a continuous scale.
- This type of measurement contains much more information than an assessment made in a binary way (yes-no, conforming-not compliant).
- Although the collection of information from continuous variables has a higher cost, it is generally necessary to collect a smaller number of data, thus reducing many costs in relation to attribute control.
- As less information is required, the time to find a problem and its resolution is also shorter, giving rise to a greater amount of product accordingly.
- Even if all individual observations are within specifications, the overall behavior of the process can be evaluated, something that is crucial in finding solutions that allow for continuous process improvement.

Variables are all characteristics likely to be expressed on a continuous scale; in this case, since the population dispersion does not depend solely on the central trend measure, two control charts should be constructed: one to control the location parameter and the other to control the scatter parameter.

If the sample size is greater than 10, it is advisable to use the mean control charts and standard deviation. Below (Table 1), it is a summary of the limits of the mean control charts and the standard deviation for variable control, when the process parameters are not known.

Table 1. Control limits

Control charts	LIC	LC	LSC
Letter X	$\bar{\bar{X}} - A_3\bar{S}$		$\bar{\bar{X}} + A_3\bar{S}$
Letter S	$B_3\bar{S}$	$\bar{S}$	$B_4\bar{S}$

The values A_3 , B_3 and B_4 depend only on the sample size and are tabled (Pyzdek, 2003).

2.13. Histogram

The histogram is a bar chart that illustrates the frequency of occurrence of the values of a continuous or discrete variable, thus allowing obtaining important information about the distribution of the collected values (Figure 10).

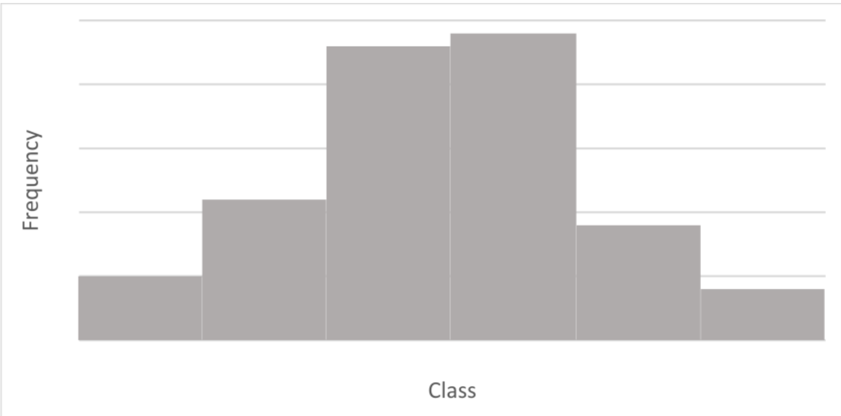

Figure 10. Example of a histogram.

For the construction of a histogram, it is first necessary to group the collected data into classes, whose amplitudes are usually the same for all classes, and then proceed to the counting of the number of occurrences in each class, which corresponds to the absolute frequency of the class. The number of classes varies depending on the total number of observations. One of the most used rules for determining the number of classes is the Sturges rule, defined by the following expression (Pyzdek, 2003):

$$K = 1 + 3.322 \log(N) \quad (14)$$

where K is the number of classes and N the total number of observations.

In the graphic representation of the histogram, the classes are entered in the axis of the abscissas and the absolute frequency is marked f_a on the axis of the ordered.

A histogram should be constructed with at least 50 observations to obtain a good approximation of the population distribution, although it is preferable to use a minimum of 100 observations.

2.14. Brainstorming

Brainstorming's technique consists of generating possible group solutions to problems, using the creativity of team members and the acceptance of all the ideas generated (Osborn, 1998).

This technique is based on the following rules (Ait and Guy, 2014):

1. Dismiss any criticism: to avoid impediments in generating ideas, participants in a brainstorming session should never criticize.
2. Failure to comply with rules and conventions is welcome: as criticism is not allowed, unusual and unconventional ideas are possible and desired.
3. The number of ideas is desired: one of the purposes of brainstorming is to collect many ideas, assuming that the greater the number of ideas, the more likely you are to find some that are successful.
4. Combination and improvement are sought after: participants are encouraged to use other people's ideas, combining them with their own and improving them.

The core of brainstorming's ideology is the number of ideas for its quality, so that it can access the collective creativity of the group by removing barriers that prevent participants from suggesting solutions (Gobble, 2014).

2.15. Cause-and-Effect Diagram

The Cause-and-Effect diagram, also known as the Ishikawa diagram, was developed by Kaoru Ishikawa in 1943. This diagram (Figure 11) aims to relate the causes with the effects (problems) that they produce graphically. This tool is particularly suitable for performing teamwork. The construction of the diagram implies the following phases (Pyzdek, 2003):

- **Clear definition of the problem -** The generalization of the problem implies that the causes will also be generalists, which complicates the analysis and resolution of the problem. Thus, all the contours of the problem in question should be discussed and accurately define a title for the problem or effect. Then a central horizontal line is drawn, and the problem is described to the right of the diagram.
- **Identification of the causes of the problem -** The causes leading to the effect can be classified at various levels; in a productive context, six categories of general causes are usually considered (the 6M – Manpower, Methods, Medium, Machinery, Materials and Measurements), although this definition of categories is not mandatory, depending on the team the definition of categories that best adapt to the problem under analysis. These general (or major) causes directly affect the problem in question. The team seeks to identify as many possible causes as possible for the problem, often through Brainstorming, and then these causes are affected by each of the previously defined categories, and there may be several subdivisions in these. The identified categories are represented by oblique arrows that converge to the horizontal axis of the Diagram. The diagram is completed considering that the causes of level 1, which directly affect the respective main categories, are represented by horizontal arrows linked to the oblique arrows of the general causes, and that the causes of level 2 are represented by oblique arrows pointed to the horizontal arrow of the level 1 cause.

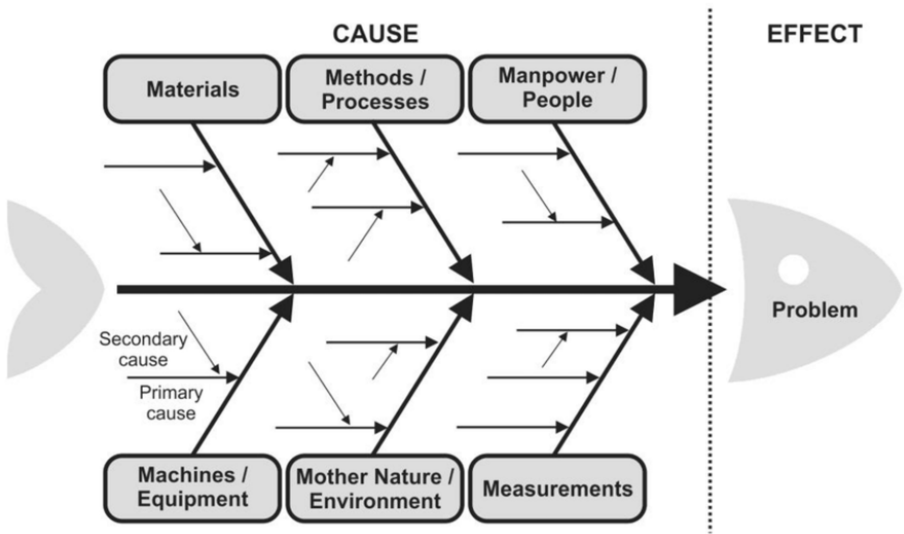

Figure 11. Cause-and-Effect / Ishikawa diagram.

- **Selection of the most likely causes -** Once the Diagram is completed, the diagram is reviewed to select the most likely causes of causing the problem in question. Each team member must individually score the causes they consider most likely, using weighted voting. Generally, 4 to 5 more probable causes are considered.
- **Definition and implementation of corrective actions - The actions** that allow the elimination of the causes of the problem are defined, those responsible for its implementation are identified and deadlines are established for its implementation. The corrective actions implemented should be monitored during the implementation phase, so that adjustments can be made if they are necessary.
- **Evaluation of the effectiveness of the implemented actions -** It should be evaluated the effectiveness of the corrective actions that were implemented, and the dissemination of the results obtained.

2.16. Pareto Diagram

The Pareto Diagram is based on the principle of the economist Vilfredo Pareto, who defined in the 19th century that 20% of the population owns 80% of the wealth. The basic principle of 80/20 was then adopted in the description of other realities, and later improved with classifications A, B and C (Pyzdek, 2003):

- Class A, which consists of approximately 20% of the attributes and accounts for 80% of the phenomenon.
- Class B, which contains the following 30% of information and accounts for 10% of the phenomenon.
- Class C, which contains 50% of the remaining items and is also responsible for 10% of the phenomenon.

This tool aims at the organization, understanding, interpretation and presentation of the collected data, by combining the absolute frequency of items with their relative frequency (Pyzdek, 2003).

The construction of a Pareto diagram is carried out according to the following steps:

1. Definition of the data to be collected, as well as the collection period.
2. Data collection.

3. Classification of the data obtained into categories and quantification of them.
4. Calculation of the relative percentage of each category.
5. Sorting the percentages obtained in descending order of value.
6. Representation of categories on a bar chart (horizontal axis) and their relative percentages (vertical axis).
7. Plot the curve of cumulative frequency values (cumulative relative frequency).

2.17. Priority Matrix

The priority matrix is a tool that comes from the combination of two others: the tree diagram and the matrix diagram. This quality tool allows the reduction of options formulated a priori to the most effective for solving the problem under analysis, these being the ones that have a higher priority index defined by certain criteria, and their use is appropriate when faced with a set of different actions/solutions that solve the issue, and the intended is consensual decision-making (Pyzdek, 2003).

Building a priority matrix should follow the next steps (consider C_i the criteria defined and O_j the options to select):

- Definition of the criteria for the consideration and allocation of their weightings.

Table 2. Criteria priority matrix

	C_1	C_2	...	C_i	Total	Average (%)
C_1						
C_2						
...						
C_i						
Total						

- Evaluation of each option O_j against the established C_i criterium, building a matrix for each criterion.

Table 3. Priority matrix of the options for each criterion

	O_1	O_2	...	O_j	Total	Average (%)
O_1						
O_2						
...						
O_j						
Total						

- Filling the priority column based on the assigned weights and the criteria defined.

Table 4. Priority matrix vs options criteria

	C_1	C_2	...	C_j	Priority
O_1					
O_2					
...					
O_j					

- Evaluation of the results obtained, giving up the options with lower percentages of importance.

The 5W2H tool is an acronym meaning:

- What?
- Who?
- Where?
- When?
- Why?
- How?
- How much?

This tool allows, through the definition of all the constituent variables of a project or a solution, to provide the performers with greater possibilities of high performance in the execution of the project. It is mainly used in the phases of identifying options for improvement, implementation of changes, evaluation of actions and monitoring planning, and continuity programs (Pyzdek, 2003).

3. Characterization of the Company

This chapter will focus on the aspects of the company where the work was carried out. First, the company history will be briefly described, followed by its current mission, vision, and objectives. Then a small approach will be made to the portfolio of products that the company has, focusing in greater detail on the products that were objects of study in this dissertation, as well as a brief mention of the technologies currently implemented. The productive capacity and the markets where the company is present will also be mentioned.

3.1. Company History

Founded in August 2005, Mar Cabo – Produtos Congelados, Lda., which will be named as Mar Cabo, is dedicated to the processing, packaging, and marketing of frozen fish, both imported and from the national coast. The company is in constant adaptation to the variations of market demand, devoting itself to seafood, such as blue shark, sardines, and octopus. It is a flexible company prepared in quality, production capacity and adequate responses to the most demanding customers with the objective of total customer satisfaction.

Headquarters and factory are located in Matosinhos (Portugal), with adequate facilities to produce frozen fish with quality control, hygiene, and food safety (Mar Cabo, 2020).

The company was recognized in 2020 with the International Featured Standard (IFS), allowing it to reach new markets and strengthen confidence on the part of their customers (Mar Cabo, 2021). Mar Cabo is focused on the innovation of its business through the increase of its portfolio and the diversification of product ranges, seeking to expand the market through product exportation, and always trying to improve and innovate the production processes. Subsequently, they decided to invest in technology, quality control and training of the employees, which allowed to cross national borders and settle in international market nowadays. Also, the company has a culture of always teaching and updating the knowledge of the employees to attain better production and customer satisfaction.

3.2. Mission

The mission of the company can be resume as:

- Maximize the potential and skills of employees.
- Attitude to overcome all the challenges we face.
- Respect as a key factor of success in establishing lasting relationships.
- Commitment to the interests of different partners.
- Audacity to always be one step ahead of customer needs.
- Search for excellence, through the establishment of ambitious goals.
- Results-oriented, through the commitment to achieving the objectives.

3.3. Products

Currently, the company has a wide range of products (an example is in Figure 12), which has been increasing due to the expansion of its portfolio to insert the company into niche markets of deep-frozen foods.

Products processed and marketed by the company are:

- Blue shark
- Horse mackerel
- Small Horse mackerel
- Pink
- Sable Petro Fish
- Perch
- Hake from Argentina
- Hake from Chile
- Cod
- Octopus
- Squid
- Shrimp
- Seafood

- Squid strips
- Seafood mix (“Mariscada”)

Figure 12. Example of a Mar Cabo final product.

The company carries out several activities, including fresh product transformation through glazing and final packaging.

The process begins when the product arrives at the factory in blocks and inside insulated trucks at a temperature of at least -15 ºC. The product is then stored in the raw material warehouse at a temperature of -18 ºC. When the product is needed, it is taken to the production area to remove it from its primary packaging, either plastic and/or cardboard.

3.4. Production Lines in Analysis

3.4.1. “Cefalópodes” Line

In the case of “Cefalópodes” line, these are placed in vats containing refrigerated water. A treatment is applied for a minimum of 36 hours to maintain the texture and favorable organoleptic properties without modifying the chemical characteristics of the species, inhibit oxidative reactions that affect lipids, decrease the rigidity of the membrane tissue, and improve the presentation of the surface among other advantages.

After the treatment of the raw material, the tins are turned to a moving carpet for washing, cutting, weighing with the aid of scales and placement on cuvettes. Water, called “glazing water”, may be added to the cuvette, or placed directly in baskets and/or carts. These carts or baskets, previously identified, go to a static tunnel at 0ºC. Frozen structures (carts or baskets) remain in the tunnel overnight, and the next day they are used to supply the “Cefalópodes” line.

When the cuvettes, from the carts or baskets, are removed to the feeding mat of the "Cefalópodes" line, these cuvettes may be subjected to jets of air and water with the purpose of removing the ice particles originated by freezing. Otherwise, the cuvettes proceed directly to the primary packaging. In the first case, more time and human resources are spent, but the final product looks brighter.

The primary packaging is performed by the sealer (ULMA - SLX300), which uses a folded film to wrap the cuvettes. They proceed to the film retraction oven (ULMA – TRX45X90 H-250), continuing to the metal detector (DIBAL – MD 5700), weighing and labeling primary by the labeler (DIBAL - LS 4000) where there is the use of two rolls of labels since there are two print heads. In this line there may be cuvettes that come out from the retraction oven unproperly sealed or even broken. They return to the feeding mat to be resealed and if necessary, replaced.

Finally, a secondary packaging of the cuvettes already labeled and placed in boxes is carried out. After these steps the product is ready to be stored and then shipped.

3.4.2. "Ensacadora" Line

At this stage and when necessary, the product is disentangled, which generates cardboard packaging and plastics wastes. The product is then ready to proceed to preparation. The skin of the product is removed with the aid of knives, it can be cut manually or with electric saws and placed in tins or baskets to be glassed. At this stage there is organic waste, which is the surplus of raw materials.

The raw material already prepared can: (i) be placed in intermediate baskets and proceed to a glazing process; (ii) suffer, one or two glazing processes, depending on the requirements of the desired final product, and then be frozen/reset at the appropriate temperature; or (iii) proceed directly to the calibrator.

The product, after passing through static/continuous tunnels to reset the temperature, is then subjected to primary weighing using a calibrator (MAREL - TBL 300). After this step, the product falls into a carpet that is connected to an automatic bagger (Pack 4 – ANNIVERSARY 45). For this primary packaging/labeling it is required a ribbon roller to make the marking and a roll of film suitable for the raw material to be bagged, which are placed on the back of the line.

The product, already in bags, is transported to the grinding mat. A weight control takes place, and the product is rejected if it is not well parameterized. There is also a metal detector on this carpet, which triggers a rejection process if the presence of metal is detected.
It is along these steps that there may be rework of the bags. This may happen soon in the line because the bags outside the line have no marking, or because the product has become stuck in its springs/welds/mold; or along the grinding mat, because it is not within the weight parameters; or rejected for containing metal. The product is then removed from the bags and returns to the calibrator feeding pad at the beginning of the line. Finally, the bags are placed in boxes, and a secondary packaging/labeling is carried out. The boxes already labeled are still placed on the end-of-line mat and pass through the second metal detector before being placed on the pallets and stored.

3.4.3. "Higienização" Line

This line has in common the procedures referred in the "Ensacadora" line from the preparation steps till packaging.
The line begins by unloading the product that comes from the glazing process; one of the operators places the product linearly on the band that will be inserted into the sealing machine - ULMA - SLX300), which uses a film to wrap the product. Then the product continues to the film retraction oven (ULMA – TRX45X90 H-250), metal detector (DIBAL – MD 5700), weighing and primary labeling using a labeler (DIBAL - LS 4000).
In this line, the product that was not properly sealed or that was not sealed or labeled is revised. Compared to the "Ensacadora", in this line the product is not put in a bag; it is packed as described in the "Cefalópodes" line, with a film directly wrapping the secondary packaging that is a box.
After these steps the product is ready to be stored and then shipped.

4. DMAIC in Mar Cabo

In this chapter it is presented and discussed the application of the Six Sigma methodology to a production process of Mar Cabo, particularly to the production room where various frozen fish and seafood products are cut and packed. The quality parameter chosen for the analysis was temperature, a factor of extreme importance in the frozen food sector. This study aimed to evaluate the process that is at the center of the business activity of this company, in which the temperature of these products is highly regulated and controlled by legislative means, so the objective was to decrease the temperature and decrease its variability. The statistics used to measure temperature behavior were mean and standard deviation. To achieve the objective described above, the DMAIC cycle was applied. This part presents in detail the phases of this cycle applied to the case study. Throughout this chapter, a color scheme is used, assigning a specific color for each of the phases of the DMAIC cycle, to facilitate the differentiation between them.

4.1. Define Phase

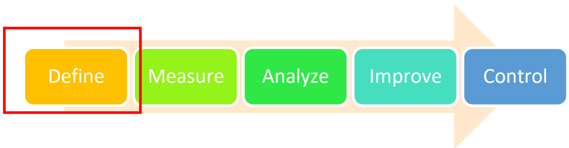

Figure 13. DMAIC - Define phase.

As mentioned earlier, the Define phase is the first in the DMAIC cycle (Figure 13). At this stage we sought to identify the problem to be improved, and consequently define the goals, scope, and objectives of the project, identify the needs of customers, identify the defects currently existing in the process, define the Six Sigma team and their responsibilities, and elaborate the project schedule.

The team of this Six Sigma project presented here was defined seeking heterogeneity of the elements, selected from distinct departments and functions, which are described below:

1. Element A - Trainee of the Production Department
2. Element B - Responsible in Quality Department
3. Element C - Responsible in Production / Packaging
4. Element D - Responsible in Maintenance Department

4.1.1. Project Selection

Initially, a meeting was held with the Quality Department, in which, based on the company's need, three possible improvement projects were identified, all of them related to one of the most fundamental and important characteristics in this type of food industry – temperature. The projects considered for selection were the following:

1. Identify problems in the various production areas that produce delay times.
2. Identify problems in the three packaging lines that lead to material losses.
3. Identify delay situations leading to rework on packaging lines.
4. Identify delays in the different adverse areas that affect the production area.
5. Identify problems that lead to downtime in production/packaging lines.

Any of these projects involves a parameter related to the most critical quality characteristics of the products. This directly affects the CTQs of customers, namely the economic and logistical factors, which in practice affect the aspect of the company's approach to customers.

The "Cefalópodes" line usually has 4 employees, 3 of which are on the supply side of the line with the cuvettes and solve the problems that may occur in the sealer and in the film retraction oven; another collaborator puts the cuvettes in the boxes and later in the final carpet. This employee is in the opposite direction of the machines that are closest to him. It can be said that if there is a problem with the metal detector or labeler, the entire line must stop until one of the developers gives the equipment a complete turn to solve the problem. Until this happens, there is accumulation of product: either at the exit of the oven, if the problem is in the metal detector, or in the separation mat / support table of the second packaging, if the problem is due to the labelers.

The "Ensacadora" line is used for products that need to be packed in bags; if the product is more sensible to packaging, the process is made mechanically by several machines. The cutting machine has problems that require product rework, and a lot of film waste is generated.

The "Higienização" line is the oldest line and the best controlled one. However, depending on the product, particular problems should be considered such as the labeler does not detect the product, or the film cutter does not cut homogeneously. This leads to rework such as manual labeling, re-passing the product, or stops of the line to check both the cutter and the labeler.

4.1.2. Project Charter

The above points were fulfilled by using the Project Charter tool, which in addition to providing a clear and concise description and definition of the problem, identifies the elements of the project team important to its realization, as well as their functions in it (Table 5). This Project Charter has been presented to the other team members and accepted globally by them. This document presents a dynamic nature, which means that throughout the case study it may change as it is found that there is a need for updating. This will possibly happen after the completion of the Measure phase of the DMAIC cycle.

Table 5. Mar Cabo project charter

<table>
<tr><td colspan="4">Project name</td></tr>
<tr><td colspan="4">Application of Six Sigma in the processing and packaging of frozen foods area.</td></tr>
<tr><td>Start date</td><td>15/02/2022</td><td>End date</td><td>15/06/2022</td></tr>
<tr><td colspan="4">Enterprise: Marcabo Lda.</td></tr>
<tr><td colspan="4">Project objective</td></tr>
<tr><td colspan="4">In the food industry, the quality and food safety of frozen foods is crucial, especially when it comes to fish and seafood, whose compositions make them very conducive to the development of microorganisms that are harmful if consumed. The company Mar Cabo, knowing this situation, practices limit values of acceptance, which when they are above it are rejected. The intended with this project is to improve the current process so that the products to be rejected at the end of production are smaller.</td></tr>
<tr><td colspan="4">Scope of the project</td></tr>
<tr><td colspan="4">The problems/errors collected at the end of the production process and during the packaging of the products, within the dates indicated in this Project Charter, are the object of study to be considered.</td></tr>
<tr><td colspan="4">Description of the problem</td></tr>
<tr><td colspan="4">The company wants to improve/reduce current product errors/problems at the end of the production/packaging process, thus ensuring that all its products that are distributed are safe for consumption, and consequently its customers have greater satisfaction with the products.</td></tr>
<tr><td colspan="4">Goal setting</td></tr>
<tr><td colspan="4">Decrease variability and improve the current packaging level, i.e., increase the current Sigma level.</td></tr>
<tr><td colspan="4">Restrictions and assumptions</td></tr>
<tr><td colspan="2">Restrictions</td><td colspan="2">Assumptions</td></tr>
<tr><td colspan="2">Difficulty in implementing improvements due to the lack of current stability of the process and some inertia on the part of the company's current organization.</td><td colspan="2">Production lines provide products with similar processing and packaging conditions, and the difference between products depends on their own morphology and ability to have packaging.</td></tr>
<tr><td colspan="4">Project risk analysis</td></tr>
<tr><td colspan="2">Risk</td><td colspan="2">Mitigation Strategy</td></tr>
<tr><td colspan="2">Non-compliance with the stipulated dates.

Not being able to reduce the variability of errors in the packaging area</td><td colspan="2">Expose the results to the production department and collaborate.</td></tr>
<tr><td colspan="4">Project team</td></tr>
<tr><td colspan="2">Name</td><td colspan="2">Responsibility</td></tr>
<tr><td colspan="2">João Peixoto (M.Sc.)

Luís Rodrigues (B.Sc.)

Valeria Enriquez (B.Sc.)</td><td colspan="2">Project coordinator

Responsible in Production / Packaging

Trainee of the Production Department</td></tr>
</table>

4.1.3. Gantt Diagram

Together with Project Charter, a Gantt diagram was presented for each phase of the DMAIC cycle and its corresponding activities (Table 6), so that there are completely defined milestones that allow the team to stay focused on the tasks.

Table 6. Gantt diagram of the project

DMAIC phases and activities	**February**				**March**				**April**				**May**				**June**				**July**				**August**			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Define																												
1. Problem formulation	■																											
2. Preparation SIPOC		■																										
3. Collection of customer requirements			■	■																								
4. Preparation Project plan					■	■																						
MEASURE																												
5. Identify and define measurements							■																					
6. Data collection								■	■	■	■	■	■	■	■	■												
7. Project Charter Update																■												
ANALYZE																												
8. Collection of possible causes												■	■	■	■	■	■											
9. Process analysis																		■										
10. Data analysis																			■									
11. Root causes check																			■									
IMPROVE																												
12. Collection of possible solutions																				■	■							
13. Selection of solutions																					■							
14. Preparation of action implementation plan																						■	■					
15. Testing and implementation of solutions																								■	■			
CONTROL																												
16. Finalize documentation																										■	■	
17. Implementation of effective long-term monitoring system																												■

4.1.4. SIPOC

Together with Project Charter, the SIPOC diagram is a tool that illustrates in detail the process to be improved, in relation to the tasks involved in the process itself, as well as to suppliers, inputs, outputs and process customers (Table 7). This allows a better understanding of the process by the project team members, as well as determining the relationship between different customers and suppliers through relevant process inputs and outputs, and identifying key customers (John et al., 2015).

For the company's privacy, Suppliers and Customers were considered with numbers.

Table 7. SIPOC of the project

Suppliers	Input	Process	Output	Clients
1 2 3	Raw material Operators Chemicals Glazing water Packaging	Packaging in "Cefalópodes" line Packaging in "Ensacadora" line Packaging in "Higienização" line	Packed Fish Packed Seafood	1 2 3

4.1.5. CTQ's

The needs verified by Mar Cabo as a client correspond to the same needs of the other customers of this organization, which were translated into the critical characteristics of the quality of the products under study, i.e., the CTQs. These needs were obtained considering the vision and objectives of the company, complemented with discussion and dialogue with those responsible for the Quality Control Department.

After hearing the company's concerns and carefully registering these, it is concluded that the critical characteristics of quality for Mar Cabo's customers are as follows:

Sensory factors - Keeping the products at low temperatures, the maximum conservation of fish and seafood is attained, thus allowing the customer to receive the product practically in the sensory conditions at which they were fished. A product with the correct packaging and sealed conditions will have quality for consumption.

Chemical factors - Negative temperatures allow the product not to undergo so many chemical decomposition changes that severely affects quality.

Physical factors - The product must not have external entities that cause cross-contamination or materials such as plastic that are not within the final content for sale to the consumer. The product must have the right size and weight to provide the consumer with what is being sold with the quality that is needed. The packaging must have the correct physical conditions to show the customer that the product is protected as it has been ordered by the customer for sale in the market.

4.2. Measure Phase

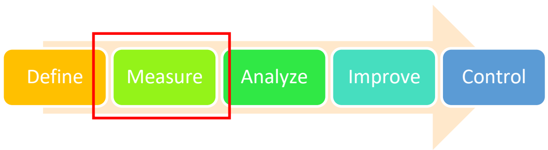

Figure 14. DMAIC - Measure phase.

Defined in detail the problem, the next step to be performed is the Measure phase (Figure 14), in which the measurements are systematically determined. If the accuracy is verified through a measurement analysis system, the analysis of the measurements is performed using tools and techniques that may or may not have a visual support, analyze the measurements for their parameters of location and dispersion, and determine the capacity of the process using the Sigma calculation of the process and other methods.

4.2.1. Process Flowchart

In a Six Sigma project, it is crucial to define precisely the process to be improved, in relation to all activities' details, resources, decisions, dependencies, and values.

Process mapping translates, into a representation, a precise process definition. At this stage of the DMAIC cycle, the flowchart (Figure 15) allows to define the location (or activity) for appropriate data collection to achieve more information about the process.

DESCRIPTION OF THE MANUFACTURING PROCESS

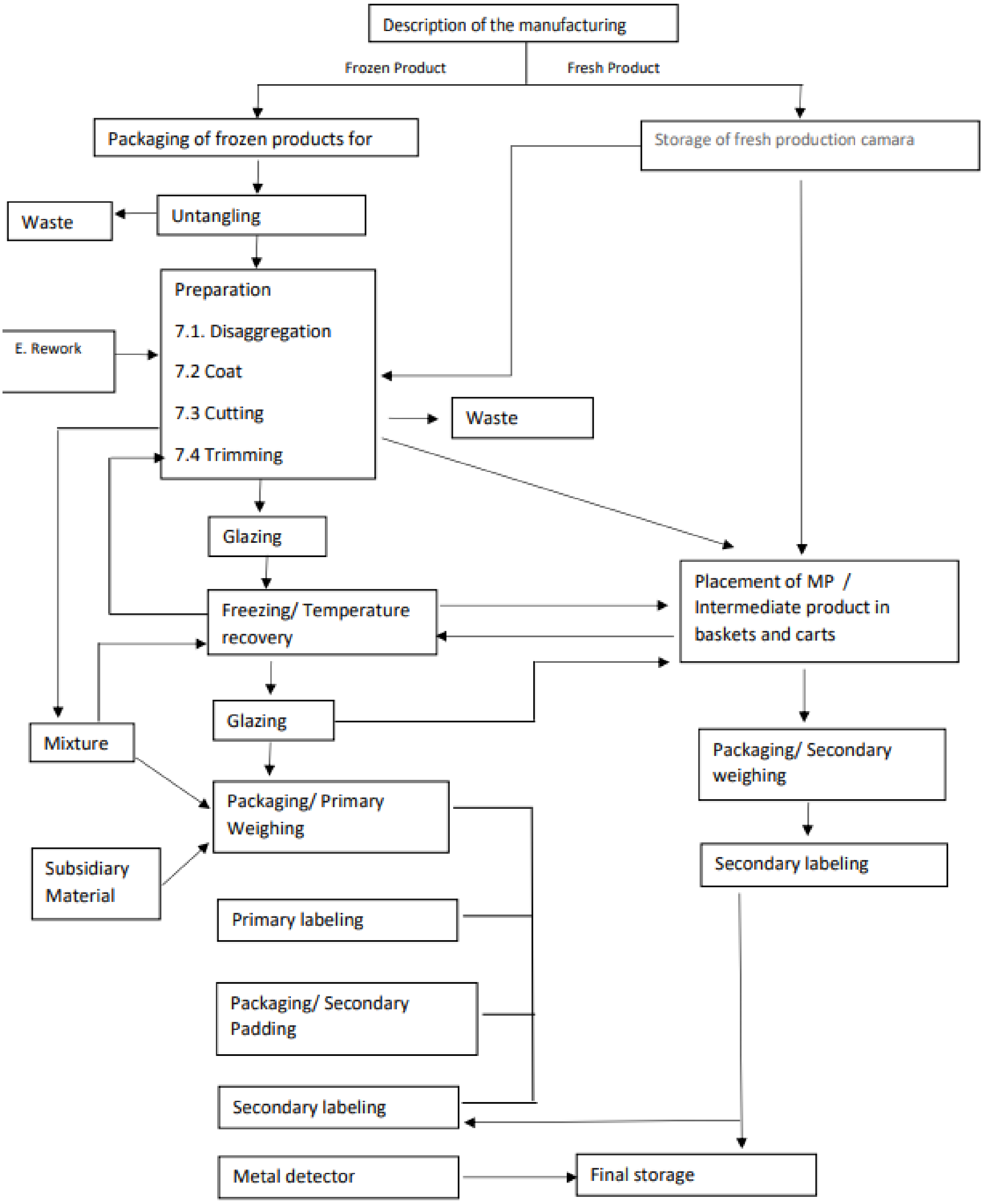

Figure 15. Mar Cabo flowchart.

Based on the flow diagrams of the packaging lines of the Mar Cabo company, it was carried out an analysis of the errors that occur in the lines and for which there is a loss of product at the time of packaging or problems in the packaging lines (delays and line stoppages).

Data of target parameters were collected being related to problems that occur in the packaging lines. The objectives of the Measure phase are data collection seeking the specifications necessary to meet customer requirements, ensuring the accuracy of measurements, quantifying the problems initially established and based on data collected from the process output, and the use of statistical tools and methods to describe and analyze key output measurements and identify their specific characteristics.

4.2.2. Data Collection Plan

To carry out a precise and correct data collection of the case study, it was first generally described the data to be collected, where they would be collected, at what time of the process, and who would be responsible for the task (Table 8).

Table 8. Mar Cabo data collection plan

Action	Description	Comments
What	Type of measurement	Output of production
	Data types	Continuos
	Operational definition	The product(s) packed in the production lines
How	Operational definition (how)	Periodic measurements of errors that cause losses in the production lines of the packaging area
Who	Responsible	Intership person
When	Frequency	The time interval between sample collections was 21 days
Where	Source/Location	Company packaging lines

4.2.3. Data Collection

In Mar Cabo there are products with greater relevance than others because they are more sought-after products by customers or final consumers, and consequently they are products more frequently packaged. Day by day in the packaging area, those products are packed considering the required conditions to produce them.

Data collection lasted 21 days and approached problems that affected (decreased) the production based on the daily lines programming with a duration of 4 hours. To realize the stops and the reasons for the stops, which led to these capacity losses, time and packaging material, *Ishikawa* diagrams were constructed for the three packaging lines (Figures 16,17 and 18).

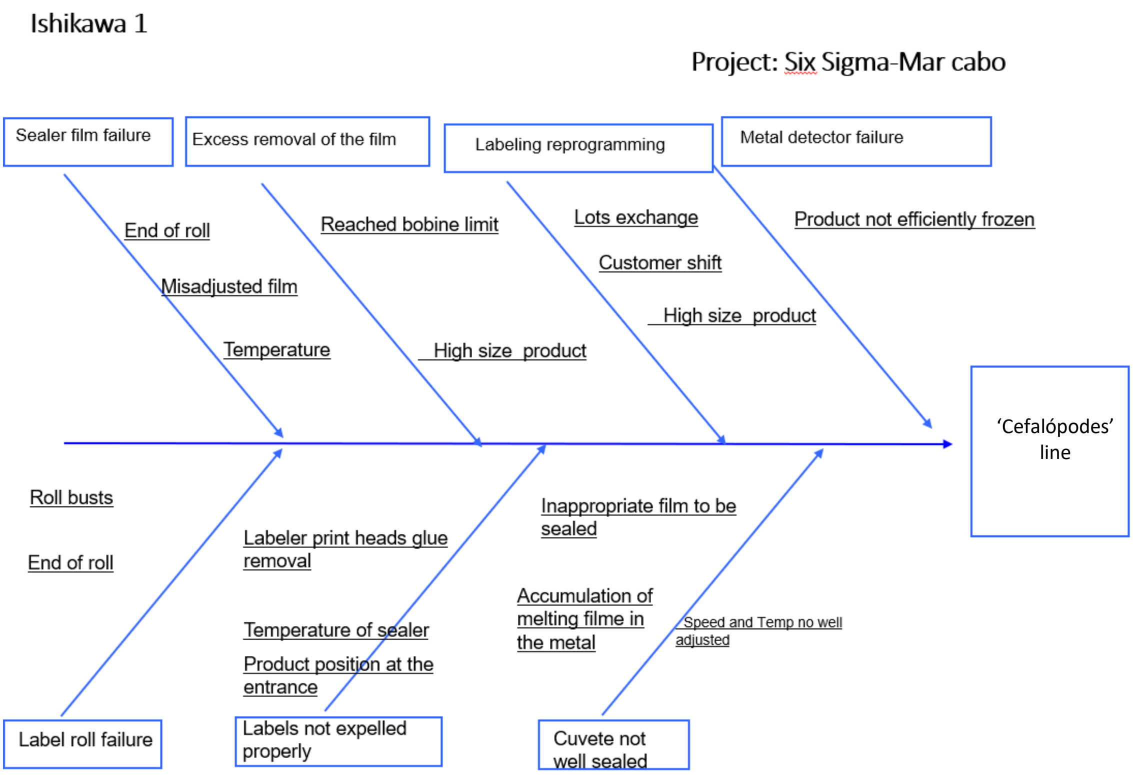

Figure 16. Ishikawa diagram for "Cefalópodes" line.

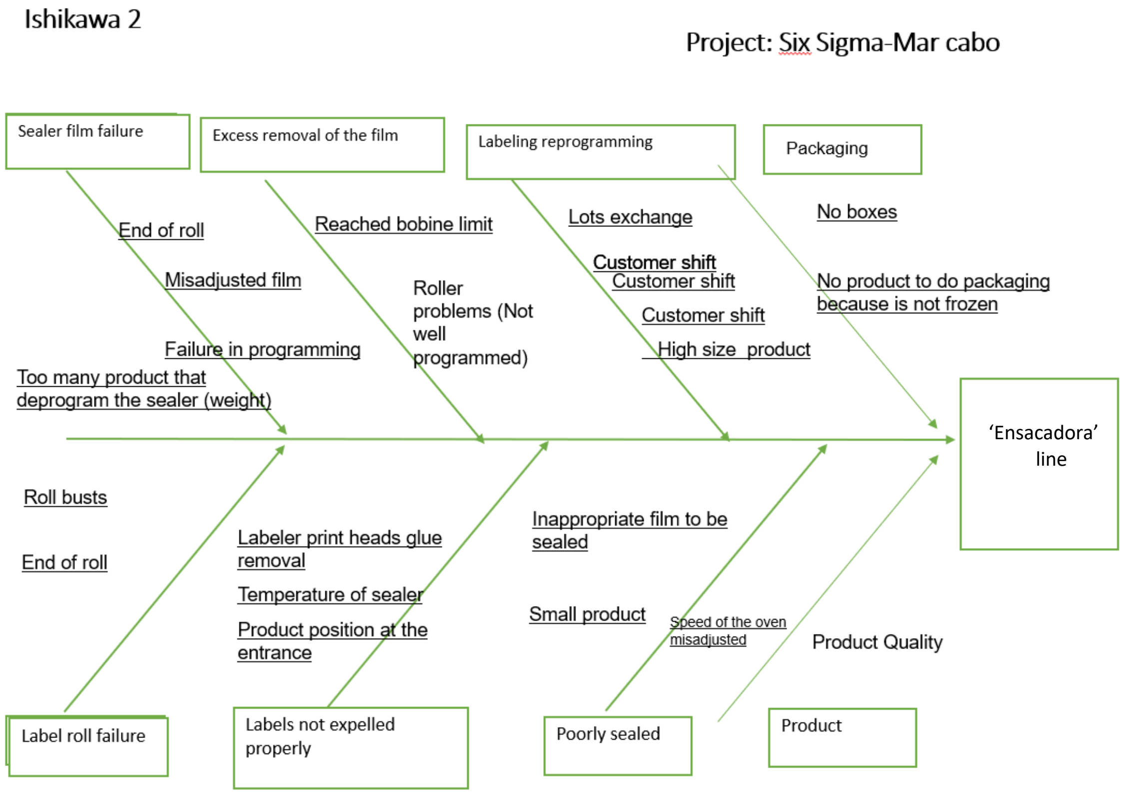

Figure 17. Ishikawa diagram for "Ensacadora" line.

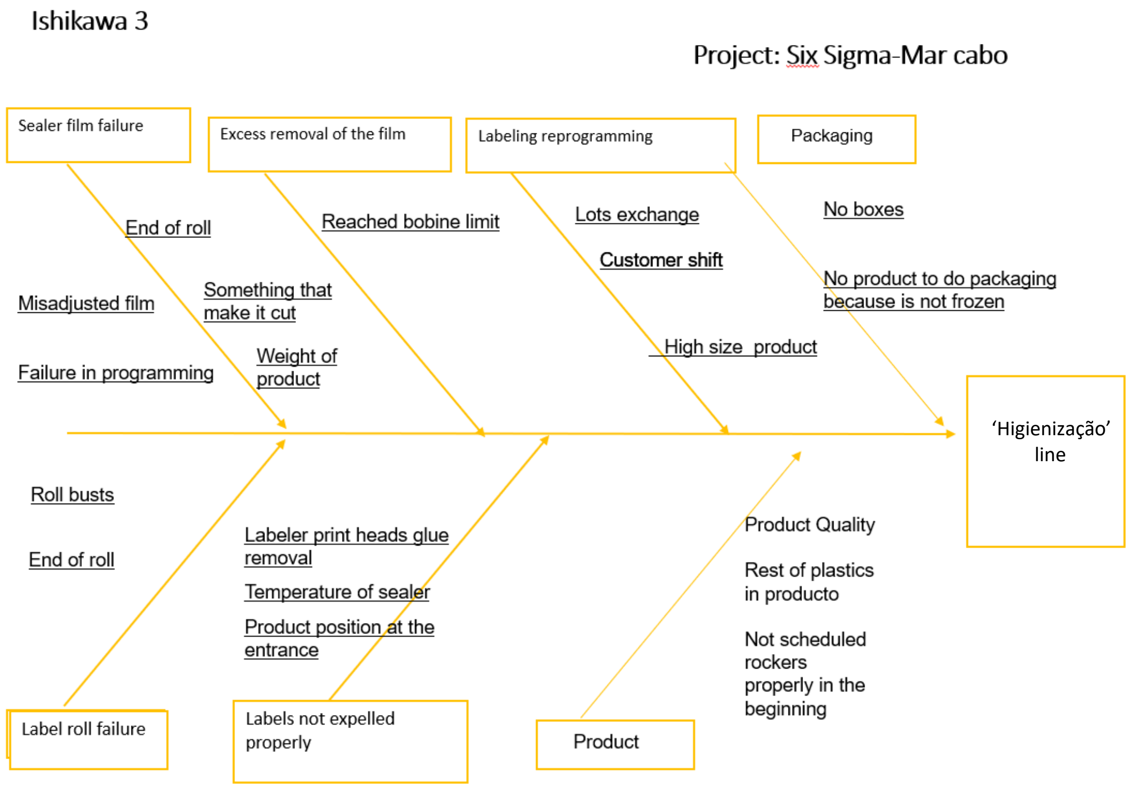

Figure 18. Ishikawa diagram for "Higienização" line.

Data collection was performed by counting the errors that occurred on the lines during the time previously determined. Then the behavior of the data was checked with the Production team to know what measurements could be made. A hypothesis test (two-sided test) was used for these purposes.

4.2.4. Control Charter

After the problems in the lines were defined, the control tests were carried out. Each sample on the line depended on the day on which the product was scheduled.

Each sample considered for a certain time interval to ensure a reliable representation of the behavior of the process throughout the production shift (of 4 hours). Samples were collected for 21 days, and control charts were prepared for "Cefalópodes", "Ensacadora" and "Higienização" lines (using Microsoft®Excel). Calculations to create control charts were done for the 4 hours (240 minutes) per day, so then it is possible to assess deviations.

The following formula was used to get the control variable:

$$defect = \frac{error\ (unity)}{240\ (\min)} \tag{15}$$

In the above, the error is the number of defects that happen in that day divided per the 4 hours (240 min):

$$defect_{"Cefalópodes"} = \frac{48}{240} = 0.2000\ unity/\min \tag{16}$$

$$defect_{"Ensacadora"} = \frac{19}{240} = 0.7917\ unity/\min \tag{17}$$

$$defect_{"Higienização"} = \frac{10}{240} = 0.0417\ unity/\min \tag{18}$$

As previously mentioned, the center line (LC) corresponds to a horizontal line that is equivalent to the average value of the quality characteristic. It is used to observe how the process acts compared to the average. Likewise, the upper and lower lines refer to the control limits (LSC and LIC, respectively) that are based on the random variation expected in the process (data in Appendix I). The values used for A_3, B_3 and B4 (Table 1) were 0.173, 0.0425 and 1.575, respectively.

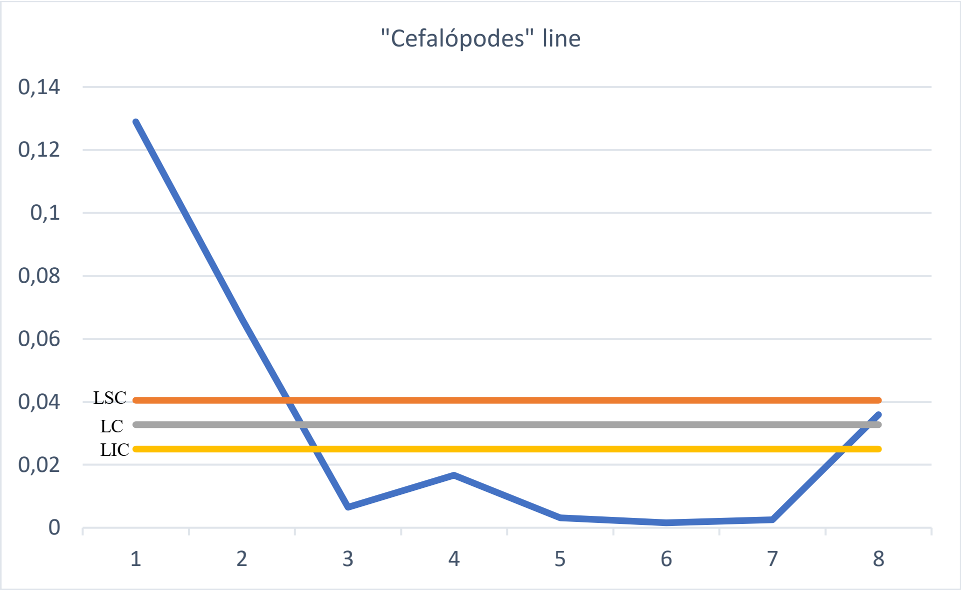

Figure 19. Control chart of "Cefalópodes" line.

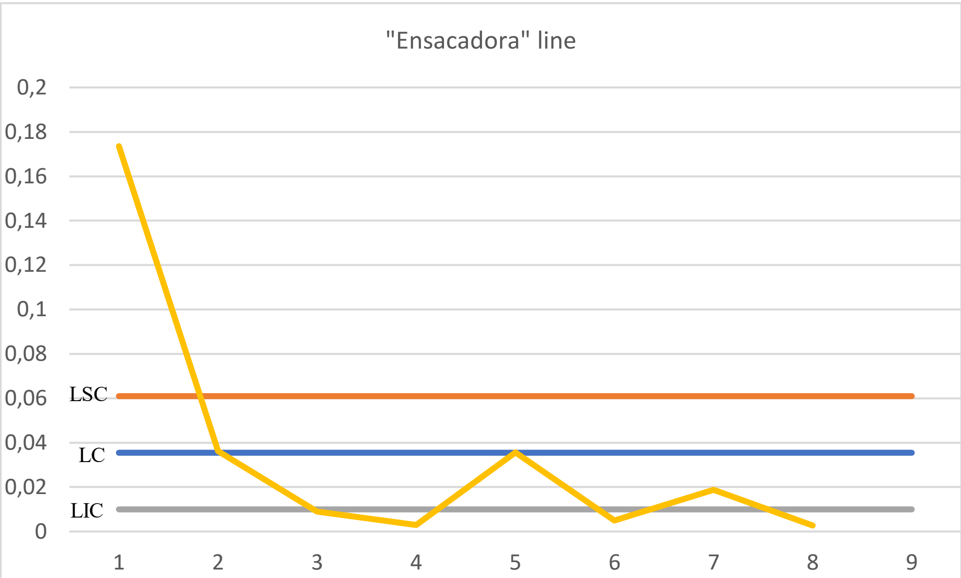

Figure 20. Control chart of "Ensacadora" line.

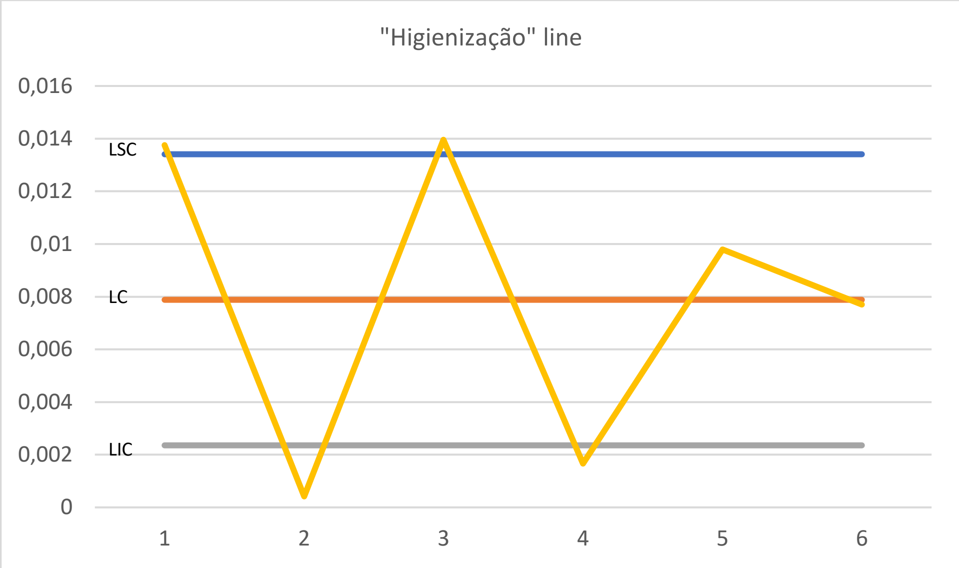

Figure 21. Control chart of "Higienização" line.

According to ISO 7870-2:2013, a process is out of statistical control when it does not comply with at least one of the following rules:

1. Any point outside the control limits (outliers).
2. Nine consecutive points from the same side of the center line.
3. Six consecutive points in an upward or downward direction.
4. Fourteen points growing and decreasing alternately.

The "Cefalópodes" line presents high deviations on certain days of the week and the "Ensacadora" line variations depend on the product to be packed since different machines are used and consequently different errors are generated at various points of the process. Outliers that may justify any deviation in the processes have not been detected. However, it can be concluded that the problems lead to a lack of processes control. The only line within control is the "Higienização" line, which can be justified by the workers experience and supervisor competence since this was the first line operating.

4.2.5. Data Normality

To be able to calculate the Sigma level of current processes, it is necessary to assume that populations follow a normal distribution. Therefore, the histograms were constructed and are included in Figures 25, 26 and 27 (data in Appendix II).

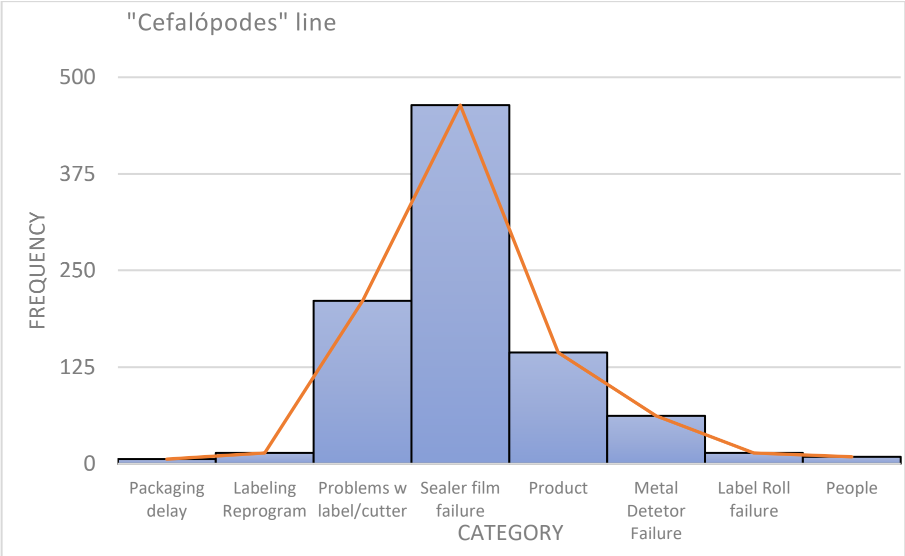

Figure 22. Distribution of data from "Cefalópodes" line.

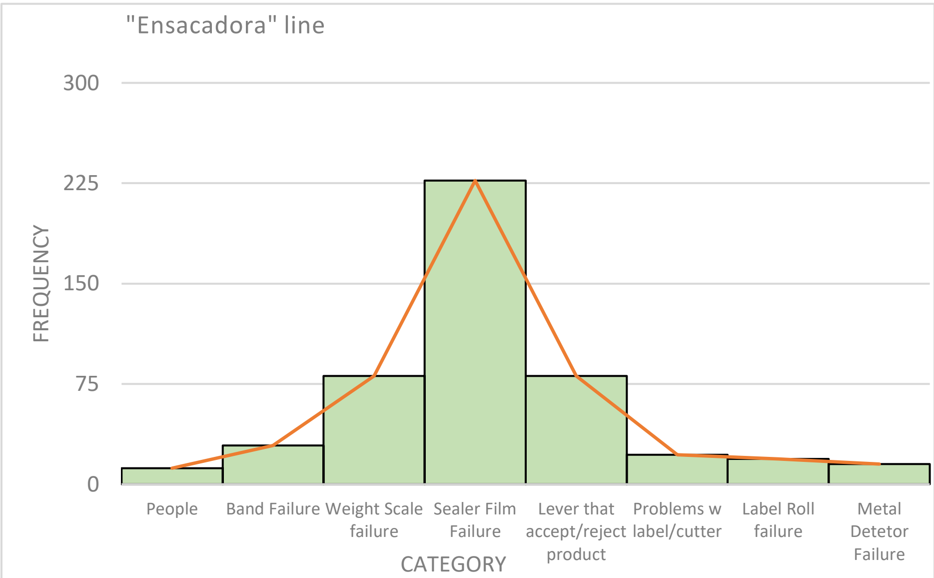

Figure 23. Distribution of data from "Ensacadora" line.

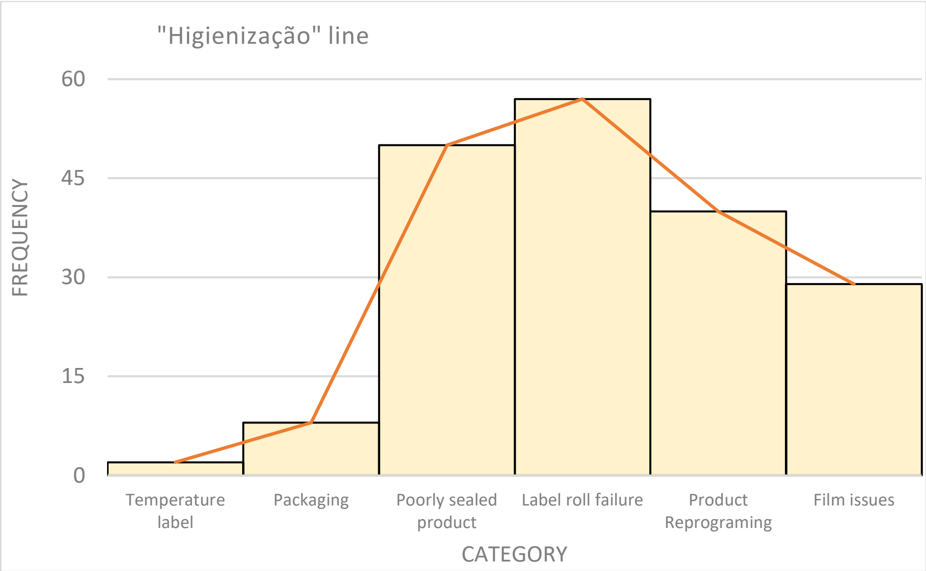

Figure 24. Distribution of data from "Higienização" line.

The number of classes can be estimated by equation 4 previously presented.

To confirm the Normality of the data set collected and considering that the parameters were estimated based on the control charts, the statistical distribution D of Lilliefors (included in the Appendix III) was used.

For n > 30 and considering a significance level of α=5%, the critical values of D are given by:

$$D_{critic} = \frac{0.866}{\sqrt{n}} \tag{19}$$

Table 9. Checking the Normality of the packaging lines

Information for checking Normality	**"Cefalópodes" line**	**"Ensacadora" line**	**"Higienização" line**
n (sample dimension)	924	486	186
K (number of classes)	4	5	2
D	0.70	0.91	0.95
D_{critic}	1.48	1.34	1.65
Distribution	Normal	Normal	Normal

Considering the quality specifications of the client and that the data follow a normal distribution, to perform the calculation of the Sigma level the normal distribution Z was used through the probability p. Knowing this probability, the approximate DPMO value for each line and consequently the current Sigma levels can be determined. Table 10 includes these results (data in Appendix IV).

Table 10. Current Sigma level for each packaging line

Information for Sigma calculation	**“Cefalópodes” line**	**“Ensacadora” line**	**“Higienização” line**
Mean	3.10	3.14	3.14
Standard deviation	1.76	1.77	1.77
Z	0.788	-4.59	-3.77
p	0.7900	0.9998	0.9992
DPMO	115500000	60750000	3100000
Sigma	4.57	3.37	4.05

The Sigma level defined as a goal in the project charter elaborated in the Define phase was considered suitable for the “Cefalópodes” and “Higienização” lines, but it is unrealistic for the “Ensacadora” line. Consequently, the project charter was rectified in relation to the current Sigma levels to achieve the established goal (Table 11).

Table 11. Mar Cabo project charter rectified

Project name			
Application of Six Sigma in the processing and packaging of frozen foods area.			
Start date	15/02/2022	End date	15/06/2022
Enterprise: Marcabo Lda.			
Project objective			
In the food industry, the quality and food safety of frozen foods is crucial, especially when it comes to fish and seafood, whose compositions make them very conducive to the development of microorganisms that are harmful if consumed. The company Mar Cabo, knowing this situation, practices limit values of acceptance, which when they are above it are rejected. The intended with this project is to improve the current process so that the products to be rejected at the end of production are smaller.			
Scope of the project			
The problems/errors collected at the end of the production process and during the packaging of the products, within the dates indicated in this Project Charter, are the object of study to be considered.			
Description of the problem			
The company wants to improve/reduce current product errors/problems at the end of the production/packaging process, thus ensuring that all its products that are distributed are safe for consumption, and consequently its customers have greater satisfaction with the products.			
Goal setting			
Decrease variability and improve the current packaging level, i.e., increase the current Sigma level.			
Restrictions and assumptions			
Restrictions		Assumptions	
Difficulty in implementing improvements due to the lack of current stability of the process and some inertia on the part of the company's current organization.		Production lines provide products with similar processing and packaging conditions, and the difference between products depends on their own morphology and ability to have packaging.	
Project risk analysis			
Risk		Mitigation Strategy	
Non-compliance with the stipulated dates. Not being able to reduce the variability of errors in the packaging area.		Expose the results to the production department and collaborate.	
Sigma project level			
Initial Situation: “Cefalópodes” 4.57; “Ensacadora” 3.37; “Higienização” 4.05			
Project team			
Name		Responsibility	
João Peixoto (M.Sc.) Luís Rodrigues (B.Sc.) Valeria Enriquez (B.Sc.)		Project coordinator Responsible in Production / Packaging Trainee of the Production Department	

4.3. Analyze Phase

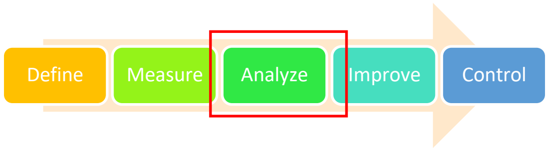

Figure 25. DMAIC- Analyze phase.

At this stage of the DMAIC cycle (Figure 25), it is intended to identify the potential causes of the problem under study, analyze the current process to identify weak points, identify and collect the measurements of the process and critical inputs and analyze its possible relationship with the outputs, and perform the analysis of the data collected and treated in the Measure phase.

4.3.1. Brainstorming

Through brainstorming sessions by the project team, collecting information by employees who spend more time on the ground, and by observation from the team members of the different stages of the current processes in the three lines ("Cefalópodes", "Ensacadora" and "Higienização"), potential causes for the problem under study were identified and listed as:

1. Product arrives at production already with low temperature / incorrect glazing.
2. Indeterminate time spent on the ground and product falling during the line.
3. Production stops due to machine failure.
4. Production stops due to the absence of operators in the line.
5. Lack of stability of parameters in the cryogenic tunnel.
6. Lack of equipment maintenance.
7. Excessive waiting time in the cutting phase.
8. Excessive time spent on depalletization.
9. Excessive time spent in the breakout phase.
10. Lack of organization in the queue for the sealing of products.
11. Excessive time spent on the reclaimers of the dosage zone.
12. Lack of organization in waiting to pack.
13. High performance variation between operators.
14. Product gets stuck in the middle of the line.
15. High number of phases of the process dependent on human intervention.

16. Negligence on the part of operators.
17. Lack of training of operators.
18. Glazing water temperature.
19. Improper maintenance of the machines.
20. Balance calibration error at the end of production.
21. Metal detector calibration error at the end of production.
22. Programming of incorrect metal scales and detectors.
23. Misfit quality specification.
24. Obsolete equipment.
25. High-length production lines.
26. Inadequate production room layout.
27. Production size unsuitable for packing.
28. Placement of the product so the product is stuck.
29. Delay time to enable production lines.
30. Maintenance area precarious.
31. Poor quality area.
32. Changes of stickers in the middle of the production time.
33. Lack of organization in the planning of commodities.
34. Missing boxes to continue the packaging.

4.3.2. Affinity Diagram

The high number of causes identified during the Brainstorming session, as well as its diversity in type and qualitative nature led to the need to construct an affinity diagram to categorize the different causes and facilitate their subsequent evaluation by the project team. The causes were grouped by affinities and a level 1 title was attributed aiming at categorizing ideas in a general way. This information is in Table 12.

Table 12. Grouping of ideas and assignment of level 1 titles

1. Stops	**2. Customer specification**	**3. Unforeseen times**	**4. Time of activities**	**5. Layout of the room**	**6. Cryogenic tunnel**	**7. Measurement**
Stops due to malfunctions	Customer specification misadjusted	Product remains on the ground indefinitely when it falls	Excessive waiting time in the cutting phase	Inadequate room layout	Lack of stability	Measurement uncertainties
			Excessive time spent on depalletization			
Stops for missing product		Product gets stuck in line	Excessive time in the disaggregation phase	High-length production lines	No good speed	Variability
Stops due to the absence of operators on the line			Excessive time spent in the stoves			

8. Maintenance	**9. Organization**	**10. Human factor**	**11. Production errors**	**12. Equipment**
Lack of maintenance	Lack of organization in the sealing of the product	Variation in the operators performance	Error in the scale's calibration	Obsolete equipment
		Negligence on the part of operators	Error in the calibration of metal detectors	
		Lack of training		
Inadequate maintenance	Lack of organization in the cutting phase	Production with high demand Human dependence	Incorrect balance programming	Equipment without serving
			Incorrect target detector programming	

4.3.3. Pareto Diagram

After grouping the causes, the work team sought to identify the main causes that most affect the lack of conformity at the end of the production process. Having categorized 22 initial causes, 8 related to "Cefalópodes" line, 8 to "Ensacadora" line and 6 to "Higienização" line, each team member was asked to score the causes considered the most driving causes of the problem under study. A scoreboard with an odd system of scores was used, in which each actor assigned each cause a score of 9, 5, 3 or 1. The cause considered most important by the element was assigned a 9, and the remaining most important causes were attributed the remaining scores, in descending order. Results are in Table 13.

Table 13. Score table assigned by each element

Actor	Punctuation			
	9	**5**	**3**	**1**
A	11	1	5	14
B	7	14	14	8
C	3	11	10	11
D	14	7	10	8

The total scores attributed to each of the causes and their respective percentages in relation to the total score were calculated (Appendix V) and sorted by descending order of relevance. This information allowed to draw up the Pareto diagram for the main causes (Figure 26), on which the Improve phase of the DMAIC cycle will be focused.

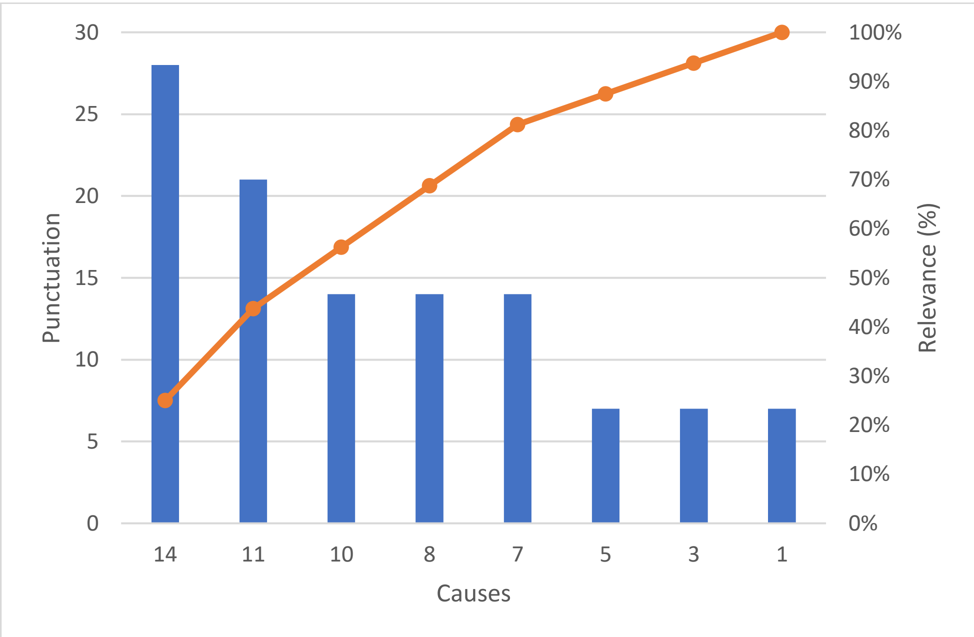

Figure 26. Pareto diagram.

Once the Pareto diagram is constructed and considering its postulates, it is possible to verify that the first 2 causes have the greatest relevance, since cumulative percentage presents a higher slope. As such, the following relationships have been established:

Class A (2 Causes): 47%
Class B (2 causes): 33%
Class C (3 causes): 20%

It was decided among the team members that the solutions in the Improve phase will be made only on the causes belonging to class A in the Pareto diagram, to focus the company's efforts on the causes with the greatest impact, thus producing the best results without the need for allocation of resources unnecessarily. Based on the decision to focus only on class A and the results obtained through categorization and scoring of causes, we came to the causes that most affect the central problem in this case study, which are as follows:

- Human factor
- Unforeseen times
- Time of activities
- Stops
- Organization of the production room.

4.4. Improve Phase

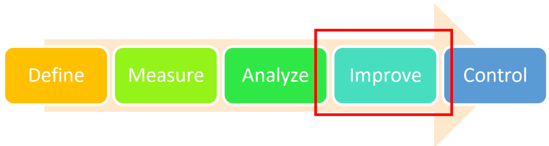

Figure 27. DMAIC - Improve phase.

Identified in the Analyze phase the main causes of the existence of non-conformity products in the production process, the Improve phase is followed (Figure 27). The main objective is the creation of solutions based on root causes, the selection of the best solutions / improvement actions, and ensure the implementation of the measures derived from the solutions.

As in the Analyze phase, brainstorming sessions with team members were used to discuss and collect possible solutions and/or improvement actions for each root cause. Results are in Table 14.

Table 14. Identification of improvement solutions/actions

Root category / Cause	Solution / Improvement action
Human factor	Specialized training plan, evaluation of its effectiveness, periodic review of procedures and actions to verify and evaluate the performance of employees.
Unforeseen times	Restructuring the production, quality, and maintenance plans to be more efficient at work and do not have delays in the lines.
Time of activities	Restructuring of the activities carried out in the production process, have a planning system that goes correctly with the needs of the company and the stock that it is ready to be used (row material and row product) to now have a delay or change of plans.
Stops	Check one day before all the needs form the lines (human and material) to not have stops.
Organization	Plan of activities in production, quality, and maintenance departments.

4.4.1. Priority Matrix

Once the solutions that are thought to have the greatest impact on the identified causes were defined, it was tried to define criteria for solutions. This evaluation considered not only the efficacy of the solution, but also the cost-benefit dichotomy, and the time that is necessary for the implementation. For this purpose, the Priority Matrix was used as a decision tool for arriving at a decision on which solution should be implemented, and where the identification of possible solutions should begin.

Possible solutions:

S1 - Specialized training plan, evaluation of the effectiveness of the same, periodic review of procedures and actions of verification and evaluation of the performance of employees.

S2 - Restructuring the production, quality, and maintenance plans to be more efficient at work and do not have delays in the lines.

S3 - Restructuring of activities carried out in the production process.

S4 - Check one day before all the needs form the lines (human and material) to not have stops.

S5 - Plan of activities in production, quality, and maintenance departments.

Definition of criteria:

The cost, impact and speed of implementation were considered as the criteria of greatest impact in choosing the most appropriate solution.

A - Cost of implementing the solution.

B - Impact of the solution on the problem.

C - Speed in the implementation of the solution.

The same weighting for the possible solutions and for the criteria were chosen:

1 - The same importance

5 - More important than the alternative

10 - Much more important than the alternative

1/5 - Less important than the alternative

1/10 - Much less important than the alternative

The criteria priorities will be following described.

Table 15. Matrix of criteria priorities

	A	B	C	Total	Punctuation (%)
A	1.0		0.2	1.2	5.63
B		5.0		5.0	23.47
C	0.1	10.0	5.0	15.1	70.89
Total	1.1	15.0	5.2	21.3	100.0

To obtain the weights in Table 15, the sum of each row A, B and C was divided by the total value. For example: (1.2 / 21.3) × 100 = 5.63%.

It was carried out in a similar way the establishment of priorities for each criterion A, B, and C in relation to the solutions identified (Tables 16, 17 and 18).

Table 16. Priority matrix for criterion A

Criteria A	S1	S2	S3	S4	S5	Total	Punctuation (%)
S1	1.0		10.0		0.2	11.2	22.90
S2		5.0	0.2	0.1	1.0	6.3	12.88
S3	5.0	1.0		0.1		6.1	12.47
S4		0.2		10.0		10.2	20.86
S5	10.0		0.1		5.0	15.1	30.88
Total	16.0	6.2	10.3	10.2	6.2	48.9	100.0

As in the matrix of criteria priorities, the weights were calculated by dividing the sum of each row by the total value. For example: (11.2 / 48.9) × 100 = 22.90%.

Table 17. Priority matrix for criterion B

Criteria B	S1	S2	S3	S4	S5	Total	Punctuation (%)
S1	5.0	5.0	0.1	1.0	1.0	12.1	19.55
S2	0.2		5.0	5.0		10.2	16.48
S3	0.1	0.2		10.0	0.1	10.4	16.80
S4	1.0	1.0	10.0		5.0	17.0	27.46
S5	10.0	1.0		0.2	1.0	12.2	19.71
Total	16.3	7.2	15.1	16.2	7.1	61.9	100.0

Table 18. Priority matrix for criterion C

Criteria C	S1	S2	S3	S4	S5	Total	Punctuation (%)
S1	1.0		5.0		0.2	6.2	15.12
S2	1.0	0.2		10.0		11.2	27.32
S3	0.2	0.2	1.0		5.0	6.4	15.61
S4	5.0	1.0	0.2		1.0	7.2	17.56
S5		10.0				10.0	24.39
Total	7.2	11.4	6.2	10.0	6.2	41.0	100.0

Now that calculations are done, the last step consists in determining the importance of each solution against the established criteria. Table 19 includes the summary of the weighting coefficients for each criterion obtained from the previous tables. The matrix of priorities *versus* solutions criteria is in Table 20.

Table 19. Weightings of solutions by criterion

	A	B	C
S1	22.90	19.55	15.12
S2	12.88	16.48	27.32
S3	12.47	16.80	15.61
S4	20.86	27.46	17.56
S5	30.88	19.71	24.39

Table 20. Matrix of priorities vs solutions criteria

	A	B	C	Importance	Priority
S1	0.0129	0.0459	0.1072	0.1660	4
S2	0.0073	0.0387	0.1937	0.2396	1
S3	0.0070	0.0394	0.1107	0.1571	5
S4	0.0117	0.0645	0.1245	0.2007	3
S5	0.0174	0.0463	0.1729	0.2365	2

To obtain the values of columns A, B, and C, the weighting coefficients calculated in the matrix of criteria priorities are multiplied by each weighting coefficient of each solution relative to each criterion. For example, for the first cell we have $0.0563 \times 0.2290 = 0.0129$.

The values of the Importance column are calculated by summing the values of each row. For example, the sum of the values in the first row is $0.0129 + 0.0459 + 0.1072 = 0.1660$. Finally, the solutions are sorted in descending order and given a priority number.

For the implementation of the selected priority solution to be successful, an action plan was delineated using the 5W2H action plan management tool presented in Table 21. As previously mentioned, it uses 7 questions (What, Why, Who, When, Where, How and How much) that allow the creation of an effective plan with a high probability of success.

Due to time constraints and lack of availability, it was not possible to perform the pilot study in the company. However, if the pilot study had been carried out, it would have been for 1 month in which the company would be governing the new rules of procedure.

Table 21. 5W2H action plan

Question	Actions
What?	Restructuring the production, quality, and maintenance plans to be more efficient at work and do not have delays in the lines.
Why?	Because nowadays the lines have a stop during the working hours, due to the machines, the enough product to continue (raw materials), not enough person to continue, and quality of the product (size)
Who?	To the Production, Maintenance and Quality departments of the company.
When?	Training actions: in 1 month. Application of techniques for better product retention in line: 3 months from now Pilot study: Immediate; Audits: 4 months.
Where?	Training actions: Mar Cabo. Pilot study: Mar Cabo. Audits: Mar Cabo.
How?	Training Actions: New procedures to get productivity in the company. Time and activity management carried out for periodic control of the machines of the production lines and continuous verification of the product before being packed, planning of packaging area. Quality and maintenance review during active production hours to verify that everything is in order. Review by the quality area of the cleaning of the production area that is in line to be used, as well as the product to be packaged to see if they contain the specification of both the customer and the size of the bag where it will be packed
How much?	Training actions: 1 day (8 hours). Application of techniques for better product retention in the line: Undefined. Pilot study: no charge. Audits to the production lines.

4.5. Control Phase

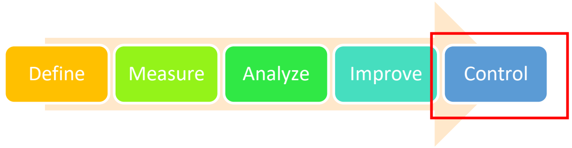

Figure 28. DMAIC - Control phase.

This phase aims to control and monitor the improved process and the effectiveness of the actions implemented to ensure the sustainability of the project and its long-term success (Figure 28). Although in this study it was not possible to properly monitor the long-term success of the proposed actions (due to the impossibility of implementing them), it was outlined a plan of what should be carried out to ensure the success of the solutions in terms of monitoring, control and correction of the processes, and improvement actions:

- **Standardization and institutionalization of improvement actions in the company** - Through periodic scheduled evaluations that allow the evaluation of the performance of new methods of procedures and new acquisitions in production lines.

- **Execution of new follow-up control charts** - Periodic realization of control charts to monitor the behavior of errors that happen in production lines and to be able to follow up to minimize the mistake.

- **Creation of Six Sigma working groups** - In the future it is crucial to create teams that can continue the improvement projects carried out, and also that through the transmission of knowledge it is possible to carry out the other projects taken into account in the Define phase of this study, as well as the implementation of new and possibly more appropriate solutions for solving the problem.

- **Cost-benefit comparison** - Conduct statistical studies of the evolution in the company's costs in relation to production and raw material, check how much it cost to waste material to pack the product in the lines, and compare that with the cost of the cost of the final product.

- **Awareness training plans** - It is up to the company to raise awareness and give its employees the importance of ensuring that the product remains in the conditions of the stipulated specifications.

5. Conclusions and Suggestions for Further Work

In this chapter the conclusions of the work developed are presented as well as the limitations found throughout the project. Theoretical and practical contributions that may result from the development of this dissertation are also presented. Finally, proposals are presented for the development of future work in the company.

This study demonstrated the usefulness and applicability of the Six Sigma methodology in the food industry sector, particularly in the frozen food industry. It was also confirmed that the DMAIC cycle is an effective method for supporting the implementation of the Six Sigma methodology, through the combination of quality tools and techniques applied in each phase, bringing to the project an organized form in the coherent structuring of the steps to be followed.

Throughout the project, bibliographical research was carried out, mainly based on articles and books, among other relevant documents. This research provided the basis for an effective, organized application and making use of quality tools and techniques appropriately in each phase of the DMAIC cycle.

Highlighting the problems reviewed in Mar Cabo company, it is considered that many production processes with a Lean effect (which means faster solutions to improve the line and continue the production/packaging) are missing to reduce the errors that currently exist. The lack of follow-up in the areas of quality and maintenance have created many errors that are daily present in the production lines.

The lack of planning and control of the raw materials to be packed in terms of specifications (size, temperature and cleaning of plastic debris or other materials) is a problem that generates delays in the production and packaging lines. The quality department must have plans to avoid these delays and lead a teamwork with high production efficiency. It is also important a plan of actions that helps in the stock management of the materials and products to reduce time delays in the packaging lines.

As already mentioned, there was no possibility to implement the improvement actions identified in the Analyze phase due to time constraints, and consequently it was not possible to verify whether these would be effective in improving the current performance of the production process. The current Sigma level obtained at the end of the Measure phase was 4.57 for

“Cefalópodes” line, 3.37 for “Ensacadora” line, and 4.05 for “Higienização” line, which means that there is clearly an opportunity for quality improvement.

To follow up on the Six Sigma methodology, the Control phase requires a period of evaluation of the effectiveness of the improvements implemented in the process, using control charts applied periodically, comparing with each other, and verifying improvements and making adjustments.

In this study, several quality control tools and techniques were applied. However, there are others that may be appropriate to apply as well, as they serve the same purpose. As an example, in the Analyze phase, a risk matrix may be adequate in the hierarchy of the possible causes of the problem instead of the Pareto diagram.

The most frequently processed products in the company were selected for this study. In the future it would be of interest to extend the study to the entire range of products processed by Mar Cabo, to obtain a more detailed view of the production process by considering the different morphological, chemical, and dimensional characteristics of the products.

6. Bibliography

- Adamson, M. W. (2004). Food in medieval times, pp 64-67; Greenwood Publishing Group, 88 Post Road West, Westport, CT 06881.
- Ait, H., & Guy, H. (2014). Prediction of Ideas Number During a Brainstorming Session, Springer Science+Bussiness Media B.V.
- Bifani, P. (2007). Medio ambiente y desarrollo. México, Centro Universitario de Ciencias Biológicas y Agropecuarias, Universidad de Guadalajara.
- Cape Sea (2020). About Us, Brands and Products. Accessed: April 6, 2021. Available in: marcabo.pt.
- Cape Sea (2021a). Manual of Good Practices of the Cape Sea - Frozen Products Lda. p. Eight of them.
- Cape Sea (2021b). Review of the HACCP Cable Sea Plan - Frozen Products Lda. p. Six-four.
- Dudbridge, M. (2011). Handbook of Lean Manufacturing in the Food Industry. John Wiley & Sons, United Kingdom.
- Dusharme, D. (2003). Six Sigma Survey: Big Success… What About Other 98 Percent? Quality Digest Magazine, 23(2), 15-22.
- Fikiin, K. (2007). Handbook of frozen food processing and packaging. International Journal of Refrigeration. 30, 745-746.
- Gobble, M. M. (2014). The Persistence of Brainstorming, Research-Technology Management, 57(1), 64-67.
- Grunert, K. G. (2005). Food quality and safety: consumer perception and demand, European Review of Agricultural Economics, 32 (3), 200-250.
- Ishikawa, K. (1994). What is Total Quality Control. The Japanese Way. Prentice Hall Direct, Upper Saddle River, New Jersey, United States.
- ISO 7870-2. (2013). Control charts – Part 2: Shewhart Control Charts. International Organization for Standardization, Genève, Switzerland.
- John, A., Meren, R., Roenpage, O., & Christian, S. (2015). Six Sigma + Lean Toolset, 2nd Edition, Springer-Verlag GmbH, Berlin, Germany.
- Mar Cabo (2020). Sobre Nós, Marcas e Produtos. Accessed: April 6, 2021. https://marcabo.pt/

- Mar Cabo (2021). Manual de Boas Práticas da Mar cabo – Produtos Congelados Lda. p. 18.
- Marín-Garcia, J. A., Pardo del Val, M., & Bonavia, T. (2008). Continuous improvement as incremental innovation: the case of a Spanish industrial company, 368, 105-201.
- McCarty, T., Daniels, L., Bremer, M., Gupta, P., Heisey, J., & Mills, K. (2004). The Six Sigma Black Belt Handbook, Chapter 1 - Introduction to Six Sigma: McGraw-Hill Education. New York, United States.
- McKeever, C. (2006). The Project Charter - Blueprint for Success. The Journal of Defense Software Engineering, (January).
- Montgomery, D. C., & Woodall, W. H. (2008). An Overview of Six Sigma. International Statistical Review, 76(3), 329-346.
- Osborn, A. F. (1998). Your creative power. Charles Scribner's Sons. New York, United States.
- Pyzdek, T. (2003). The Six Sigma handbook. McGraw Hill Education. New York, United States.
- Saetersdal, G. (1992). Los recursos pesqueros y su medio ambiente, ordenación y desarrollo. Cancún, Instituto de investigaciones Marinas. Bergen, Noruega. Conferencia Internacional de Pesca Responsable FAO, Mayo 1992.
- Zhan, X., Sun, D. W., Zhu, Z., & Wang, Q. J. (2017). Improving the quality and safety of frozen muscle foods by emerging freezing techniques: A review. Critical Reviews in Food Science and Nutrition, 58(17), 2925-2938.

Appendixes

Appendix I – Data to create control charts

a) “Cefalópodes” line

	1	2	3	4	5	6	7	8	9	10
“Cefalópodes” (problem/min)	11/abr	12/abr	13/abr	18/abr	19/abr	20/abr	21/abr	22/abr	26/abr	27/abr
Sealer film failure	0.200	0.138	0.121	0.142	0.175	0.050	0.075	0.146	0.146	0.113
Problems w label/cutter	0.09	0.07	0.08	0.05	0.07	0.04	0.09	0.06	0.07	0.06
Labeling Reprogram	0.008	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
Metal Detetor Failure	0.017	0.017	0.021	0.0042	0.013	0.017	0.013	0.008	0.017	0.021
Label Roll failure	0.004	0.017	0.004	0	0.025	0.004	0	0.004	0	0
Packaging delay	0.004	0.004	0	0.0042	0.004	0	0	0	0	0
People	0.004	0.008	0	0	0	0.004	0.004	0	0	0
Product	0.058	0.042	0.054	0.025	0.071	0.025	0.042	0.05	0.075	0.038

	11	12	13	14	15	16	17	18	19	20	21
“Cefalópodes” (problem/min)	28/abr	29/abr	02/mai	03/mai	04/mai	05/mai	06/mai	09/mai	10/mai	11/mai	12/mai
Sealer film failure	0.133	0.117	0.138	0.125	0.117	0.125	0.117	0.154	0.138	0.125	0.117
Problems w label/cutter	0.05	0.04	0.06	0.08	0.06	0.08	0.07	0.06	0.07	0.06	0.08
Labeling Reprogram	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.03	0.02
Metal Detetor Failure	0.029	0.021	0.017	0.025	0.021	0.021	0.029	0.008	0.004	0.017	0.013
Label Roll failure	0	0	0	0	0	0	0	0.004	0	0.004	0
Packaging delay	0.004	0	0.004	0	0	0	0.004	0	0.004	0	0
People	0	0.004	0	0.008	0.004	0	0	0.004	0	0.008	0.004
Product	0.042	0.021	0.029	0.017	0.013	0.029	0.033	0.021	0.029	0.017	0.025

b) "Ensacadora" line

"Ensacadora" (problem/min)	1 11/abr	2 12/abr	3 13/abr	4 18/abr	5 19/abr	6 20/abr	7 21/abr	8 22/abr	9 26/abr	10 27/jan
Sealer Film Failure	0	0.079	0.021	0.0333	0.017	0.008	0.017	0.021	0.017	0.05
Weight Scale failure	0	0.004	0	0.0083	0.021	0.013	0.004	0.008	0	0.021
Band Failure	0	0.013	0.004	0.0083	0.013	0.004	0.008	0.008	0.004	0
Metal Detetor Failure	0	0.004	0	0	0.008	0.008	0	0.004	0	0
Lever that accepts/reject product	0	0.029	0.038	0.0292	0.021	0.021	0.029	0.017	0.013	0.021
Label Roll failure	0	0.017	0	0.0083	0.004	0.004	0	0.004	0	0
Problems w label/cutter	0	0.038	0	0	0	0	0	0	0	0
People	0	0.004	0.004	0.0042	0.004	0.004	0.004	0.004	0	0

11 28/abr	12 29/abr	13 02/mai	14 03/mai	15 04/mai	16 05/mai	17 06/mai	18 09/mai	19 10/mai	20 11/mai	21 12/mai
0.058	0.042	0.042	0.208	0.333	0.05	0.058	0.417	0.5	0.625	0.875
0.038	0.033	0.075	0.058	0.054	0.021	0.079	0.075	0.067	0.063	0.083
0	0	0	0.033	0.025	0	0	0	0	0.033	0.025
0	0.004	0.008	0.013	0.004	0	0	0.004	0	0	0
0.029	0.029	0.021	0.021	0.017	0.013	0.063	0.075	0.067	0.075	0.088
0	0	0	0.025	0.017	0	0	0.004	0.004	0.008	0.004
0	0	0	0.033	0.021	0	0	0.075	0.063	0.075	0.071
0	0	0.004	0.008	0.008	0	0	0	0.004	0	0

c) “Higienização” line

	1	2	3	4	5	6	7	8	9	10
“Higienização”	11/abr	12/abr	13/abr	18/abr	19/abr	20/abr	21/abr	22/abr	26/abr	27/jan
Label roll failure	0	0.042	0.033	0.0583	0.021	0.004	0.004	0.008	0.013	0.021
Temperature label	0	0.004	0	0.0042	0	0	0	0	0	0
Poorly sealed product	0	0.021	0.013	0.0292	0.029	0.013	0	0.013	0.004	0.05
Packaging	0	0.017	0	0	0	0.004	0.008	0.004	0	0
Product Reprograming	0	0.017	0.021	0.0417	0.008	0.013	0	0.004	0.013	0.008
Film issues	0	0.013	0.021	0.0125	0.008	0.004	0.008	0.008	0.004	0.013

11	12	13	14	15	16	17	18	19	20	21
28/abr	29/abr	02/mai	03/mai	04/mai	05/mai	06/mai	09/mai	10/mai	11/mai	12/mai
0.013	0.008	0.004	0.004	0.004	0.008	0.013	0.008	0.004	0	0.004
0	0	0	0	0	0	0	0	0	0	0
0	0.029	0	0.004	0.004	0.025	0	0.029	0.013	0	0.004
0	0	0	0	0	0	0	0	0	0	0
0.008	0.013	0.004	0.008	0.004	0.008	0.004	0.013	0.004	0	0.004
0.004	0.004	0.013	0.004	0.004	0.013	0.004	0.004	0.008	0	0.004

Appendix II - Normal distribution spreadsheets

"Cefalópodes" line	Frequency	Cumulative Frequency
Packaging delay	6	6
Labeling Reprogram	14	20
Problems w label/cutter	211	231
Sealer film failure	464	695
Product	144	839
Metal Detetor Failure	62	901
Label Roll failure	14	915
People	9	924
Sum	924	
Average	115.5	

"Ensacadora" line	Frequency	Cumulative Frequency
People	12	12
Band Failure	29	41
Weight Scale failure	81	122
Sealer Film Failure	227	349
Lever that accept/reject product	81	430
Problems w label/cutter	22	452
Label Roll failure	19	471
Metal Detetor Failure	15	486
Sum	486	
Average	60.75	

“Higienização” line	Frequency	Cumulative Frequency
Temperature label	2	2
Packaging	8	10
Poorly sealed product	50	60
Label roll failure	57	117
Product Reprograming	40	157
Film issues	29	186
Sum	186	
Average	31	

Appendix III - Statistical distribution D of Lilliefors

n\α	0.01	0.05	0.10	0.15	0.20
4	0.417	0.381	0.352	0.319	0.300
5	0.405	0.337	0.315	0.299	0.285
6	0.364	0.319	0.294	0.277	0.265
7	0.348	0.300	0.276	0.258	0.247
8	0.331	0.285	0.261	0.244	0.233
9	0.311	0.271	0.249	0.233	0.223
10	0.294	0.258	0.239	0.224	0.215
11	0.284	0.249	0.230	0.217	0.206
12	0.275	0.242	0.223	0.212	0.199
13	0.268	0.234	0.214	0.202	0.190
14	0.261	0.227	0.207	0.194	0.183
15	0.257	0.220	0.201	0.187	0.177
16	0.250	0.213	0.195	0.182	0.173
17	0.245	0.206	0.189	0.177	0.169
18	0.239	0.200	0.184	0.173	0.166
19	0.235	0.195	0.179	0.169	0.163
20	0.231	0.190	0.174	0.166	0.160
25	0.203	0.180	0.165	0.153	0.149
30	0.187	0.161	0.144	0.136	0.131
OVER 30	$\frac{1.031}{\sqrt{n}}$	$\frac{0.886}{\sqrt{n}}$	$\frac{0.805}{\sqrt{n}}$	$\frac{0.768}{\sqrt{n}}$	$\frac{0.736}{\sqrt{n}}$

Appendix IV – Calculations to get Sigma values

a) "Cefalópodes" line (Excel spreadsheet)

0	6	0	3.09632	18.57792			
1	14	14	2.09632	29.34848			
2	211	422	1.09632	231.3236			
3	464	1392	0.09632	44.69264			
4	144	576	0.90368	130.1299		Opportunity	8
5	62	310	1.90368	118.0281		Defects	924
6	14	84	2.90368	40.65152			
7	9	63	3.90368	35.13312			
	924	2861		647.8853			
	132	mean	3.09632	1.759636	DPMO	0.001082251	1082.2511
		D	0.701175		Sigma	4.566680311	

b) "Ensacadora" line (Excel spreadsheet)

0	12	0	3.13786	37.65432			
1	29	29	2.13786	61.99794			
2	81	162	1.13786	92.16667			
3	227	681	0.13786	31.29424			
4	81	324	0.86214	69.83333			
5	22	110	1.86214	40.96708			
6	19	114	2.86214	54.38066			
7	15	105	3.86214	57.9321			
	486	1525		446.2263			
		mean	3.13786	1.771401			
		D	0.918161		DPMO	0.002057613	2057.6132
					Sigma	4.369191443	

c) "Higienização" line (Excel spreadsheet)

0	2	0	3.139785	6.27957			
1	8	8	2.139785	17.11828			
2	50	100	1.139785	56.98925			
3	57	171	0.139785	7.967742			
4	40	160	0.860215	34.086			
5	29	145	1.860215	53.94624			
	186	584	3.139785	176.7097			
		mean	3.139785	1.771944			
		D	0.950052		DPMO	0.005376344	5376.3441
					Sigma	4.050634966	

Appendix V – Data of the Pareto diagram

Cause	Frequency	Punctuation	Percentage (%)	Cumulative percentage (%)
14	4	28	25.0	25.0
11	3	21	18.8	43.8
10	2	14	12.5	56.3
8	2	14	12.5	68.8
7	2	14	12.5	81.3
5	1	7	6.3	87.5
3	1	7	6.3	93.8
1	1	7	6.3	100.0
	Total	112		