Making Lean Six Sigma Project Outcomes Robust Using Risk Management Methods

Master thesis

Giacomo Pressato

Aalborg University

Master of Science in Technology in Risk and Safety Management

10th January 2019

To my grandparents
Ai miei nonni

AALBORG UNIVERSITY
STUDENT REPORT

Risk and Safety Management
Aalborg University
http://www.aau.dk

Title:
Making Lean Six Sigma Project Outcome Robust Using Risk Management Methods

Program:
Master of Science in Technology in Risk and Safety Management

Theme:
Lean Six Sigma, Risk Management

Project Period:
Fall Semester 2018

Author:
Giacomo Pressato

Professor Supervisor:
Niels Gorm Maly Rytter

Page Numbers:
62

Number of copies:
2

Date of Completion:
January 10, 2019

Abstract

The competitiveness and the increasing importance of delivering products of high quality made it necessary the creation of a method that addresses most of the challenges that an organisation face: Lean Six Sigma. However, the risk associated for all types of industries is augmenting and making projects under uncertain conditions has never been so difficult. Vestfrost Solutions is a manufacturer of refrigerators that already implements the Lean Six Sigma principles, although the company is facing issues in the production of one refrigerator, which quality costs are considered too expensive. The purpose of this report is to see how Risk Management can be applied with Lean Six Sigma to improve the performances of a project. The project follows the DMAIC methodology to study the production line and propose improvement actions. A decision-making tool has been developed as an improvement action. Furthermore, the uncertainty associated has been assessed. The Risk Assessment is performed in order to encourage wise decision-making. Thus, the improvement action has been evaluated after the Risk Management improvements to observe the evolution on an impact-ease graph. This paper concludes that Risk Management is an applicable approach for the organisation to robustify the outcomes of the Lean Six Sigma process and reduce quality costs.

Preface

The project has been conducted by a student from Aalborg University Esbjerg, studying a Master of Science in Technology of Risk and Safety Management on the 4th semester as a Master thesis. Through a period of about four months, the research process has been developed with the supervision and support of Niels Gorm Maly Rytter, associate professor at Aalborg University Copenhagen.

The author of the project has been studied the Lean Six Sigma Management during a period of 6 months before the start of the project. The learning benefit of evaluating management methodologies have been challenging and rewarding. It has been possible to gain an insight into the production and project management issues of a manufacturing company that operates in daily and special circumstances.

This report is not a representation of the business and operations that Vestfrost Solutions is involved in. Whereas this report is intended to be as an insight to the reader to understand how Risk Management can be applied to other management methodologies, in particular Lean Six Sigma. Communication and preparation of the report including description, analysis, assessment and discussion is conducted only by the author without any involvement of representatives from Vestfrost Solutions. Thus, the results of this study can be expression of the author's view. The use of methods and models can be used by Vestfrost Solutions with an attached excel document.

The sources used in the study aimed to be as academical and reliable as possible. If information was not available, non-academic sources had been used exceptionally. Limitations and assumptions should be evaluated if the analysis is desired to be used in a real context.

The sources in the text are indicated by a number in square brackets that are listed in the reference chapter as IEEE style for referencing. [1] In this report, the captions of tables and figures are situated below them. They are sorted with one sequential index. Furthermore, when a caption is reported without any reference, it has to be considered has an own illustration made from the author.

The author

Giacomo Pressato

Acknowledgement

I would like to thank my supervisor Niels Gorm Maly Rytter for the time spent to enlighten me on important matters to consider in this research thesis. He allowed me to develop this paper on my own, but steering me on the right direction when it was necessary. In addition, I thank Aalborg University Esbjerg and Prof. Anders Schmidt Kristensen for the teaching provided in the past two years.

Furthermore, I would like to praise the all the managers from Vestfrost Solutions in the Sales and Production departments, Lars Gorzelak, Christian Due and Frank Gertsen to be available at all my requests and helping me with precious information. In particular, I want to mention Nema Rahin for his will to share with me his innovative perspectives and Peter Bjerring for contributing with all his priceless experience.

Finally, I must express my gratitude to my parents and my brother for providing me continuous support and encouragement through my years of studying. This accomplishment would not have been possible without them.

Thank you.

Acronyms

CTQ	Critical to Quality
DMADV	Define, Measure, Analyse, Design, Verify
DMAIC	Define, Measure, Analyse, Improve, Control
FTA	Fault Tree Analysis
IT	Information Technology
LSS	Lean Six Sigma
VOC	Voice of the Customer
VSM	Visual Stream Map

List of Figures

Figure 1: Main site and production plant of Vestfrost Solutions in Esbjerg. [4] 1
Figure 2: Breakdown of cost and profit for VST 258 from 01/01/2016 to 20/10/2018. 2
Figure 3: The Six Sigma DMAIC process. [6] [11] 4
Figure 4: Risk Management process. [14]... 6
Figure 5: Report outline as combination of Lean Six Sigma and Risk Management cycles. . 7
Figure 6: Research structure. 8
Figure 7: Refrigerator VTS 258. [4] 10
Figure 8: Value Stream Map for the production of refrigerator VTS 258. 13
Figure 9: Scatter plot of values for Customer expectations of each feature. 18
Figure 10: Scatter plot of values for Vestfrost performances of each feature. 18
Figure 11: Section of claims database for VTS 258. [4].. 19
Figure 12: Section of failures database. [4] 20
Figure 13: Chart of average values of Customer expectations and Vestfrost performances. 22
Figure 14: Possible visual method of prioritisation. 23
Figure 15: Impact-Ease graph with group prioritisation. 23
Figure 16: Prioritisation of features by group. 24
Figure 17: Distribution of failures in terms of amount and value through the production line. 27
Figure 18: Graphs of amount and value share of responsibility in failures. 28
Figure 19: Pareto chart of the amount of failures for each classified part. 29
Figure 20: Pareto chart of the value in DKK of the total failures for each classified part. .. 30
Figure 21: Pareto chart of the amount of each different type of failures. 31
Figure 22: Pareto chart of the value in DKK of each different type of failures. 32
Figure 23: Structured brainstorming for improvement actions. 33
Figure 24: PDCA problem-solving process. [20] 34
Figure 25: Typical flow of the problem-solving A3 report. [20] 35
Figure 26: Measurement for the value of the refrigerator through the production line...... 36
Figure 27: Decision making tool.. 36
Figure 28: Ease-Impact graph for ranking improvement actions. 37
Figure 29: Division of the ease-impact graph. [22] 38
Figure 30: Fault Tree Analysis for the increase of uncertainty in the development and use of the decision-making tool. 39
Figure 31: Network diagram of the risks. 41
Figure 32: Application of uncertainty (from Appendix B). 42
Figure 33: Decision-making tool with uncertainty and decision making under risk theory. 43
Figure 34: Effect of the Risk Assessment on the decision-making tool in the Impact-Ease graph of the improvement actions. 44

List of Tables

Table 1: Comparison between Lean-thinking and Six Sigma. [3] [6] [11] [12] [13] 4
Table 2: Features breakdown for the refrigerator VTS 258.. 11
Table 3: Critical to Quality characteristics from Voice of the Customers for Customer expectations and Vestfrost performances. 16
Table 4: Customer expectations. 17
Table 5: Vestfrost performances. 17
Table 6: List of users correlated with relative operation and description of it. 20
Table 7: Prioritisation of features with the minimum distance method. 25
Table 8: Comparison between the result of the two rankings. 26
Table 9: Categorized entries of the failures database. 27
Table 10: Failures database's responsibility. 28
Table 11: Failure database's parts failed...29
Table 12: Failures database's type of failure. 31

Table of Contents

1. INTRODUCTION 1
    1.1. Problem analysis 1
    1.2. Research question 6
    1.3. Delimitations 6
    1.4. Project Outline 7
    1.5. Methodology 8
2. DEFINE 10
    2.1. Voice of the Customer (VOC) 10
    2.2. Value Stream Map (VSM) 13
    2.3. Business Case 14
3. MEASURE 15
    3.1. Critical to Quality characteristics 15
    3.2. Claims measurement system 19
    3.3. Failures measurement system 19
4. ANALYSE 22
    4.1. Analysis of CTQ characteristics 22
    4.2. Claims 26
    4.3. Failures 26
5. IMPROVE AND CONTROL 33
    5.1. Improvement proposals 33
    5.2. Discussion 37
6. RISK ASSESSMENT 39
    6.1. Risk Identification 39
    6.2. Risk Analysis and Evaluation 40
    6.3. Risk Treatment 42
    6.4. Discussion 43
7. CONCLUSION 45
    7.1. Future research and development 46
8. REFERENCES 47
9. APPENDIX 49
    9.1. Appendix A 49
    9.2. Appendix B 62

1. Introduction

The 21st-century business environment is changing rapidly, becoming more competitive than it ever was before with an increasing emphasis on the quality of products and services provided. Furthermore, the world geopolitical landscape and the global financial crisis has increasingly raised the conditions of uncertainty for all types of organizations. [2] Because of these changes, many businesses found it necessary to change their ways of doing business and deeply re-evaluate goals, procedures and structure. [3] One general discovery of improvement is strictly connected with the management when approached not from a structural but from a process point of view. [3] By introducing the concept of process management and the need to assess the uncertainty in all the processes, corporates commit themselves to implement Lean Six Sigma and Risk Management in their structure.
Vestfrost Solutions is a global developer and manufacturer of refrigerators and freezers established in Esbjerg in 1963. They furnish the professional market with one vision in mind: "to create the world's best refrigerators and freezers".

Figure 1: Main site and production plant of Vestfrost Solutions in Esbjerg. [4]

Four main production lines are present in the plant in Esbjerg. In particular one is having some problems in delivering products up to quality standards. The line is called Biomedical and it produces refrigerators and freezers specially designed with the highest standards for hospitals, health clinics, universities, laboratories and pharmacies.
Recently, the production line started following Lean Six Sigma principles to deliver the best quality. Although, they are having numerous claims, complaints and a lot of failures in the production. The management has to find a solution and take a decision about what to do and how to improve quality and productivity. The scope of the report is to apply fundamental methods of Lean Six Sigma methodology to study the case and propose improvement actions. Furthermore, Risk Management is used as a set of tools in order to robustify the outcome from the LSS project. The analysis of the statistics collected from Vestfrost, is expected to be highly valued by the company. Furthermore, the structure of the research accommodates the academic requirements and thrive to be applicable in the management areas of production, improvement and risk.

1.1. Problem analysis

The BioMedical line in Vestfrost Solutions produces 6 different types of refrigerators for three main groups of customers and purposes:

- Pharmacies: Safe and reliable storage of medicine respecting the certification 93/42/AAC.
- Laboratories and research: Ultra low temperatures for long time storage and optimal conditions.
- Hospitals: Precise, reliable and energy saving with a wide range of uses.

This kind of classification is made to suit the possible requirements for different customers in the Biomedical environment. In the production plant this separation is not perceived and the refrigerators are divided according to their three main physical characteristics:

- Size: From 74 litres to 1500 litres.
- Model: Upright, Chest.
- Temperature: Intervals that can vary between +15°C and -86°C.

According to Nema Rehn, the Innovation Manager at Vestfrost, the market for the BioMedical line is expanding but the company is experiencing difficulties in the delivery of high-quality products. In particular, one type of refrigerator is emerging for its critical outcomes.

The refrigerator in question is called VTS 258 and the failures and claims are reducing the total net profit of 40%. The Figure 2 is a representation of how the entire revenue (for the total units produced) has been divided in the past years, from the 1st January 2016 until the 20th October 2018.

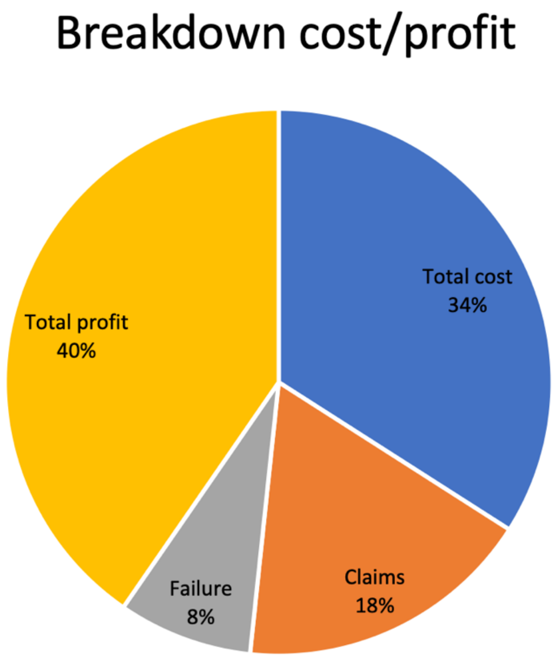

Figure 2: Breakdown of cost and profit for VST 258 from 01/01/2016 to 20/10/2018.

In the pie-chart above, the total cost is represented in blue and it comprehends the raw material and the manpower. The total profit, in yellow, stands for the net profit that is the profit minus the cost for claims and failures. Although, this data is provided by the Production Department and they don't take into account other costs related like salaries and inputs from other departments, taxes and eventual unforeseen costs that would shrink the share even more. "Claims" is the sum of the cost of the material for all the claims received after sales in that interval of time. The "Failure" cost is shown in grey; it is classified as a failure when an operator detects a defect on the machine and the unit needs more material to be repaired or dismantled. The presented issue is a high percentage of production costs due to a high amount of failures and claims. The unknown causes and the not determined solutions in a manufacturing industry make this case a process improvement problem that can be solved through a Lean Six Sigma project. Furthermore, the necessity of taking a decision to develop a reliable action under uncertain conditions, perfectly conveys with the core of Risk Management.

1.1.1. Lean Six Sigma

The Lean Six Sigma (LSS) methodology is an organization-wide operational philosophy with accountability and strategic focus. It combines two of today's most popular performance improvement methodologies: Lean methods and the Six Sigma approach.

The Lean methodology is an operational philosophy that emphasize on elimination of wastes and improvement of production time by enhancing what customers really consider quality. The first time that was introduced in an entire production process was in the early 1900s in the automotive industry by Henry Ford, the inventor of the assembly line. [5] The issue with Ford's system was the inability to provide customization. Toyota, thanks to Kiichiro Toyoda and Taiichi Ohno, started looking at Ford's production line and came out with a series of innovations that allowed to implement the variety that the customers were asking. In 1986, Masaaki Imai's book, "Kaizen" (the Japanese word that means "continuous improvement"), described the Toyota Production System (TPS) and two years later the term "Lean" has been used to identify the TPS and the set of tools to eliminate waste and increase quality. [6] [7]

The core principles of the Lean Management are:

- Maximize the value-adding activities: specifying the values desired by the customer, eliminating waste (in Japanese, muda), cutting batch size, pull-out process and mapping the value stream.
- Implement stable, standardized processes: through fail-safe operation (in Japanese jidoka) and workplace organization.
- Self-learning, continuous improvement: conducting rigorous root-cause problem solving and creating transparency on problems.
- Take a holistic Supply Chain perspective: Integrating the suppliers in the management, zero inventory, study time and motion.
- People development: Building employees' skills. [3] [6]

Today, Lean thinking continues to spread all around the world and its tools are being adapted to all types of private and public organizations. [8] The Lean tools that are worth mentioning are: Value Stream Mapping, Kaizen, Just in Time (JIT), Poke Yoke, Jidoka, Heijunka (Japanese term for Line Balancing), Gemba (Go and See) and Kanban (Visual Management technique). All these tools are made to target the eight main wastes identified in Lean methodology that take the acronym of DOWNTIME: Defects, Overproduction, Wait, Non-utilized talent, Transportation, Inventory, Motion, Extraprocessing. Only few of these are used for the scope of this project.

The Six Sigma (SS) methodology is a business-management strategy that aims at minimizing variation and causes of defects in order to improve the quality of process outputs. It is more recent than the Lean one. In the second half of the 80's, William B. Smith started developing Six Sigma at Motorola. The trigger was a specific quality problem in Motorola's semiconductors division; the request of performance level of 6σ. The engineers in Motorola developed a new standard to measure the defects per million of opportunities in which a part or a process can have more than one defect opportunity. In this way the processes were set to perform a number of defects minor than 3.4 per 1 million of opportunities. Thanks to this methodology, Motorola documented savings for more than 16 billion dollars. [9] Although, the successful implementation of Six Sigma and role model is considered to be

General Electric. It broadens the implementation of SS in all the organization and since the first two years saved 700 million dollars. [6] [10] Six Sigma establishes a particular framework within the organization in which everyone is specially trained in statistical methods and problem solution schemes that work as experts. The two schemes that these experts use in the problem analysis and decision making are:

- DMAIC (Figure 3): Define, Measure, Analyse, Improve and Control.
- DMADV: Define, Measure, Analyse, Design and Verify.

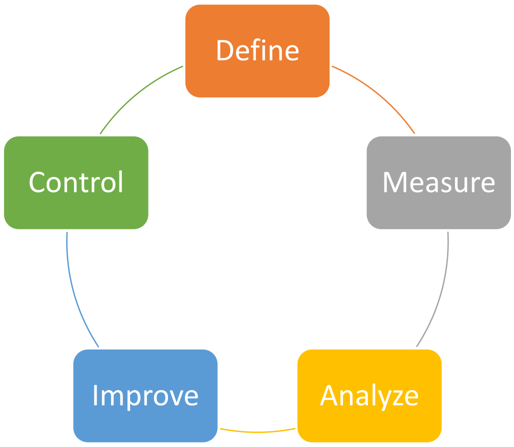

Figure 3: The Six Sigma DMAIC process. [6] [11]

The aim of Six Sigma is to eliminate variation in the process and make improvements based on customers definition of quality, measurements of performances and estimation of changes effects.

The following Table 1 provide a brief understanding of the analogies and differences between Lean Management and Six Sigma.

	Lean	Six Sigma
Assumptions	Discontinous value-stream is caused by waste, push principle and plant utilization Problems are opportunities and employees are the experts to solve problems in their processes	Variation of property in the output are caused by variations in the process and in the inputs Reduce unwanted variations to improve the quality of the output
Objective Reduce costs by Increase customer satisfaction by Potential	The entire company Efficient, stable, standarized and harmonized processes Achieve quality and availabiity of requirements Waste, inventory, stocks, cycle of times, unfulfilled requirements	Selected products or services Elimination of defects, time delays, resource usage Identification, prioritization and relization of customer requirements Costs of stocks, inventory, waste
Focus Organization Group-work	Value chain processes in all departments Continuous improvement and regular meetings	Program to improve specific products/services Solve the identified problems
Approach [Role: Task (Time frame)]	Management: Identify appropriate methods (once) Experts: Implement and adapt methods (periodically) Employees: Eliminate waste, standardize process (continuously)	Employees, Management, Customer: Identify problem (continously) Management: Prioritize and select problems to solve (periodically) Project team: Solve selected problem (temporary)
Principles	Customer requirements are the value Identify the values Identify and optimize the value-stream Implement pull-principle and act orderly (JIT) Implement continous-improvement process (KAIZEN)	Identify, collect, prioritize and select problems Qualify Six Sigma experts and a sponsor for the project Implement project Calculate financial benefits
Methodology	Methods and recommendations for wide range of applications (For example, KPI-system, Visible Management, Decentral End-to-End Process Responsibility, Improvement Teams, Incentives, Value Stream Analysis and Design, Kanban, OEE, TPM, 5S, Standardisation, Waste elimination)	Scientific methodology Generic problem solving using DMAIC Statistical analysis and test
Character	Strenghten processes	Treat problems
Advantage	Involve all employees, integrated optimisation of all departments	Financial benefits calculable, identification of root causes for complex problems
Disadvantage	Company cultural change necessary, decision based on perception and not on data	Optimization of sub-processes without cosnidering the whole context, majority of employees are not involved in the improvements

Table 1: Comparison between Lean-thinking and Six Sigma. [3] [6] [11] [12] [13]

Despite the fact that Lean and Six Sigma focus on cost reduction and customer satisfaction, there are differences in their features. However, in the recent years these practices have been combined to create Lean-Six Sigma. According to Dr. Reiner Hutwelker, this methodology requires a lot of effort and the benefits are only gradually becoming apparent; persistence of the management is one major success factor and it cannot easily be copied by competitors. [6] Lean Six Sigma Management combines the strong points of today's most popular performance improvement methodologies in which elimination of waste and increment of quality rate are targeted with the objective to provide the customer the best products and services.

1.1.2. Risk Management

The ISO 31000:2018 specifically defines Risk as "effect of uncertainty on objectives" and Risk Management as "coordinated activities to direct and control an organization with regard to risk". [14] It is important to notice that the effect of a risk could be positive, negative, both or neither, and it can be the direct or indirect cause of opportunities or threats.

Risk management has many diverse origin points and is today practiced by a wide range of professionals. One of the early developments in risk management arose in the insurance management in the United States. In the 1950s, the insurance industry had to improve the coordination and increase the practice of risk management due to the prohibitive costs and extremely limited coverage. Organizations were unsatisfied when purchasing insurance if there was inadequate attention to the protection of property and people. Therefore, insurance customers became concerned with the quality of property protection, the standards of health and safety, product liability issues and other risk control concerns. [2]

In 1970s, in Europe, the risk approach developed and the concept of total cost of risk started becoming more and more important. In the meantime, technology and culture evolved and organizations started facing risks that were not insurable. Thus, the tools and techniques of risk management started being applied to many other disciplines. [2] Today, risks related to finance, market, operations and technological issues are recognized as highly important and everything has been developed in the insurance industry, it became a useful risk control technique. [2] In this way, Risk Management is considered as a set of tools that is integrated in the framework in different areas of organizations for all type of activities and functions. The purpose is to protect the value by managing the effects of uncertainty on its objectives. The effectiveness of Risk Management depends on the integration in the management and the governance, including the decision-making process. The process to perform Risk Management is shown in Figure 4. [14]

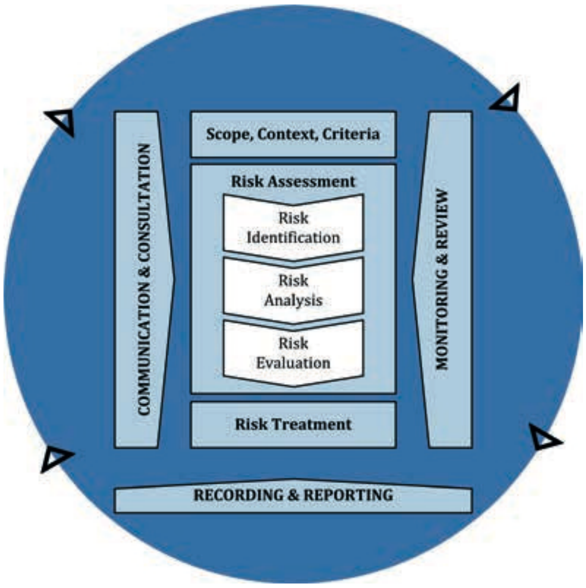

Figure 4: Risk Management process. [14]

The application of the Risk Management process is dynamic, thus customized to the organizations, the objectives to achieve and the whole context in which it is applied. The dynamicity feature is due to the variable and unpredictable nature of the human behaviour and the internal and external factors that have to be taken into consideration.

1.2. Research question

"How can Risk Management methods be applied in combination with a Lean Six Sigma approach to improve performance of a production line?"

By developing a Lean Six Sigma project with the aim of reducing quality costs and by assessing the uncertainty with Risk Assessment methods, the resulted impact on the performances of the project is observed.

1.3. Delimitations

To delimit the research and evaluate the project whether applying the outcome of Six Sigma process and Risk Management are beneficial for Vestfrost, it has been necessary to exclude some areas of interesting. Those areas could be interesting to research further, but it was necessary to dismiss them due to scope, time and extension of the project.

Not all the waste to consider in Lean thinking are considered since the research focus on the reduction of costs and increment of valuable quality to the customer.

Only the Production Line has been considered in the project although it would be interesting to extend the observations to include suppliers and customers as main stakeholders of the process.

When performing the Six Sigma process, the Control phase has been considered only as a forecast of the possible outcomes and not as making sure that the improved actions are well-implemented, effective and maintained.

The associated risks are assessed with the Risk Management standard according to ISO 31000:2018 [14], which contains element not included in the analysis such as communication, monitoring and recording. Furthermore, risks that are not direct related to the topic (i.e. natural disasters, terrorism, global financial crisis) are not taken into account.

1.4. Project Outline

The Lean Six Sigma process follows the Six Sigma methodology combined with the improvement principles and the strategy of Lean Thinking.
According to the ISO 31000:2018, Risk Management is necessary in every part of organizational processes and decision making of a business. [14] Risk Management can be seen as a management tool formulated to improve every core management process and to take more well-informed strategies and business decisions. Moreover, the framework to perform Risk Assessment reflects the Six Sigma ones.
The outline of the project follows the Six Sigma structure DMAIC and Risk Management is integrated as a tool in the decision-making process. The Risk Management process is without the elements that makes the flow a cycle: monitoring, control, reporting. Although, it takes into account the development made in the previous chapters as a background.

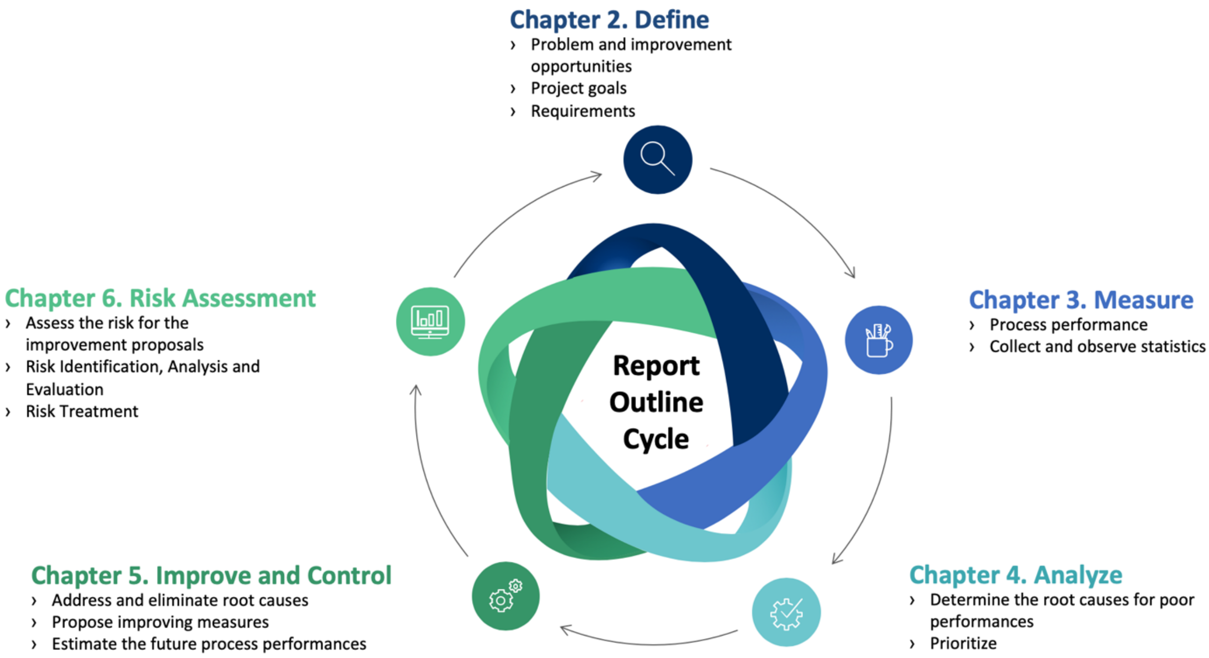

Figure 5: Report outline as combination of Lean Six Sigma and Risk Management cycles.

As shown in Figure 5, this project is structured with a section in which Risk Management is integrated to consider the uncertainty before a decision is made.
The first chapter of the report is the introduction chapter in which the context is established and the objectives of the research defined. Moreover, it incorporates an academical description of the report where methods and terminology are analysed.
The main and larger part of the report is the Lean Six Sigma project that includes chapters two, three, four and five. The process starts with the Define phase in which the business case is constructed. The Measure and Analysis phases (chapters four and five) present a statistical analysis of the data that lead to improvement activities. The Improve and Control chapter describes and evaluates the improvement actions proposed.
The sixth chapter is the Risk Assessment based on ISO 31000:2018. The Risk Assessment is performed with the aim of the project that is to make the improvement actions identified more robust.
The last chapter is a summary and discussion of the results obtained with proposals of recommendations for future applications.

Furthermore, all the descriptive and statistical analysis generated from the Lean Six Sigma and Risk Management process are consultable from the attached excel in Appendix B.

1.5. Methodology

The methodology of the project contains the different activities that have taken place in order to investigate the research problem. It describes the collection, generation and analysis of data.

The research is divided into two parts: the first is a Six Sigma project and the second a Risk Assessment. The Six Sigma project represents the major part of the report due to the aim of the project. In fact, to answer the research question, it is required that Risk Management is applied to a Six Sigma project to make the outcome robust. Furthermore, a well-developed Six Sigma project paves the way to a more valuable Risk Assessment for both academical and business purposes. In Figure 6 it is shown how the research is divided.

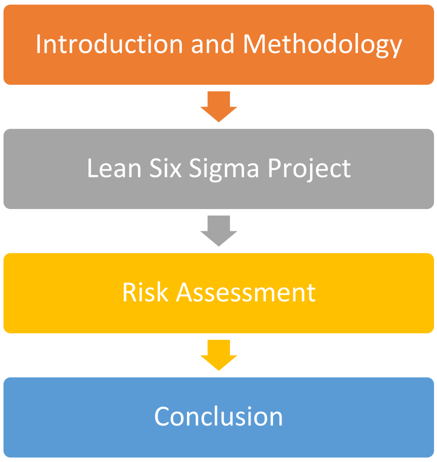

Figure 6: Research structure.

The scope with the LSS process is to understand and analyse the problem and to reach outcomes that are aligned with the scope of the project. Then, the Risk Assessment investigates the uncertainty to robustify the LSS project's results.

1.5.1. Research methods

The research was conducted as a quantitative research based on data received from Vestfrost Solutions used mainly in the LSS process. To perform the risk assessment, it was necessary to approach the study semi-qualitatively. To evaluate the effect of the project it was necessary to estimate number. The evaluation has been made by the author of the project according to its own gut feelings. This way of conducting evaluation has high uncertainty because it is the point of view of only one person. To make the evaluation more reliable, it is possible to use a Delphi method in which more experts come to agree on the evaluation of different parameters. Furthermore, informal interviews are performed in order to obtain initial information and data. [15] The advantages of this methodology are that it allows to the researcher to change the questions during the interview and follow up with more precise questions when it is appropriate. Furthermore, it allows the interviewed to answer with their own language and a detailed knowledge related to their own competences. The disadvantages of an informal interview are that it is necessary to have knowledge and proper preparation on the topic of discussion, and that it is difficult to stay on topic and keep the track towards the scope of the conversation. Moreover, it is difficult to summarize and analyse data. [15] To contain these pitfalls, the author kept writing by e-mails to the interviewed managers using follow-up questions to control the correct understanding of the conversations.

1.5.2. Data analysis

The analysis of the data collected from the informal interview have been translated and cleansed by the author and reviewed by the managers of Vestfrost Solutions. Furthermore, more meetings have been made in order to control and enforce the statistical outcomes. The quantitative analysis has been made with data, when possible. In case complete data were not present, the evaluation has been made with the gut feelings of the author.

1.5.3. Terminology

This report has been used using terminology that originates primarily from ISO 18404:2015 [11], ISO 13053:2011 Part 1 [13] and Part 2 [12] and ISO 31000:2018 [14].
The complete name of the company involved in the project is Vestfrost Solutions, although it has also been referred only as Vestfrost from the managers and the author of the report.
Furthermore, the word robust in general use means strong, healthy and able to withstand adverse conditions [16]. The term has been used in this report to describe the characteristic of being reliable and able to operate without failing under a variety of scenarios [17].

2. Define

This chapter analyses the Voice of the Customers (VOC) to understand the features that the product should have. Moreover, through a Gemba walk (Process walk) the process of the production is defined using a map called Value Stream Map (VSM).
The refrigerator under examination, shown in Figure 7, is an upright model with a net capacity of 221 litres and it usually works at -86°C.

Figure 7: Refrigerator VTS 258. [4]

According to the Innovation Manager, it represents the state of the art in terms of technological development since it is the most advanced for precision and performances. These features come with a cost. The materials used to produce this unit are expensive and the technicians involved in the manufacturing have to be meticulous.
Different departments are striving to improve this production line, in particular:

- Innovation
- Production
- Sales and claims

To better comprehend the problem from different points of view, individual and group interviews have been made.

2.1. Voice of the Customer (VOC)

The analysis of the VOC is an in-depth description of the customer expectation in order to deliver products with the best design for the service.
As first step, an example of customer requirements has been analysed. In Appendix A, it is possible to consult the tender published from a public client for a laboratory in Denmark. The features of the tender have been examined during an informal interview with Mr. Nema Rehn. According to his experience, it is possible to divide the characteristics of a refrigerator in essential and valuable. The first ones are characteristics that are minimum standards or a necessity for all the producers for this type of refrigerator, i.e. use stainless steel material.

The valuable features are the ones that convince the customers in choosing Vestfrost as supplier and can be classified in three main:

- User friendly: The users are laboratory technicians, nurses and doctors. It has to be easy to understand in the installation phase, in the use and in the maintenance.
- Reliability: It will contain and keep cool very important materials that are the results of long-time researches or it will store materials for long time without being directly supervised. It is accurate and the contained material is not in danger.
- Energy consumptions: It has to consume a relatively low amount of energy.

In order to understand the critical parts of a refrigerator that enhance these three characteristics, the following Table 2 has been developed.

Main	Secondary
User friendly	Controller General use (handler) Noise Easy to clean Moving wheels Customization Size Documentation (IQ OQ PQ) Ice scraper
Reliability	Alarm Sensors Back-up system Temperature recovery Insulation Uniformity temperature Temperature stability Dry contact Pressurized ventil door Ventilation Pull down time Hold over time
Energy	Low energy consumption

Table 2: Features breakdown for the refrigerator VTS 258.

On the first column the three main features are shown and the second column is a list of the parts or design characteristics that enhance the value of the three main characteristics.
User-friendliness include the following characteristics that make the refrigerator easier to utilize and maintain for the user:

- Controller: It is represented by the small monitor that shows the outcome from different sensors placed in the refrigerator. It has to be easy to understand and to use.
- General use (handler): The refrigerator needs to be easy to use in its parts. The handler, for example, it is an important piece because it is the tool most used from

the user. It needs to be resistant and comfortable when used and it must be easy to understand the condition of the door (open/close).

- Noise: Usually the refrigerator is placed in a room with other refrigerators or in the same room where people work, so it is vital that the refrigerator is quite silent when turned on.
- Easy to clean: The design of the refrigerator allows the operator to clean and maintain it in an easy way.
- Moving wheels: Having wheels to move it around is a plus. The wheels need to have a break system to stabilize it when it is not moving. Furthermore, the wheels need to resist the weight of the refrigerator and not break when used.
- Customization: The possibility of customizing the design before and after the production (i.e. before the production with the design of different sections in the internal cabinet, after the production with the possibility to insert shelves or trails in different heights).
- Size: This feature in the design is complex to define. The size needs to fit the purpose. (i.e. a small refrigerator is good for small laboratories, a big one is good for hospitals and big storages). The actual size is a compromised medium size that can fit in both cases, but it is not the ideal one for either of them.
- Documentation (IQ, OQ, PQ): It has documentation inserted in the package to assist the first installation. Installation Qualification (IQ), Operational Qualification (OQ) and Performance Qualification (PQ). It is a good quality practice in order to follow the right procedure to start the refrigerator and to record processes and parameters.
- Ice scraper: Include an ice scraper to remove the ice formed from the moisture.

Reliability is defined by different systems:

- Alarm: System that goes off in case a failure happens.
- Sensors: Sensors need to accurately measure sensitive data. They need to be precise and last long.
- Back-up system: Refrigeration system that works in case the main system can’t work and need reparation.
- Temperature recovery: Ability to recover the set point temperature after a door opening.
- Insulation: Components and material (foam) that insulate the inside temperature from the outside one.
- Uniformity temperature: Ability of the refrigerator to have a uniform temperature from top to bottom. It means low difference of temperature between the top part and the bottom part of the inside of the refrigerator.
- Temperature stability: Ability to maintain a certain temperature after reaching it.
- Dry contact: It is a contact used for remote alarm systems. It allows to send a signal to an external alarm system when the internal device alarm goes off.
- Pressurized ventil door: Automatic hermetic closing of the door when left opened.
- Ventilation: Capacity of the air to pass through the component and cool down.
- Pull down time: Ability to quickly pull down the temperature to the desired one.
- Hold over time: Ability to keep the refrigerator cold without electricity.

Finally, the low energy consumption is the ability to be sustainable and consume a fair amount of energy. At the end of Appendix A it is possible to see an example of how the energy consumption is calculated.

2.2. Value Stream Map (VSM)

Value stream mapping is a technique used to analyse the flow of materials through a process from beginning to delivery to the customer. This tool includes different steps that start with the creation of a flowchart of the existing process and through analysis and elimination it reaches the construction and implementation of a future value stream map.
The scope of the VSM in this project is to visualize and help in the definition and identification of the different steps in the production of a refrigerator VTS 258.
The VSM constructed is the result of a Process Walk (or Gemba Walk) with a representative of the Production Management in the line of production. During the informational tour, informal interviews took place in order to gain a comprehensive understanding of the whole process. The Value Stream Map constructed, Figure 8, is the representation of the current situation for the typical process to build the refrigerator.

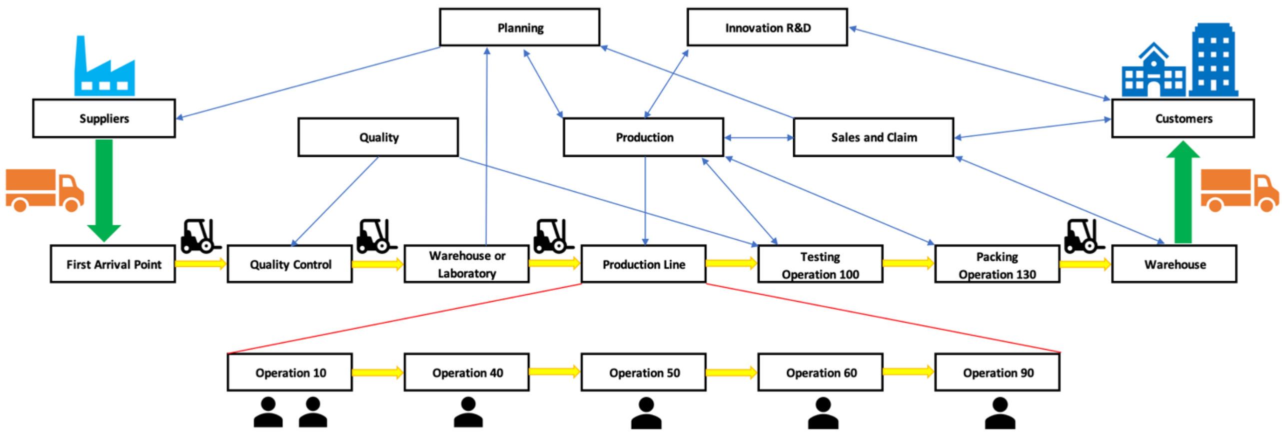

Figure 8: Value Stream Map for the production of refrigerator VTS 258.

In a typical VSM, the time of each operation is shown but, in this case, the leaning time is not a condition. In the presented VSM, the rectangular boxes represent the steps where information and materials are produced or transformed. The thick arrows, coloured in green and yellow, represent flow or transportation of material while the thin blue arrows represent exchange of communication that can be one way or double way. From the left side, Suppliers are the producers of material and resources (inputs) for the process. The materials arrive at the First Arrival Point in Vestfrost and with the use of loaders it is brought to the Quality Control area where a sample of pieces or all the pieces in each box are controlled or tested from one operator for their specific design or use according to the standards deliberated from the Quality Department. If the components are conformed, they are brought to the warehouse. When the Planning Department, together with the Production Department plan to produce that specific refrigerator that needs those materials, the materials are brought to the Production Line. The Production Line is where the materials (inputs) are transformed into the refrigerator (output) through five major steps that are represented on the chain by a computer station. These stations in the system are named under "Operation" followed by a number, as shown in Figure 8. On the map, it is possible to notice that this kind of caption is used also in the following Testing and Packing stages; this is because the captions refer to a specific computer station where the operators can record data about failures that are collected and deal with from the Production Department. The packed refrigerators are stored in the warehouse and ready to be sent to the customers. In the top central area of Figure 8 are represented the five most influent departments in the production of the refrigerator and the connections between them and the process. The target of this project is mainly what concerns the Production and Sales Department.

2.3. Business Case

Vestfrost Solutions is having some issues in the Biomedical Production Line, in particular with the refrigerator VTS 258, a model that should respect very high standards and be accurate while working in extreme conditions. The problems are connected with the number of failures happening in the Production Line, before the refrigerator is dispatched, and with the number of claims received. The company furnished data about both failures and claims and together they reach 28% of the total revenue from the selling of this type of refrigerator. Furthermore, the amount of net profit would be shrunk if the cost analysis is extended to unforeseen costs like the work from other departments of the organization (i.e. Sales and claims Department, Innovation and R&D Department, Quality Department, IT Department, etc.). To increase the profit, it is important for the company to keep producing refrigerators that the customers consider of valuable high quality. This project focuses on the needs of the customers and the performances of the production line in order to propose improvements that will decrease the rate and the costs of failures and claims.

3. Measure

In this chapter the Measure phase of the project is presented in which metrics for measurements are established to help monitor data and progress toward the goal defined in the previous chapter. In order to assemble measurable data, the current baseline from the Define phase is further analysed in the first section. Thus, exploratory and descriptive data analysis is performed to understand the database created. In the following sections, the actual system of collection of data for failures and claims are presented.

3.1. Critical to Quality characteristics

The Critical to Quality (CTQ) characteristics are the key measurable features of the product, whose performance standards, specification limits or descriptive characteristics, must be met in order to satisfy the customer. [6] Hence, these must be specific, measurable and actionable. In this project, the Critical to Quality characteristics are studied in order to evaluate the features in which it is be necessary to improve in order to provide a higher value to the customer. The characteristics are taken into account as they are and not further developed in the specific process or design to enhance the quality.

The results obtained in the Voice of the Customer, are evaluated to make a rank of the customers' expectations and the performances of the producer. In order to do that, informal interviews have been conducted with three managers from different departments in Vestfrost:

- Innovation R&D: Responsible of analysing the market, the business and technology trends.
- Sales and claims: Responsible for sales and to deal with claims from customers.
- Production: Responsible for production and processes in the plant. He receives indications from different departments and both the two other managers.

During the interviews, the managers agreed with the features identified in the VOC and they evaluated each one taking in mind the refrigerator VTSs 258 from two different perspectives:

- Customer expectation: Numerate from 0 to 10 where 10 stays for an essential feature and 0 stays for a not necessary feature.
- Vestfrost performances: Numerate from 0 to 10 where 10 represent a positive, modern and state of the art performance in the production and 0 represent a feature that has not being implemented in the product.

The result is represented in Table 3.

Features		Customer expectation			Vestfrost performances		
Main	Secondary	0=Not necessary at all 10=Essential			0=Not implemented 10=Advanced, modern, state of the art		
		Innovation R&D	Claims	Production	Innovation R&D	Claims	Production
User friendly	Controller	8	10	5	3	6	10
	General use (handler)	9	8	5	2	6	5
	Noise	7	8	8	5	5	2
	Easy to clean	4	7	8	8	7	4
	Moving wheels	7	10	8	3	8	8
	Customization	8	5	10	3	5	2
	Size	9	8	10	2	6	2
	Documentation(IQ OQ PQ)	8	7	10	0	7	1
	Ice scraper	7	2	4	0	2	8
Relaibility	Alarm	10	10	5	7	10	8
	Sensors	6	5	5	6	8	8
	Back-up system	10	8	8	7	6	5
	Temperature recovery	8	8	8	4	8	4
	Insulation	9	5	9	3	8	3
	Uniformity temperature	9	9	7	5	7	5
	Temperature stability	10	9	9	6	7	4
	Dry contact	9	10	6	10	8	9
	Pressurized ventil door	9	8	9	4	6	3
	Ventilation	10	5	4	10	8	9
	Pull down time	8	8	8	9	8	4
	Hold over time	10	8	8	7	7	4
Energy	Low energy consuption	10	8	8	6	7	7

Table 3: Critical to Quality characteristics from Voice of the Customers for Customer expectations and Vestfrost performances.

The characteristics are now represented with a quantitative index from three points of view. In order to deeply understand the meaning of this elaboration, the Customer expectations and the company's performances are studied. These data are initially compared through their average and the difference between the maximum and the minimum value given from the three managers.
In Table 4 and Table 5 the calculations are done for Customer expectations and Vestfrost performances, respectively.

CUSTOMER EXPECTATIONS					
Features	**Innovation R&D**	**Claims**	**Production**	**AVERAGE**	**DIFFERENCE**
Controller	8	10	5	7,7	5
General use	9	8	5	7,3	4
Noise	7	8	8	7,7	1
Easy to clean	4	7	8	6,3	4
Moving wheels	7	10	8	8,3	3
Customization	8	5	10	7,7	5
Size	9	8	10	9,0	2
Documentation	8	7	10	8,3	3
Ice scraper	7	2	4	4,3	5
Alarm	10	10	5	8,3	5
Sensors	6	5	5	5,3	1
Back-up system	10	8	8	8,7	2
Temperature recovery	8	8	8	8,0	0
Insulation	9	5	9	7,7	4
Uniformity temperature	9	9	7	8,3	2
Temperature stability	10	9	9	9,3	1
Dry contact	9	10	6	8,3	4
Pressurized ventil door	9	8	9	8,7	1
Ventilation	10	5	4	6,3	6
Pull down time	8	8	8	8,0	0
Hold over time	10	8	8	8,7	2
Energy consumption	10	8	8	8,7	2

Table 4: Customer expectations.

VESTFROST PERFORMANCES					
Features	**Innovation R&D**	**Claims**	**Production**	**AVERAGE**	**DIFFERENCE**
Controller	3	6	10	6,3	7
General use	2	6	5	4,3	4
Noise	5	5	2	4,0	3
Easy to clean	8	7	4	6,3	4
Moving wheels	3	8	8	6,3	5
Customization	3	5	2	3,3	3
Size	2	6	2	3,3	4
Documentatio	0	7	1	2,7	7
Ice scraper	0	2	8	3,3	8
Alarm	7	10	8	8,3	3
Sensors	6	8	8	7,3	2
Back-up system	7	6	5	6,0	2
Temperature recovery	4	8	4	5,3	4
Insulation	3	8	3	4,7	5
Uniformity temperature	5	7	5	5,7	2
Temperature stability	6	7	4	5,7	3
Dry contact	10	8	9	9,0	2
Pressurized ventil door	4	6	3	4,3	3
Ventilation	10	8	9	9,0	2
Pull down time	9	8	4	7,0	5
Hold over time	7	7	4	6,0	3
Energy consumption	6	7	7	6,7	1

Table 5: Vestfrost performances.

In the column of the average, the customer expectations reach the highest values for the Temperature Stability (9.3) and the Size (9.0). Thus, these two characteristics are considered the most important to consider for having a satisfied customer. Furthermore, to understand the less important ones, you have to look at the lowest average that is the Ice scraper (4.3).
However, the Vestfrost performances appear to be the best on other features, such as the Dry contact (9.0). For what concerns the worst performances, the Ice scraper is one of the poorest performing (3.3), at the same level of Customization and Size, close to the presence of appropriate Documentation (2.7). It is noticeable that the Size is at the same time one of the most important for the customers and one of the least for the performances. More information can be deduced from the difference between answers in different departments. As it is possible to see, in both tables there are remarkable differences between the answers from the three departments. Especially for Table 5, Vestfrost performances, the difference between the perceptions from distinct departments reached a peak of 8. A visual aid to observe the distribution of the answers, is presented in the following Figure 9 and Figure 10.

Figure 9: Scatter plot of values for Customer expectations of each feature.

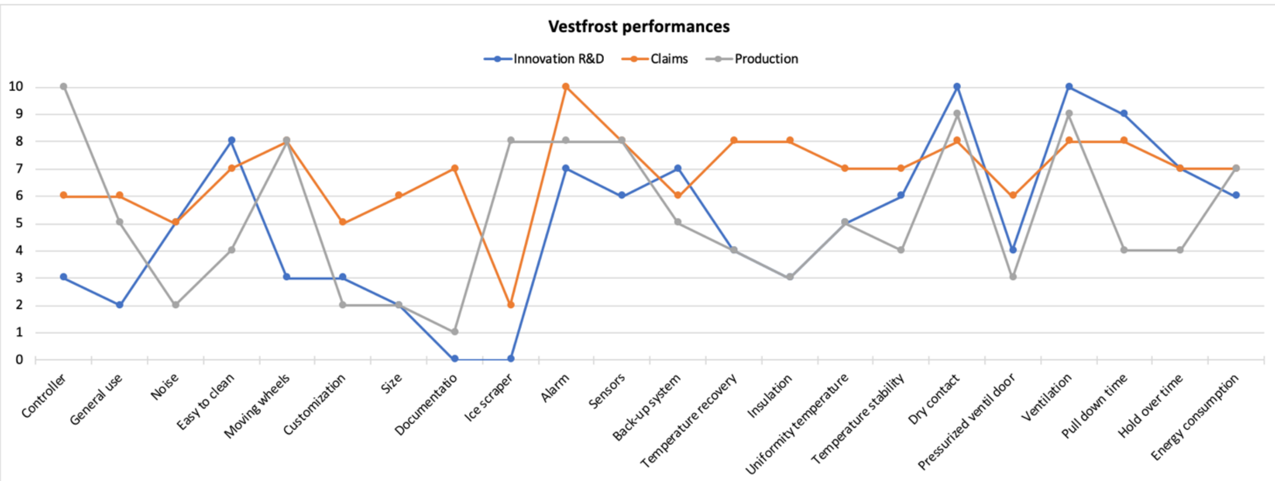

Figure 10: Scatter plot of values for Vestfrost performances of each feature.

The figures above are the scatter plots of the opinion of the Innovation R&D management, in blue, the Sales and Claims management, in orange, and the Production management, in grey. The visual impact gives an understanding of the variation of the difference in each characteristic. The immediate perception is that in both measurements there are many

discordant opinions on the importance of features for the customer and for the company performance in the attempt to deliver a product with the desired features implemented. This last one shows even more diverged evaluations.
In the next chapter, in order to pursue an increment of profit by providing valuable quality to customers, these characteristics are further analysed to prioritize eventual actions to undertake in the improve phase.
In the next sections the failures and claims collection systems are introduced to obtain more information for the possible reduction of expenditures.

3.2. Claims measurement system

In this phase of the project, the record of claims, consultable in Appendix B, has been provided from the Sales and claims Department. The database is used in this phase to get a comprehensive understanding of the claims. The data retrieved covers a period between January 2016 to October 2018.
As shown in Figure 11, the database is composed of three main columns:

- Name: Name of the claim report document.
- Title: Brief description of the claim.
- Serial number: Code of the refrigerator that is claimed.

The successive columns have been developed by the Sales and Claims Department to help the understanding of the claim, when possible. They are:

- Failure: Brief description of the failure.
- Corrective action: How the problem is solved.
- Estimated cost: Estimation of the cost made by the Manager.

Name	Titel	Serial number	Failure	Corrective action	Estimated cost
REK-00585.xml	Lasec VTS 258	60448001	Gasket not tight	Gasket modified	5.000 kr.
REK-00617.xml	VTS 258 - Temperaturproblem	51798475	Temperature problem	New gas charging	5.000 kr.
REK-00626.xml	VTS 258 - temperature drop	60651133	Clocking of cooling system	Appliance changed	50.000 kr.
REK-00630.xml	VTS 258 - temperature goes to -63°	61665585	Leak in the coolingsystem	New gas charging	5.000 kr.
REK-00639.xml	VTS 258 kan ikke komme længere ned end til -20°C	44843496	Temperature problem	Appliance changed	35.000 kr.
REK-00645.xml	VTS258 DUAL med fejl på lys	60651134	No Light	Door switch changed	5.000 kr.
REK-00664.xml	VTS 258 - water leakage	61361167	Ice deformation	Appliance changed	35.000 kr.
REK-00666.xml	Can't hold the temperature	31939486	Temperature problem	New gas charging	5.000 kr.
REK-00670.xml	VTS 258 - Gasket problem	60651130	Gasket not tight	Appliance changed	35.000 kr.
REK-00674.xml	VTS 258 - Leakage shortly after installation	62812133	Clocking of cooling system	Appliance changed	35.000 kr.

Figure 11: Section of claims database for VTS 258. [4]

As it is possible to see from this cross section on the claims database, Figure 11, a proper register that follows a standard procedure for the collection of qualitative and quantitative data is not present in Vestfrost Solutions. According to the manager responsible for the claims, the current methodology of dealing with claims is the change of the defected unit with a new one. This happens in most of the cases in order to keep the customer satisfied. More analysis on the system is performed in the Analysis chapter.

3.3. Failures measurement system

This section is to describe the database of failures recorded from the Production Department from 1st January 2016 to 16th October 2018. As mentioned before, a failure is considered as the detection of a defect, an abnormal condition, on the refrigerator and, as a consequence, the unit needs to be repaired or dismantled.
The database of failures in the Production Line is big and composed by different entries. To focus only on the VTS 258 the Manager had to properly filter data according to hierarchy parameters and select the correct refrigerator type. At this point the view is the one that is possible to see in the sheet “BIO Scrap work” in Appendix B. As it is possible to see from Figure 12, this database is implementing a more precise system compared to the claims’ one.

Row Labels	Navn	Varenummer	Navn	Values Økonomisk Kost	Antal
⊟B1901				-211.673,25	-9.883,93
⊞210-2	Coil - Fejl på plade (MASKINE)			-46.583,16	-1.938,53
⊞241-2	Bule inderbeholder (MASKINE)			-28.407,25	-1.183,37
⊞210-3	Coil - Fejl på plade (LEVERANDØR)			-24.137,02	-803,80
⊞210-1	Coil - Fejl på plade (OPERATØR)			-15.095,38	-635,85
⊞220-2	Skumudtræk/skum (MASKINE)			-14.927,76	-979,82
⊞251-3	Lakfejl inderbeholder (LEVERANDØR)			-8.557,08	-390,73
⊞221-2	Skumprøver			-8.481,92	-490,62
⊞240-2	Bule kabinet (MASKINE)			-5.934,95	-526,57
⊞240-1	Bule kabinet (OPERATØR)			-5.674,82	-359,00
⊞231-2	Bukkefejl (MASKINE)			-5.035,60	-43,00

Figure 12: Section of failures database. [4]

The first column, "Row Labels" is filled with identification codes for user and failure. In Figure 12, for example, "B1901" indicates a user, that is a computer station where failure is collected whereas "210-2" is the code for the particular type of defect; in the figure it is possible to see only some codes for the first user. The description of the failure is under the column "Navn". In the last two columns, on the right side of Figure 12, it is possible to see the cost of that error for that operator and the amount of material necessary to solve all the failures related to that code. The description of the failure is usually composed by the part that contains the defect and the typology of failure. Furthermore, it is often mentioned the responsible of the failure as "machine", "operator" or "supplier". The Table 6 below shows the correlation between the operator codes and the operations in the production line.

USER	Operation	Description
B1901 B1908	Operation 10	Assembly of coil, electrical cables and idraulic parts to form the container. Assembly of the external cabinet. Preparation for the foaming and foaming.
B1902	Operation 40	After passing the foaming control, in this phase electrical components, door, drwers are mounted in the inner part of the refrigerator. Furthermore, the top and the bottom part are mounted in the extremities and the ventilation panel.
B1903	Operation 50	The refrigerator is put standing and the back part assebled with the cooling wires and the two compressors.
B1904	Operation 60	The gas is filled in and it is tested for leakings.
B1906	Operation 90	Finalizing of the unit before test, deep visual check for non conformity.
	Operation 100	Testing area. 24 hours of accelerated life test.
	Operation 130	Packing and storing in the warehouse.
OBSERVATION: PRODUCTION LINE SCRAP WORK (FAILURES) DON'T TAKE INTO ACCOUNT TESTING AND PACKING!!!!!!		

Table 6: List of users correlated with relative operation and description of it.

The Table 6 enlisted the operation in order as they are performed to build the refrigerator as previously shown in Figure 8. The first operation is Operation 10 in which the coil parts, electrical cables and the spiral pipes are assembled by two operators. When the process is finished the unit is pushed in the foaming machine in which the thermos-insulating foam expands in controlled temperature and pressure in the cabinet. As it is possible to notice from the above Table 6, the Operation 10 has two computer stations that refer to it: one before and one after the foaming phase. The second stage, computer station B1902, is where the inside, top and bottom parts of the refrigerator are mounted. Furthermore, the door and the ventilation fans are inserted in this phase. The next step, Operation 50, is when the refrigerator is put in vertical position. In this phase the back of the refrigerator and the compressor are mounted. Then, the refrigerator is filled with gas and tested for leaks in the pipes. The final process relative to the failures in the Production Line is Operation 90, in which the refrigerator is cleaned and visually checked in its components and quality conformity. All these phases are linked to a computer station point in which the operator responsible for that step can insert failures and the decision of dismantling the unit or the rework cost. The database provided contains 185 entries of different failures somehow linked to user, responsible, item, type of failure, value and amount of material used as consequence of the recorded failure. Its statistical information is further analysed in the next chapter.

4. Analyse

This chapter is divided in three sections in which the information from the Measure chapter are manipulated in order to get more information. By investigating statistical data coming directly from the people involved it is possible to identify the root causes of the issue. The first section contains a study of the Critical to Quality (CTQ) features derived from the Voice of the Customer (VOC). The next two sections are statistical analysis of claims and failures from the databases presented in the previous chapter.

4.1. Analysis of CTQ characteristics

In the previous chapter, it has been given a value for the customers' expectations and Vestfrost's performances in each feature defined in the VOC. In this section, the Critical to Quality characteristics are quantitatively analysed. The scope of doing that is to prioritize the actions that is necessary to undertake in order to furnish products with the highest quality value for the customer.
As first step in the ranking process, the features are represented in a chart, Figure 13.

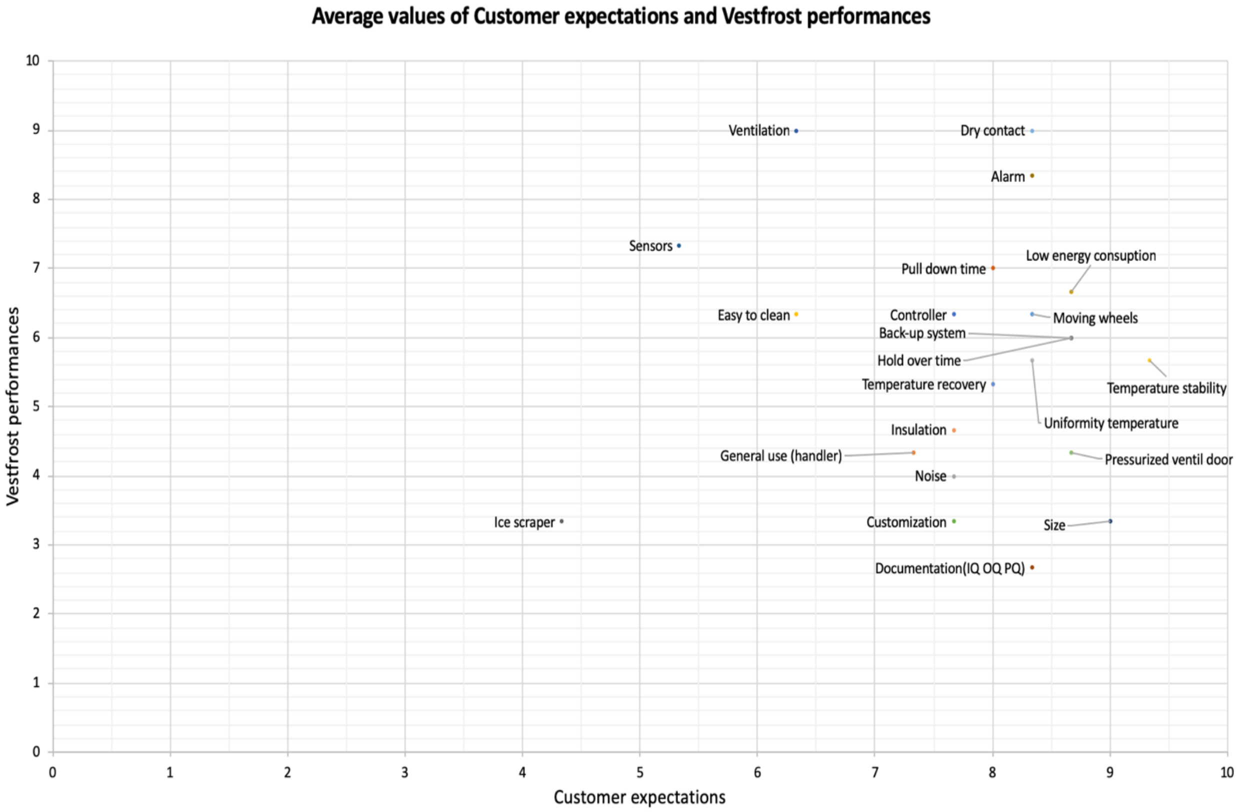

Figure 13: Chart of average values of Customer expectations and Vestfrost performances.

The above chart shows the disposition of the features using as horizontal axe the Customers' expectations and in the vertical one, the Vestfrost Performances. The values are generated from the average of the answers of three manager of Vestfrost. Most of the entries are situated on the right side of the graph, where the features are considered important from the customers' point of view, leaving in the left side only the ice scraper. Thus, the graph is divided in different "priority" zones like shown in Figure 14. [18]

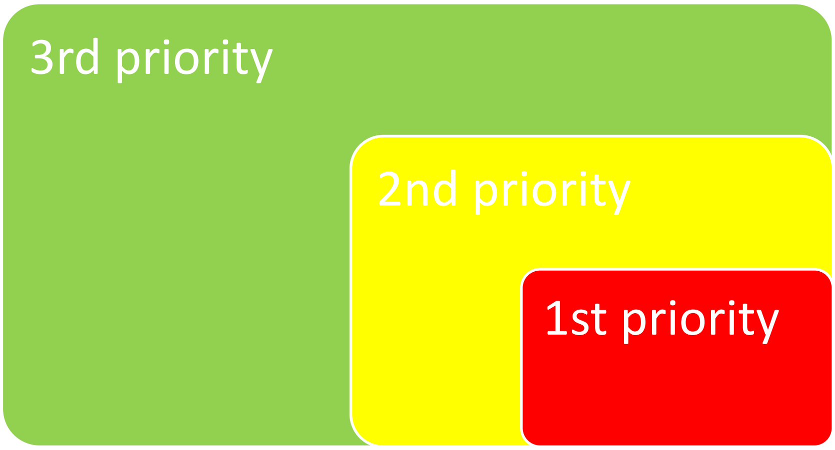

Figure 14: Possible visual method of prioritisation.

This differentiation of priorities is based on the fact that on the very low-right corner of the above graph is present the feature with highest priority for improvement. The highest priority is defined in the lowest performance from the company and, at the same time, the highest expectation of quality from the customer. This method is helpful to gather and rank three or more groups of features. Although, the features can differ for very few decimals and sometimes it is difficult to discriminate the parameters of each priority group. The results of this prioritisation are shown in Figure 15 below.

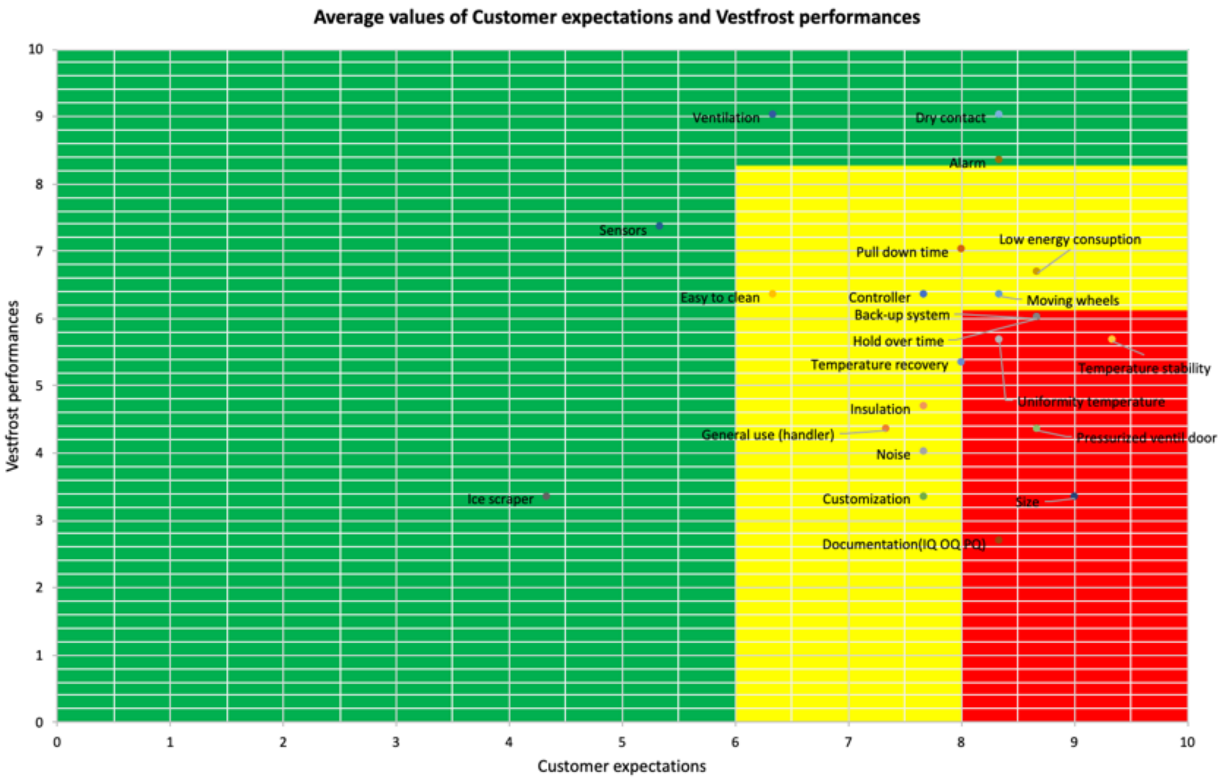

Figure 15: Impact-Ease graph with group prioritisation.

	Feature	Customers' expectation	Vestfrost performances
1	Temperature stability	9,3	5,7
2	Size	9,0	3,3
3	Back-up system	8,7	6,0
4	Hold over time	8,7	6,0
5	Pressurized ventil door	8,7	4,3
6	Documentation(IQ OQ PQ)	8,3	2,7
7	Uniformity temperature	8,3	5,7
8	Temperature recovery	8,0	5,3
9	Low energy consuption	8,7	6,7
10	Moving wheels	8,3	6,3
11	Pull down time	8,0	7,0
12	Controller	7,7	6,3
13	Insulation	7,7	4,7
14	Noise	7,7	4,0
15	Customization	7,7	3,3
16	General use (handler)	7,3	4,3
17	Easy to clean	6,3	6,3
18	Dry contact	8,3	9,0
19	Alarm	8,3	8,3
20	Ventilation	6,3	9,0
21	Sensors	5,3	7,3
22	Ice scraper	4,3	3,3

Figure 16: Prioritisation of features by group.

Figure 15 and Figure 16 show the result of prioritisation by group from red, as highest, to green, as lowest. The main parameter used to rank the priority is customers' expectations sorted from the highest to the lowest value and after the Vestfrost's performances from the lowest to the highest. The red colour represents the rectangular area with the higher rank value, the customers' expectation is major than 8,0 and the Vestfrost performances is lower than 6,0. The green colour is for the lowest ranked features with a customers' expectations lower than 6,0 or performances in production higher than 8,0. The yellow colour is the medium rank between the red and the green ones. The outcome of this ranking is three groups of features that rank high, medium and low in the prioritisation:

- High priority features: Temperature stability, Size, Back-up system, Hold over time, Pressurized ventil door, Documentation, Documentation (IQ, OQ, PQ), Uniformity temperature, Temperature recovery
- Medium priority features: Low energy consumption, Moving wheels, Pull down time, Controller, Insulation, Noise, Customisation, General use, Easy to clean
- Low priority features: Dry contact, Alarm, Ventilation, Sensors, Ice scraper

Another method to prioritize is to use the characteristics of the features. The idea is to use a combination of the highest value of Customers' expectations and the lowest of Vestfrost's performances because they are the characteristics that make a feature more important in respect to the others. The low-right corner is the reference point for the prioritisation, so from that point it is just necessary to calculate the minimum distance for each point and the lowest distance ranks first. The formula to calculate the distance for a particular feature is the following:

$$Distance = \sqrt{(10 - C.E.)^2 + V.P.^2}$$

Where, C.E. stands for the value of customers' expectations and V.P. stands for the value of Vestfrost's performances. In the formula, the customers' expectations are subtracted from 10 because that is the maximum value reachable by that variable and the distance goes backwards on the x-axis. The result of this ranked calculation is shown in the Table 7.

	Features	Customers' expectations	Vestfrost's performances	Prioritisation
1	Documentation(IQ OQ PQ)	8,3	2,7	3,14
2	Size	9,0	3,3	3,48
3	Customization	7,7	3,3	4,07
4	Pressurized ventil door	8,7	4,3	4,53
5	Noise	7,7	4,0	4,63
6	General use (handler)	7,3	4,3	5,09
7	Insulation	7,7	4,7	5,22
8	Temperature recovery	8,0	5,3	5,70
9	Temperature stability	9,3	5,7	5,71
10	Uniformity temperature	8,3	5,7	5,91
11	Back-up system	8,7	6,0	6,15
12	Hold over time	8,7	6,0	6,15
13	Moving wheels	8,3	6,3	6,55
14	Ice scraper	4,3	3,3	6,57
15	Controller	7,7	6,3	6,75
16	Low energy consuption	8,7	6,7	6,80
17	Pull down time	8,0	7,0	7,28
18	Easy to clean	6,3	6,3	7,32
19	Alarm	8,3	8,3	8,50
20	Sensors	5,3	7,3	8,69
21	Dry contact	8,3	9,0	9,15
22	Ventilation	6,3	9,0	9,72

Table 7: Prioritisation of features with the minimum distance method.

The lower the result of the operation, the higher the ranking. The result of the operation is shown on the right column of Table 7 in which the features are already ranked.

The difference in this kind of prioritisation is that it gives a value to rank each individual feature instead of giving it an area. To sum up the results from both of the prioritisations, Table 8 is constructed merging the results from both methodologies proposed.

Grouping prioritisation	**Feature**	Minimum distance prioritisation
1	Temperature stability	9
2	Size	2
3	Back-up system	11
4	Hold over time	12
5	Pressurized ventil door	4
6	Documentation(IQ OQ PQ)	1
7	Uniformity temperature	10
8	Temperature recovery	8
9	Low energy consuption	16
10	Moving wheels	13
11	Pull down time	17
12	Controller	15
13	Insulation	7
14	Noise	5
15	Customization	3
16	General use (handler)	6
17	Easy to clean	18
18	Dry contact	21
19	Alarm	19
20	Ventilation	22
21	Sensors	20
22	Ice scraper	14

Table 8: Comparison between the result of the two rankings.

As a result, it is possible to recognize that three of the most important features that are necessary to improve and maintain in high quality standards are the Size, the Pressurized ventil door and the Documentation. These three features are ranked in the top with both methods. Although, the consideration and introduction of other factors might affect the final result of the prioritisation.

4.2. Claims

The database of the claims for the period under study has been created for the scope from the Claims Manager. The database, Appendix B, is summarized and not precise. It is possible to notice different incoherencies such as different corrective actions for the same failure. Furthermore, for what concern the estimated cost, it is possible to notice some discrepancies such as the same corrective actions for the same kind of failure that have different values. Although, the average cost of the claims is 24.286 DKK that is close with the information that the organisation is not having a developed system of claim handling. The questionable reliability of the system doesn't allow further analysis on claims handling to find root causes and decrease the costs of claims.

4.3. Failures

The Failure database provides enough information to extrapolate valuable data. As mentioned in the previous chapter, it is possible to separate the failures in each operation according to the computer station used to record the failure. The result of this operation is shown in Figure 17 below.

User	Amount of failures	Value of failures	Amount of material
B1901	51	kr. 212.421,38	9.913,93
B1908	50	kr. 50.346,53	375,58
B1902	38	kr. 54.676,93	908,82
B1903	20	kr. 5.120,64	231,09
B1904	3	kr. 2.826,88	160,70
B1906	23	kr. 43.902,58	1.475,83
Grand Total	185	369.294,94 kr.	13.065,95

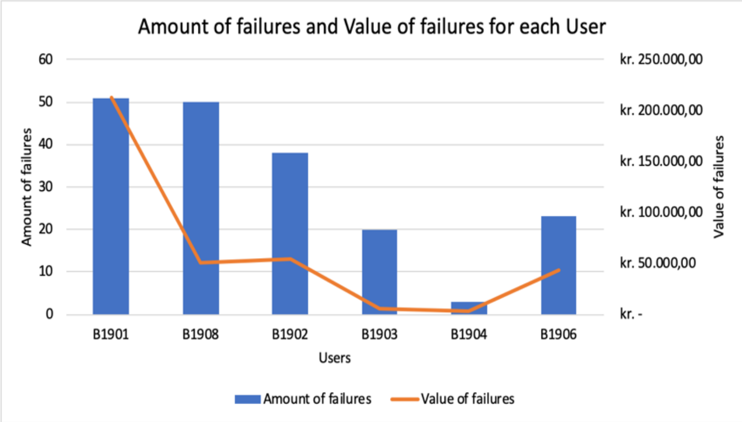

Figure 17: Distribution of failures in terms of amount and value through the production line.

The total amount of failures registered between 2016 and October 2018 is 185 for a value of 369.294,44 DKK. The amount of failures drops during the production with a sudden substantial increase in the last operation, B1906. Moreover, a peak for the value of failures is noticeable in the first operation. According to Vestfrost's management, in the ideal production of this type, a continuous high attention in the detection of anomalies from the employees would make the number of failures decrease steadily during the line. [4]
Furthermore, in Appendix B it is possible to see that the column with the name of the failure, that is in fact the description of it, has been translated in English and each entry has been divided into the part that failed, the type of error and the responsible. To do that, the entries have been manually categorized into groups as shown in Table 9.

Parts failed
Cabinet
Coil
Container
Cooling system
Door
Electrical error
Equipment
Foam
Frame
Glass
Installation
Inventory
Other
Panel
Plastic
Plate parts

Type of failure
Bad assembly
Broken
Bump
Drill
Lack
Lacquer
Other
Scrap
Scratch

Responsability
Machine
Operator
Other
Supplier

Table 9: Categorized entries of the failures database.

Thanks to a counting method, each recurrence of the word in question on the list. In this way it has been possible to establish analysis for each of the three categorises. The analysis of these three categories is performed in order to track down root causes or find improvement actions to implement. The databases are consultable in Appendix B.

4.3.1. Responsibility

The responsibility of a failure is normally attributed to Machine, Operators or Suppliers. In extraordinary cases or in case that the responsibility is not mentioned, the responsibility is counted in the “Other” division. The results of this analysis are shown in the following Table 10 and Figure 18.

Responsability	Amount	Percentage	Value	Percentage
Machine	54	29,19%	kr. 187.372,17	50,74%
Operator	82	44,32%	kr. 96.395,32	26,10%
Supplier	34	18,38%	kr. 55.467,77	15,02%
Other	15	8,11%	kr. 30.059,68	8,14%
TOTAL	185		kr. 369.294,94	

Table 10: Failures database’s responsibility.

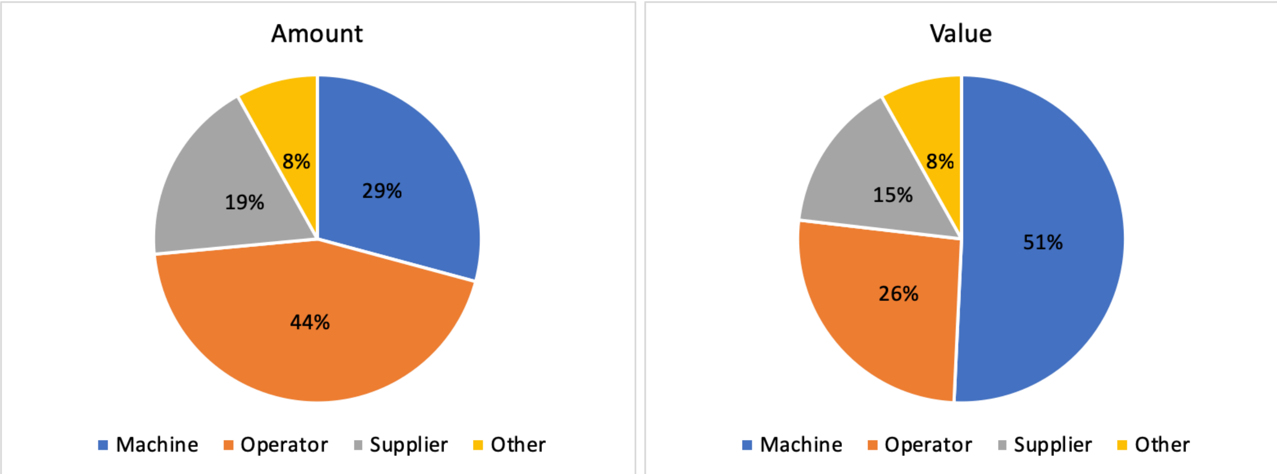

Figure 18: Graphs of amount and value share of responsibility in failures.

The pie-charts above specifically indicate operators and machines as the two responsible for the high amount and cost of failures. For the scope of cost reduction, it is important to notice that machines are responsible for more than half of the total expenditures of failures. Furthermore, an increment in the precision of reporting, with the aim of avoiding “Other” as an entry, could increment the other percentages of about 8% in total. This is about 15 failures and around 30.000 DKK that are now without a clear guilty party.

4.3.2. Parts failed

The parts failed are determined by the reported names in the description of the failure. When it was not possible to identify a major group for the failure, it was counted as “Other”. Furthermore, they have been counted for the amount and the total value. The result is shown in Table 11.

Parts failed	Amount	Percentage	Value		Percentage
Cabinet	23	12,4%	kr.	44.388,42	12,0%
Coil	21	11,4%	kr.	117.021,74	31,7%
Container	13	7,0%	kr.	57.196,12	15,5%
Cooling system	8	4,3%	kr.	14.415,64	3,9%
Door	18	9,7%	kr.	26.311,68	7,1%
Electrical error	4	2,2%	kr.	575,30	0,2%
Equipment	10	5,4%	kr.	8.186,94	2,2%
Foam	14	7,6%	kr.	43.532,65	11,8%
Frame	8	4,3%	kr.	5.454,63	1,5%
Glass	6	3,2%	kr.	2.188,47	0,6%
Installation	7	3,8%	kr.	13.453,43	3,6%
Inventory	1	0,5%	kr.	2.681,36	0,7%
Other	38	20,5%	kr.	26.463,50	7,2%
Panel	3	1,6%	kr.	1.465,77	0,4%
Plastic	5	2,7%	kr.	1.104,33	0,3%
Plate parts	6	3,2%	kr.	4.854,96	1,3%
TOTAL	185		kr.	369.294,94	

Table 11: Failure database's parts failed.

To better represent the effect of each item on the total failures, the data from the above Table 11 are represented in a Pareto Chart. This particular type of chart is made by a bar chart and a line graph, in which the values are represented in descending order by the bars and the cumulative frequency by the line. In Six Sigma principle, the Pareto Chart is used with the 80/20 principle, a general principle in which 80% of the results comes from a 20% of causes. [6] Figure 19 and Figure 20 are the graphical representation of a Pareto Chart.

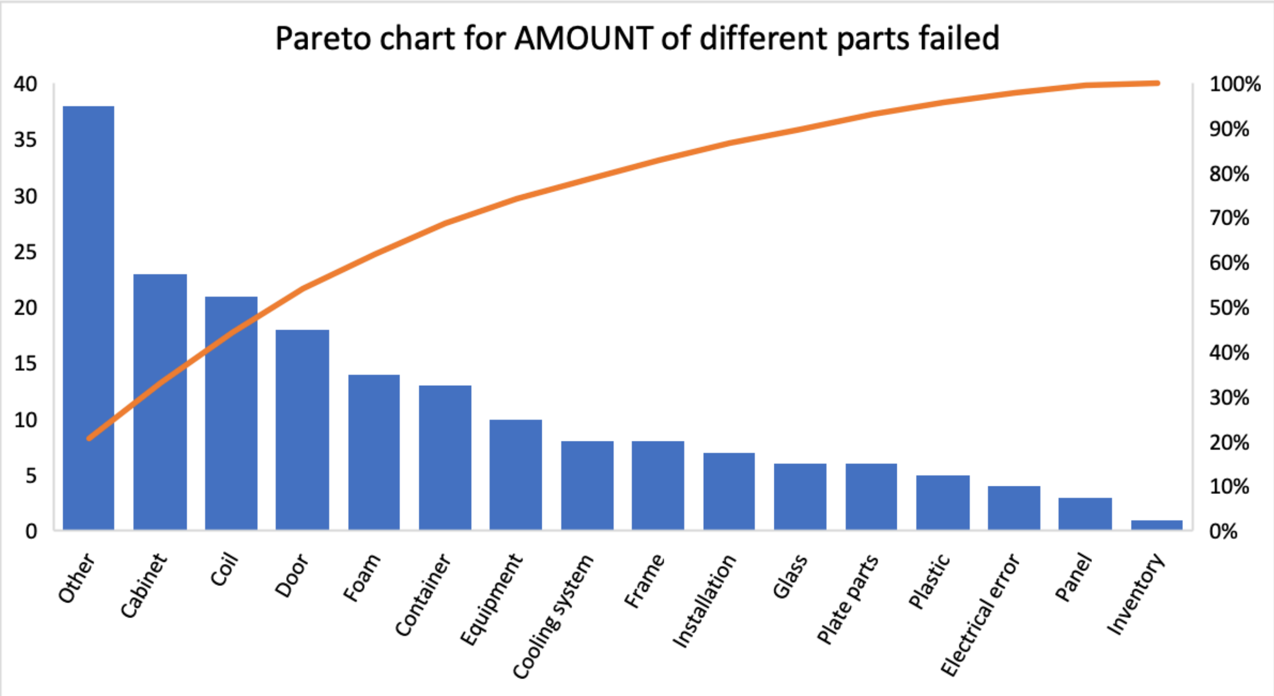

Figure 19: Pareto chart of the amount of failures for each classified part.

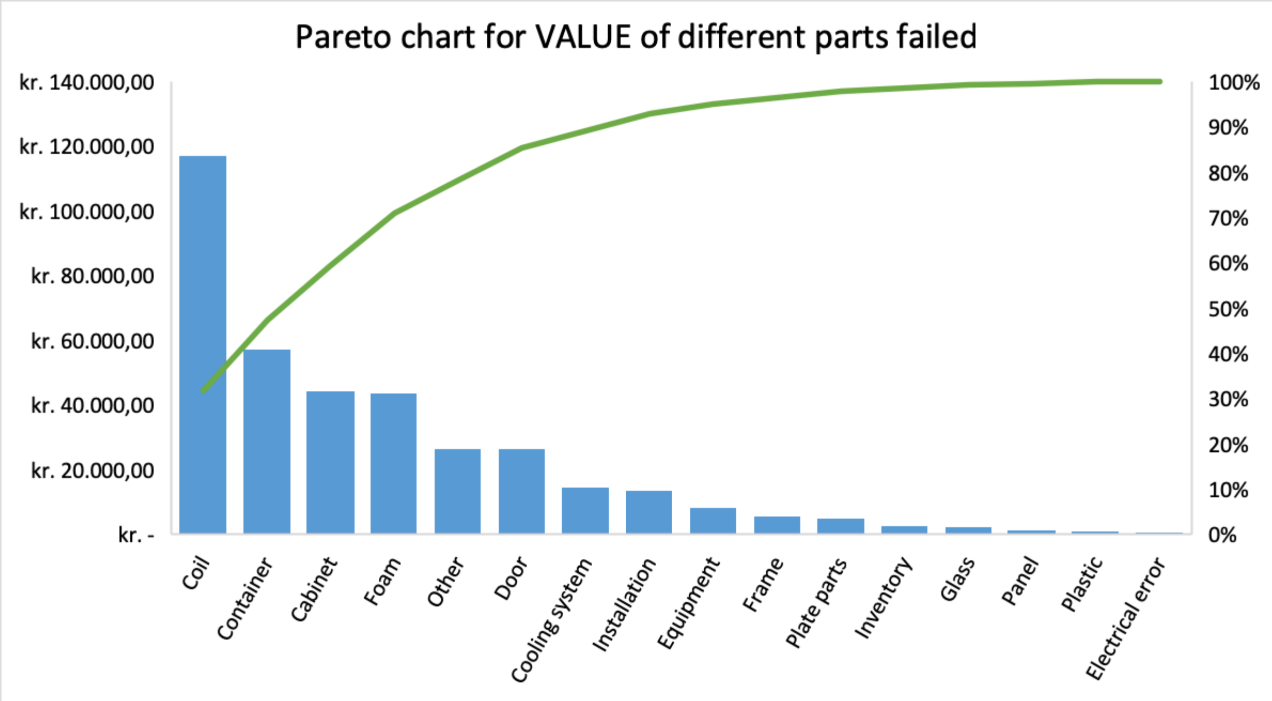

Figure 20: Pareto chart of the value in DKK of the total failures for each classified part.

The application of the 80/20 principle, or Pareto Principle, has different outcomes for the two analyses. In the first case, the amount of failures, almost 80% of the total failures is composed by the first seven items on the graph:

- Other: 20,5%
- Cabinet: 12,4%
- Coil: 11,4%
- Door: 9,7%
- Foam: 7,6%
- Container 7,0%
- Equipment: 5,4%

In the second case, the 80 percent of the total value is accumulated by the five first elements of the horizontal axis, which are:

- Coil: 31,7%
- Container: 15,5%
- Cabinet: 12,0%
- Foam: 11,8%
- Other: 7,2%

According to the Pareto Principle, it is possible to obtain major improvements targeting only the elements listed above. [19] Although, it is noticeable that the element "Other" is present in both the lists and it is equivalent of having biased data; the meaning of this is that it is necessary to improve the definitions in order to address real causes and not general issues.

4.3.3. Type of failure

The type of failure is the modality in which a failure emerges. When it was not possible to define a group for one or more types of failure from the description, it was counted as "Other". Like in the previous section, the types of failure are counted for the amount and their value are summed to understand the cost of each type of failure. The understanding of this is useful to discover particular operations that damage parts in a certain way or that produce flawed products. The result is shown in Table 12.

Type of failure	Amount	Percentage	Value	Percentage
Other	119	64,3%	kr. 306.124,79	82,9%
Bump	5	2,7%	kr. 696,74	0,2%
Scratch	23	12,4%	kr. 25.647,20	6,9%
Scrap	13	7,0%	kr. 16.787,12	4,5%
Bad assembly	5	2,7%	kr. 4.098,59	1,1%
Broken	6	3,2%	kr. 2.225,90	0,6%
Lack	7	3,8%	kr. 8.782,19	2,4%
Lacquer	5	2,7%	kr. 2.937,52	0,8%
Drill	2	1,1%	kr. 1.994,89	0,5%
TOTAL	185		kr. 369.294,94	

Table 12: Failures database's type of failure.

The Pareto Charts for the amount and value for each different type of failure are represented in Figure 21 and Figure 22 respectively.

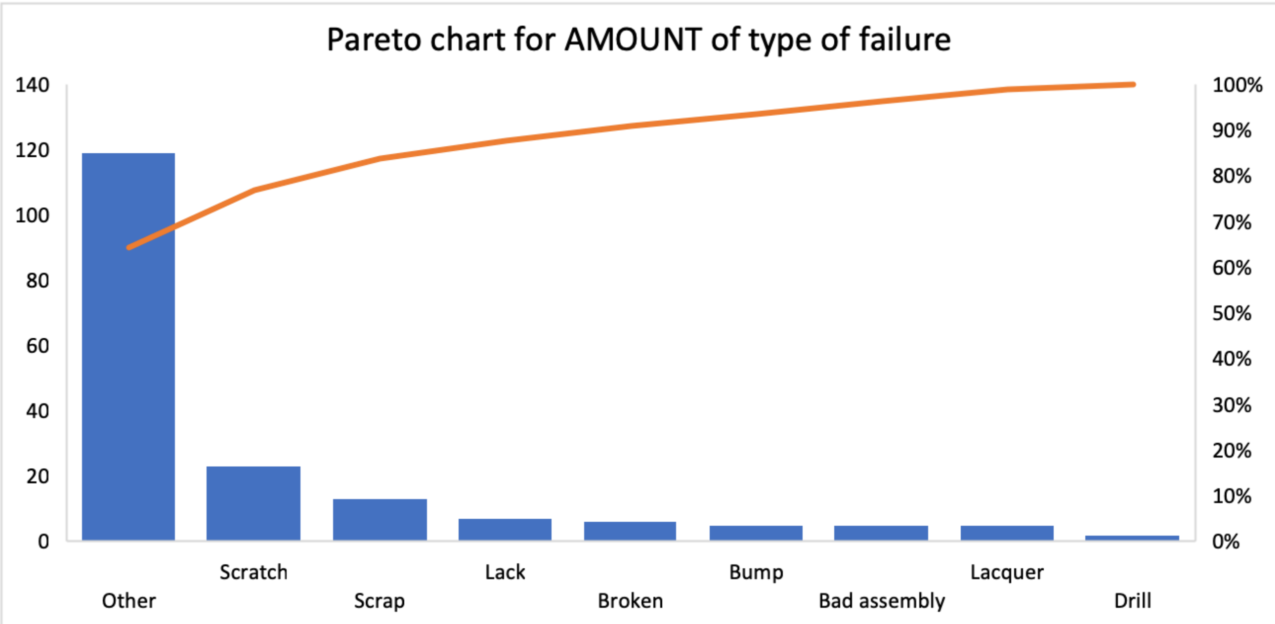

Figure 21: Pareto chart of the amount of each different type of failures.

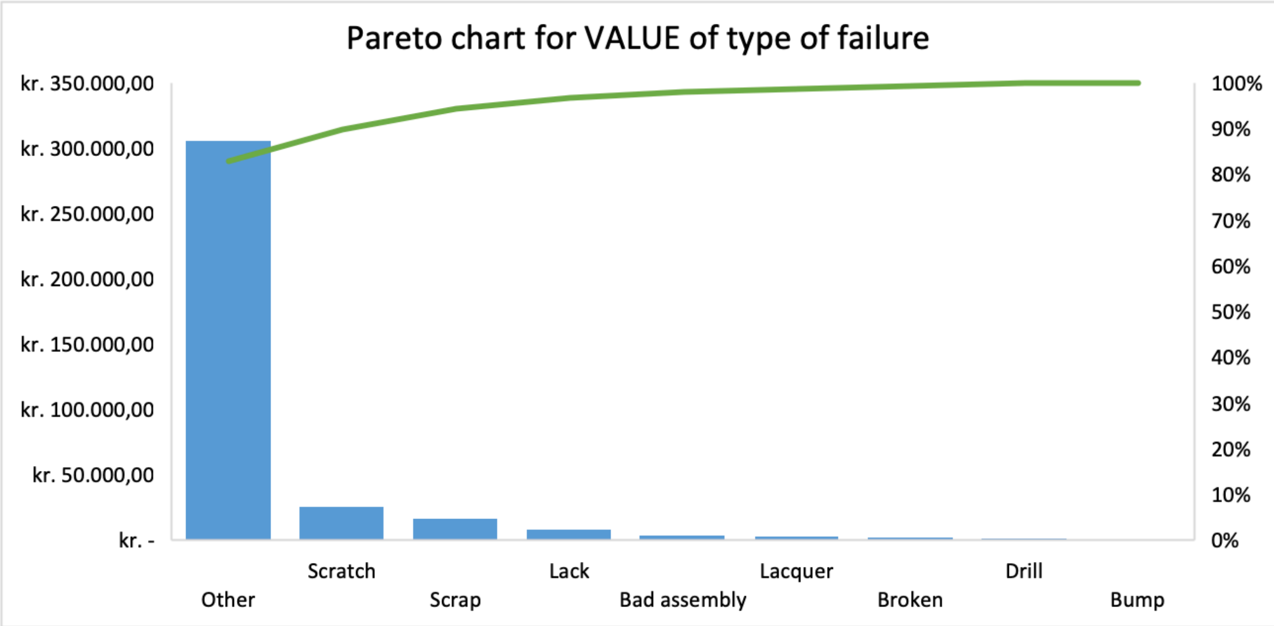

Figure 22: Pareto chart of the value in DKK of each different type of failures.

It is noticeable from both the graphs that “Other” fills more than 60 percent of the total amount and more than 80 percent of the total value. An improvement in the database is necessary in order to better categorise the type of failure registered.

5. Improve and Control

In this chapter the phases of Improving and Control are merged together. In the Six Sigma process, these two phases have the scope of identifying and implementing the improvement actions and ensuring that those actions will sustain. In the first part of this chapter some improvement actions are proposed. For the scope of the project, only few of them are described and deeply analysed. Finally, one is chosen in order to perform the risk assessment in the next chapter.

5.1. Improvement proposals

The suggestion of improvement actions has been made with a brainstorming session in the light of the analysis performed, on the issues observed and taking into account the idea proposed by the managers of Vestfrost Solutions. The structured brainstorming session performed is shown in the Figure 23 below.

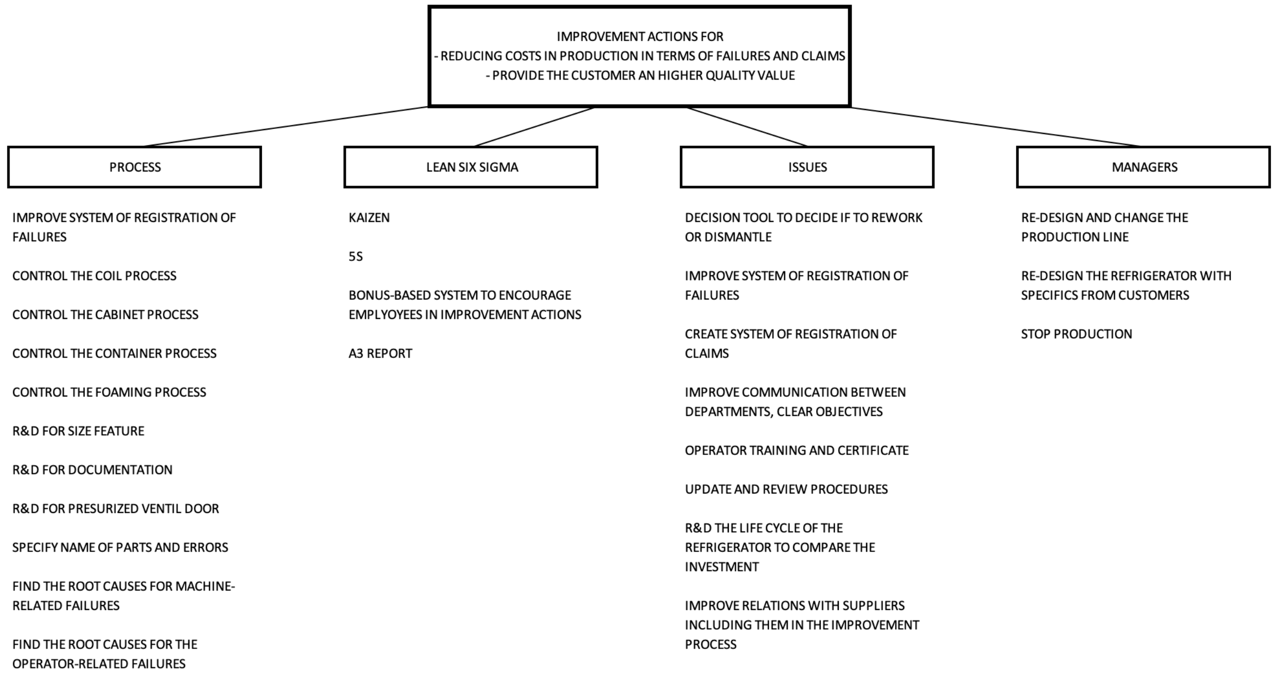

Figure 23: Structured brainstorming for improvement actions.

On the top centre of the brainstorm is the theme of the brainstorming: improvement actions for reducing costs in production due to failures and claims while providing high quality value to the customer. The four main classes related to the topic are:

- Process: improvement actions that came out as result of the Six Sigma process, for example the control actions come from the analysis of the failures database and the R&D from the study of the refrigerator's features and the company's performances.
- Lean Six Sigma: typical Lean Six Sigma improvement strategies that can fit in the case.
- General issues: ideas that came out studying the problem of the production line.
- Managers: proposals coming from the managers during informal interviews done in the early stage of the project.

Some of the proposals are connected with each other and have been selected to be further analysed and eventually implemented. In order to decide which action to undertake, few proposals are described and evaluated in the following sections.

5.1.1. Kaizen

In a Lean Six Sigma context, kaizen is a versatile and systematic approach to "change for the better" all processes. It is commonly described as continuous improvement and practiced individually or in team by all the employees. All the staff and managers need to be trained in Kaizen in order to change the culture of the organisation. The application of Kaizen is made through different steps and tools. In general, all the improvement processes start with Standardize-Do-Check-Act (SDCA) and then it moves to Plan-Do-Check-Act (PDCA). [3] The typical problem-solving procedure for improvement process is shown in Figure 24 below. [20]

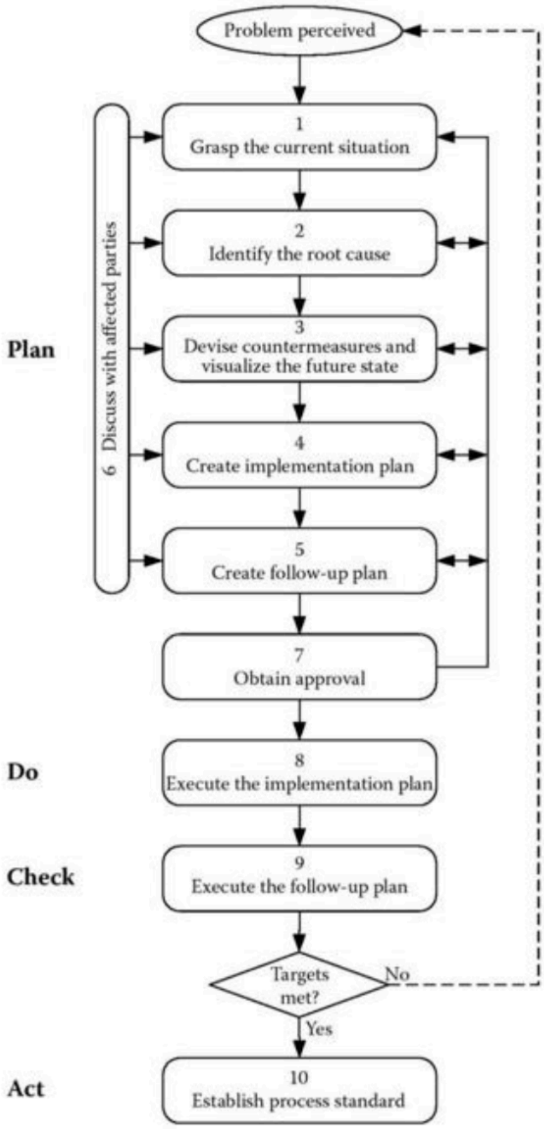

Figure 24: PDCA problem-solving process. [20]

The kaizen improvement is the representation of the PDCA cycle and that is now accredited and well-known as the A3 report. [20]

A3 Report

The A3 is a 297 x 420 mm piece of paper and the imperative is to write the whole report in only one side of the paper. The typical report consists of a theme, or title, and seven sections: background, current condition, goal, root-cause analysis, countermeasures, effect confirmation and follow-up actions. The structure of the report is the reflection of the importance of each phase for the Lean Management; as it is possible to see from Figure 25 below, the understanding of the problem is the most important part and it takes the left-half of the paper. [20]

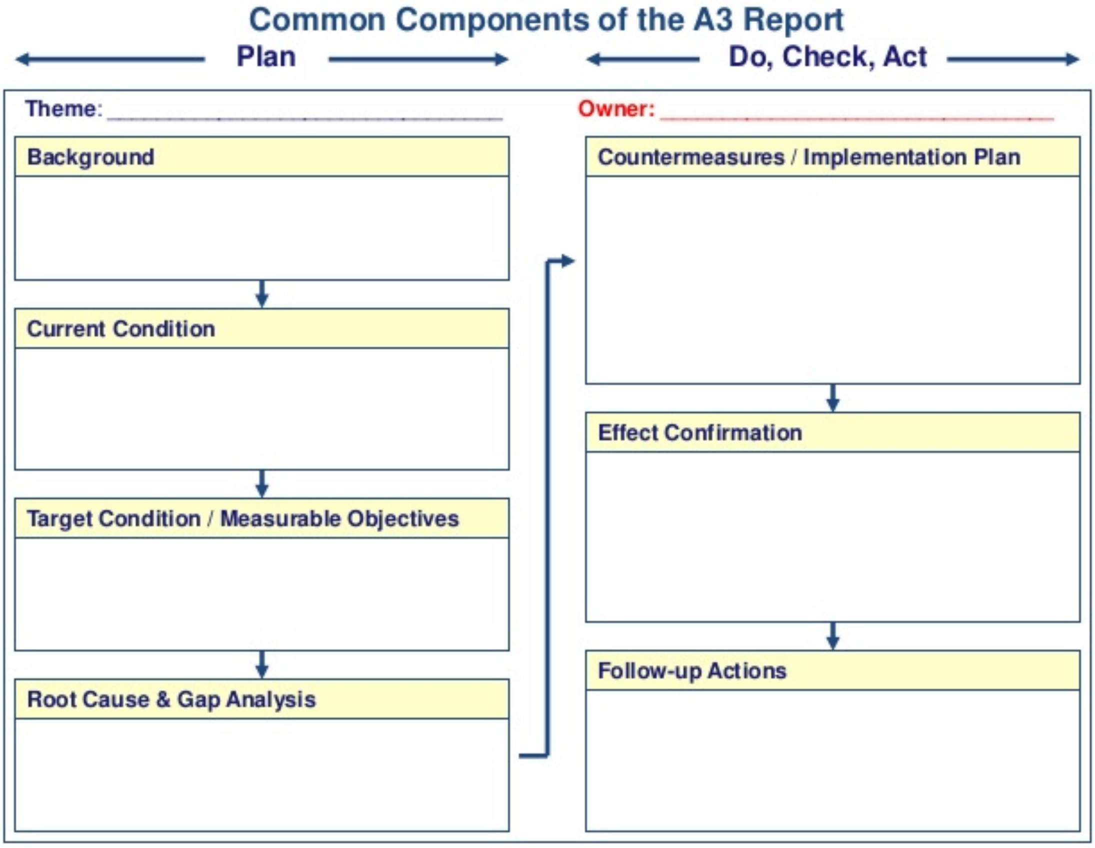

Figure 25: Typical flow of the problem-solving A3 report. [20]

This improvement action can be applied in Vestfrost in the different steps of the production line with a personalisation for each step of the process. The application of kaizen and the use of A3 report need an open mentality and a will to change in the organisation. It is necessary a big effort from the management and a low effort from all the operators. The result is a medium range as difficulty of implementation. The correct application can bring positive results on a wide spectrum for the production line and the effect in for cost reduction and it can be overall evaluated as medium-high.

5.1.2. Decision-making tool

This improvement action is a decision-making tool to help the operators when they detect a failure in a machine and have to choose to re-work or dismantle it. Now the decision is made according to the gut feelings of the operators whose opinion is shaped by their technical knowledge and experience. The tool will give the operator an understanding of the value of the material mounted and the work performed until that moment. If the price of reparation is higher than the value of the piece constructed, the machine will be dismantled. Otherwise, it will be repaired. A practical approach to do that, is to measure the manpower used in each operation and the value of the machine by controlling the type and amount of material used. These measurements have been taken for the development of this tool and are shown in Figure 26.

Operation	Raw material (dkk)	Percentage	Cumulative	Amount of work (h)	Cost (dkk)	Percentage	Cumulative
Operation 10	1956,56	21%	21%	3,27	788,77	35%	35%
Operation 40	5047,23	55%	76%	2,75	663,34	29%	64%
Operation 50	1536,5	17%	93%	1,8	434,19	19%	83%
Operation 60	317,4	3%	96%	0,7	168,85	7%	91%
Operation 90	270,25	3%	99%	0,37	89,25	4%	95%
Operation 100	0,77	0%	99%	0,17	41,01	2%	96%
Operation 130	95,19	1%	100%	0,33	79,60	4%	100%
TOTAL	9223,9	1		9,39	2265	1	

Figure 26: Measurement for the value of the refrigerator through the production line.

With the above data, a tool is constructed and consultable from Appendix B. Using arithmetic evaluation, the decision is taken as shown in Figure 27 below.

Operation in which the failure has been found:

Operation 10

Approximate value of the refrigerator:

Material	1956,56	dkk
Manpower	788,77	dkk
Total	2745,33	dkk

Reparation cost (estimation)

Material	1000	dkk
Time of work	3	h
Cost of work	723,64	dkk

DECISION **REPAIR**

Figure 27: Decision making tool.

As shown in the above Figure 27, the operator selects the operation from the drop-down list in the first box when the failure is found. An approximate value of the machine constructed until that point is shown in the rows below. Finally, the operator has to insert in the bordered boxes the values of material and time of work that, in his opinion, are necessary to complete the reparation and the decision to take appears written in red in the last box. The expected reduction of costs by taking the decision in a more methodological way are expected to be low. Although, the tool is very easy to implement and can be more developed to be more reliable and have a wide possibility of uses.

5.1.3. Failures tracking system

The fact that the system of collection of data needs improvement is the result of the process and the analysis of the current databases. In fact, an issue spotted since in the early stages of the process is the inaccuracy of the database. After this study, it is possible to see how the statistics could be used by the Production Department to conduct root cause analysis on the processes or components. The first observation to make the reporting of failures more reliable and useful is to modify the insertion with different spaces for responsibility, part failed and type of damage. Furthermore, it is possible to develop the whole system training and rewarding operators to properly compile the failure reports and make the system more and more precise with time. The correct data with development of statistics will improve the general Lean Six Sigma process. For these reasons, the reduction in cost is to be considered of medium-low value. The difficulty of implementation is related to the involvement of different departments, the development of IT and the training of operators and managers and is considered in the medium range.

5.1.4. Coil problem solving

Even though the database needs improvements, an important fact is possible to retrieve from the analysis of the statistics: the value of failures in the coil is the highest and reach 32% of the total. This means that coil needs to be deeply investigated. To do that, it is suggested to use the Six Sigma process. The specifics of the coil need to be defined and it must be measured where and how the failures happen, discover the root causes and treat them. This improvement action is connected with the one described before, Failures tracking system. In fact, a developed and precise database of failures would help the identification of the causes in the early stages and less effort in the performance of the cycle would be necessary. Overall, the implementation has a high level of difficulty in the realisation, requires a general effort of the organisation and the impact is of medium value. The evaluation of the impact is made taking into account that on one hand, if the action could solve 80% of the total value of coil failures, the company would save about 94.000 DKK. On the other hand, this action influence only one part of the cost reduction of the total business.

5.2. Discussion

In the previous section, some improvement actions have been taken into account and described. The study of the improvement actions is useful when deciding which one to take first. A visual aid for ranking and helping in the decision making is the construction of the ease-impact graph shown in Figure 28 below. [21]

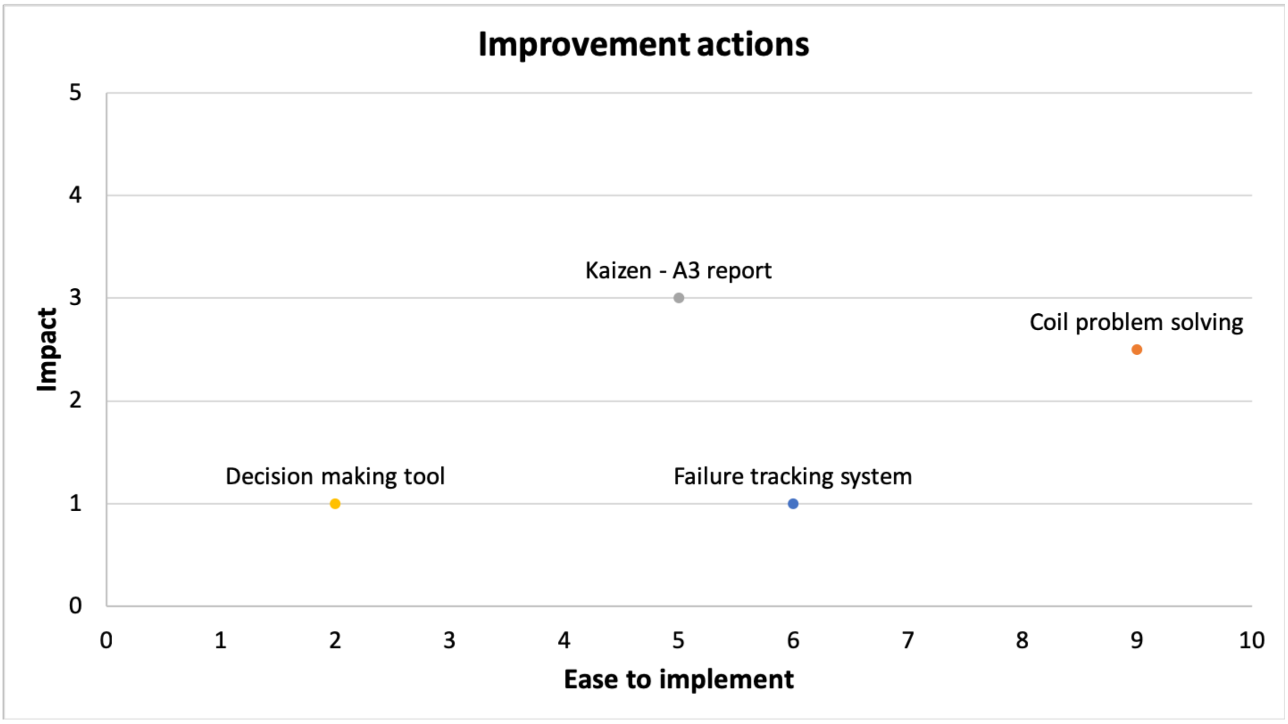

Figure 28: Ease-Impact graph for ranking improvement actions.

On the y-axis the impact is shown on a scale from zero to five where zero means extremely low impact and five is extremely high impact. In this case, the impact is considered a positive effect, not only for the reduction of costs, but also to improve quality, safety, productivity, and general business. On the x-axis there is the ease to implement scale that represents the effort that the organisation has to make in order to achieve the goals of the activity; it goes from zero to ten where zero stands for extremely easy and ten for extremely difficult. The analysis made in the previous section made it possible to insert the four selected improvement actions in the graph. The values correspond to the understanding of the author. Kaizen has a higher value of impact compared to the others because it affects the whole business of the organisation whereas the others are more related only to quality and the reduction of costs. The Figure 29 below, illustrate how the graph can be divided to take the decision on the action to undertake.

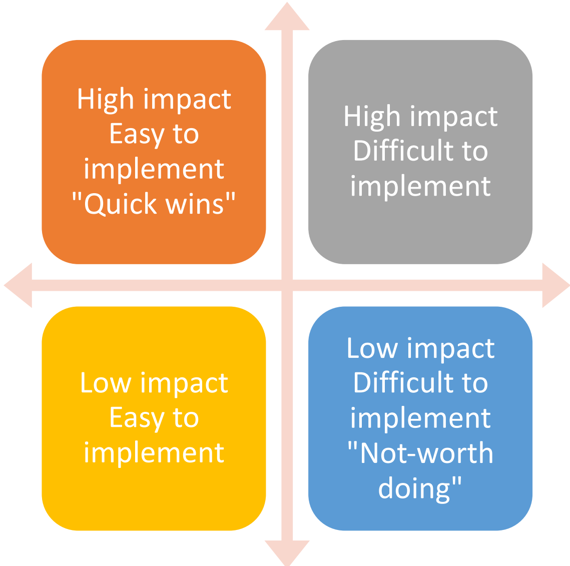

Figure 29: Division of the ease-impact graph. [22]

The actions to pursue are situated in the top-left corner and the actions to avoid are usually situated in the bottom-right corner. The actions situated in the grey and yellow squares need to be further assessed by the decision maker before the decision to follow an improvement is made. For the project developed for Vestfrost Solutions, the improvement action developed is the decision-making tool. The decision has been taken for the scope of the project. In the next chapter the tool is assessed from a risk point of view.

6. Risk Assessment

The outcome of the steps previously performed is a prioritized list of actions to undertake in the improvement chapter, following the typical Six Sigma process. In this chapter, a Risk Assessment is performed in order to make the decision tool more robust. To assess the uncertainty, the Risk Management ISO 31001:2018 framework presented in Chapter 1 is used. [14] Hence, this chapter is structured with the identification, analysis, evaluation and finally treatment of risks related to the development and use of the decision-making tool. The context is established by the previous chapters.

6.1. Risk Identification

The decision-making tool is strictly related to the management of failures and reduction of the cost in the production line. Although, the tool can suggest operations that have unexpected outcomes due to higher or lower costs than expected. This happens because of the uncertainty that derives from many factors. The notion of uncertainty is defined as those events that are impossible or difficult to predict. [23] This section identifies the causes that can bring to an increment of uncertainty related to the development and use of the decision-making tool. To identify the risks that increase the uncertainty a Fault Tree Analysis (FTA) has been constructed, as shown in Figure 30. An FTA is a deductive tool used in Risk Management to attempt to determine the causes that can bring to an undesired event.

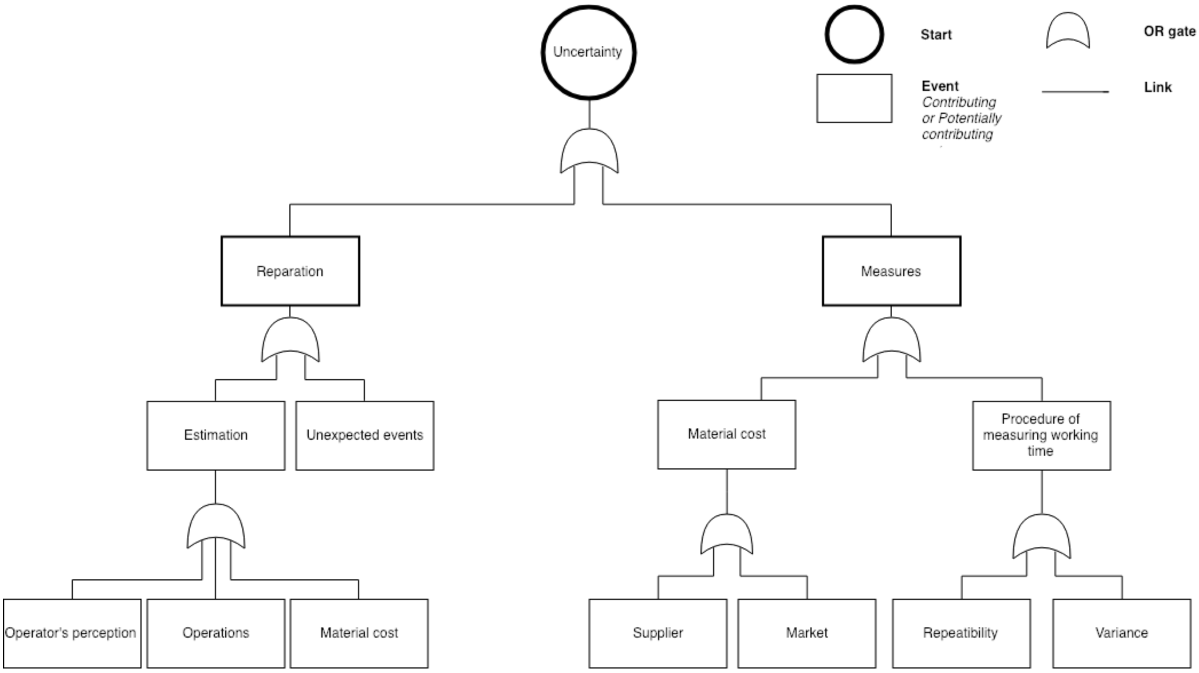

Figure 30: Fault Tree Analysis for the increase of uncertainty in the development and use of the decision-making tool.

The above FTA shows the possible components of the uncertainty that the tool doesn't take into account. In the first level, the left branch, there is the reparation event that take into account the uncertainty coming from the decision of repairing a machine. The right branch of the tree is related to uncertainty from the events that built up to the decision, or rather the measurement part. The logical operator that links all these events is an Or Gate. This means that it is necessary that one of the events happens to have an increase of the uncertainty. The more basic or final events that have been found and need to be further investigated are:

- Operator's perception: This is the perception of the cost for the reparation. The operator can be biased in the estimation because of his/her own experience with that type of failure or for not having knowledge at all on how to repair it. Furthermore, the operator might be pessimistic or optimistic in his/her judgment.
- Operations: The reparation itself can bring uncertainty for the time to perform the reparation in the system. For example, disassembling a machine can take more or less time than assembling it and the reparation itself can change the estimation of the time needed.
- Material cost: The value of the material used for reparation can change due to availability and market. Moreover, during a reparation it might be necessary to use or to change more material than the forecasted when the failure is found.
- Unexpected events: One or more failures made during the reparation, one or more failures not detected in the first place, impossibility to finish the reparation. All these are examples of possible unexpected events that can change the result of a reparation.
- Supplier: Changing or not precise cost of material can influence the material cost when measuring the material cost for each operation in the production.
- Market: External forces can modify the prices of an asset.
- Repeatability: The customisation or minor changes in the production introduces a degree of uncertainty in the time it takes to perform the operation.
- Variance: The operators can change. This can slightly affect the modality in which the processes are performed and also the time. Furthermore, the machines used in the process have their own percentage of error or variability in the result and this variances in the processes raise the uncertainty.

These are some of the factors that can increase the uncertainty when the decision-making tool is used by an operator to decide whether or not to repair or dismantle a refrigerator during its production. These factors are further analysed in the next section.

6.2. Risk Analysis and Evaluation

The purpose of this section is to deeply understand the nature of the risk, its characteristics, how it is connected, the likelihood and the magnitude of the consequences. Furthermore, some treatment options are considered in the required cases. The decision-making tool is an instrument to improve the way judgments are made in the production line when a failure is detected. The risks identified in the previous section are the ones that increase the uncertainty that influence the occurrence of undesired outcomes from the improvement action developed.

6.2.1. Analysis

The quantification of the identified risks can be difficult to perform. Although, it is possible to study the interconnection between them. To do that, a network diagram is built in Figure 31. A network diagram is a schematic picture to shows how the risks are connected in order to evaluate the complexity and degree of propagation of uncertainty. The graph is composed of nodes that are connected by links. The connections between the nodes are the representation of a certain kind of relation.

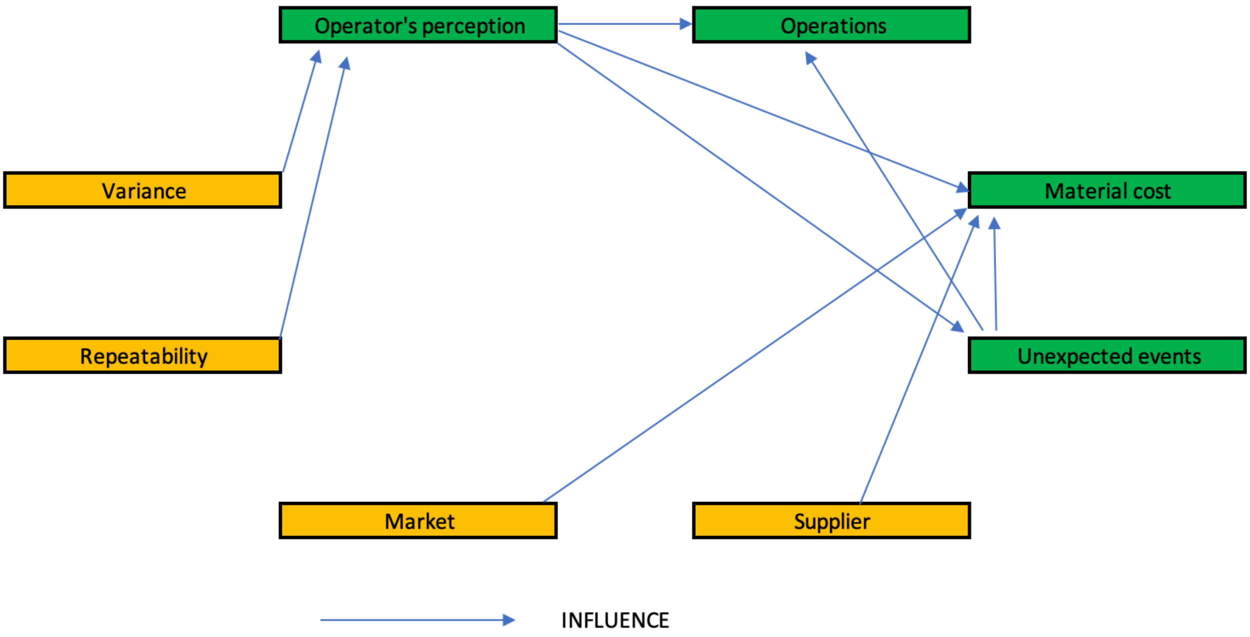

Figure 31: Network diagram of the risks.

In Figure 31, the nodes represent the risks of the system and the links illustrate the influence between them. The links have an arrow on their extremity to show the orientation of the action. For example, Variance influences Operator's perception. Furthermore, it is noticeable that the nodes are coloured in two different ways. The risk coloured in green are related to the left branch of the FTA that is the reparation part. The orange colour is for the right branch and it represents the measures. The connections have been inserted checking the influence of each item over the others. Overall, it is possible to notice that the green nodes are the most influenced and influencing nodes. The diagram provides an immediate understanding of the sensitivity of each risk and how it might affect the others. According to this analysis, the material cost is the risk that is influenced the most and the operator's perception is the most interconnected risk.

6.2.2. Evaluation

The observations of the previous phase suggest that a proper system of measurement decreases the creation and propagation of uncertainty through the decision-making tool. A proper system of measurements is constituted of precise procedures that define how the measurements are taken and allow the management to know the sensitivity of the variables. With this knowledge it is possible to assess the uncertainty. A treatment option to strengthen the measurement is to create a database and perform audits in order to study the variability of the measures.

Furthermore, the diagram is a monitor of the nature of the decision-making process. This is where most of the uncertainty is accumulated. Whenever a decision has been taken, the main connected node of uncertainty is the operator's perception. In fact, the operator has to estimate the cost of material and time according to his/her own perception, but these are not the only factors. According to decision-making theory [24], there are different ways to take decision under uncertainty. The treatment tool proposed is the development of the tool with taking into account uncertainty and developing different strategies of decision making in order to help in the decision-making process.

6.3. Risk Treatment

This phase addresses risk by selecting and implementing options to improve the decision-making process. The decision-making tool under analysis, consultable in Appendix B, includes from now the request of insertion of a level of uncertainty. This level of uncertainty can be modified under discretion of the management. For this application, the level of uncertainty inserted cause the variation of the price estimated by the operator. An application is shown in Figure 32 below.

Possible variation of total costs due to uncertainty	
30 %	
Total cost	2688,50
Minimum	1881,95
Maximum	3495,05

Figure 32: Application of uncertainty (from Appendix B).

With this variation it is possible to calculate two scenarios:

- Minimum cost is the optimistic scenario, where the predicted price was higher than the resulted one and money is saved during the reparation.
- Maximum cost is the pessimistic scenario, where the predicted price was lower than the resulted one and it is necessary to spend more money for the reparation.

The two scenarios are the base to apply the decision making under risk theory in which the decision maker is divided into three categories [24]:

- Optimist: The decision maker acts confident that they will get the most possible and then they take the action with the best best case scenario. In this case the best best case scenario is about the minimum of the minimum of the costs.
- Pessimist: The decision maker assumes that the worst that can happen will, and then they take action with the best worst scenario. In the case of cost for reparation, the best worst scenario is the minimum of the maximum cost.
- Opportunist: The decision is based on opportunistic loss. It is also called "minimum regret criterion" and it's like if they could look back after the reparation has been made and say "Now that I know what happened, if I had only picked this other action instead of the one I actually did, I could have done better". So, they want the best of the worst losses and to apply that to this case, it is the maximum of the differences. Otherwise, it is necessary to create a regret table and take the maximum value of the minimum regret. [24]

This distinction is made in order to help the decision maker to make the best choice accordingly to his/her own gut feeling. This theory has been developed for the decision-making tool and it is consultable from Appendix B. The following Figure 33 is the illustration of how the tool appears with the use of uncertainty. Moreover, in Figure 33 an example is shown of an operator detecting a failure just after the end of Operation 10, that is after the initial assembling and foaming process. The assumptions of the operator to repair the damage are that it will take 7 hours to complete the job and 1000 DKK of material.

Operation in which the failure has been found:

Operation 10

Approximate value of the refrigerator:

Material	1956,56	dkk
Manpower	788,77	dkk
Total	2745,33	dkk
Estimated value:	2750	dkk

Here it is empty or the operator can insert a new value if it needs correction for extra work time or material

Reparation cost (estimation)

Material	1000	dkk
Time of work	7	h
Cost of work	1688,50	dkk

HELP operation: Operation 10

Material in dkk:	1956,56
Manpower in h:	3,27

DECISION **REPAIR** Decision without uncertainty

Possible variation of total costs due to uncertainty (type of reparation, time to do it, etc...)

30 %

Total cost	2688,50
Minimum	1881,95
Maximum	3495,05

			State of nature - COSTS					
			Best case	Average case	Worst case	Optimist	Pessimist	Opportunist
			Minimum	Average	Max	Risk taker	Risk adverse	Regret
						Maximax	Maximin	Minimax
Decision	Choice A	Dismantle	2750,00	2750,00	2750,00	1881,95	2750,00	1881,95
	Choice B	Repair	1881,95	2688,50	3495,05			
		Difference	868,05	61,50	745,05	Repair	Dismantle	Repair

Figure 33: Decision-making tool with uncertainty and decision making under risk theory.

The result in the example in Figure 33 is the version with uncertainty of the tool for the operator that has to decide whether to repair or dismantle the machine under construction. The final decision suggested is the result that is possible to see under the evaluation of the three possible scenarios, on the bottom-right corner of Figure 33.

6.4. Discussion

The improvement action risk-assessed in this chapter demonstrated the presence of uncertainty and some of the risks linked to the implementation of the decision-making tool. Assessing the uncertainty can save money when taking a decision. The amount of money saved is related to the percentage of uncertainty taken into account and the methodology in which it is used. When an organization implements Risk Management in their culture, the effort to improve decision making and every business activity is very low. [14] The assumptions made with lack of knowledge on the statistics and probability of processes with failures and their outcomes, introduced a certain grade of uncertainty that is not easily evaluated. The inserted number is a possible real estimation according to the perception of the author. The effect on the impact-ease graph of performing Risk Assessment is visible from the red box in Figure 34.

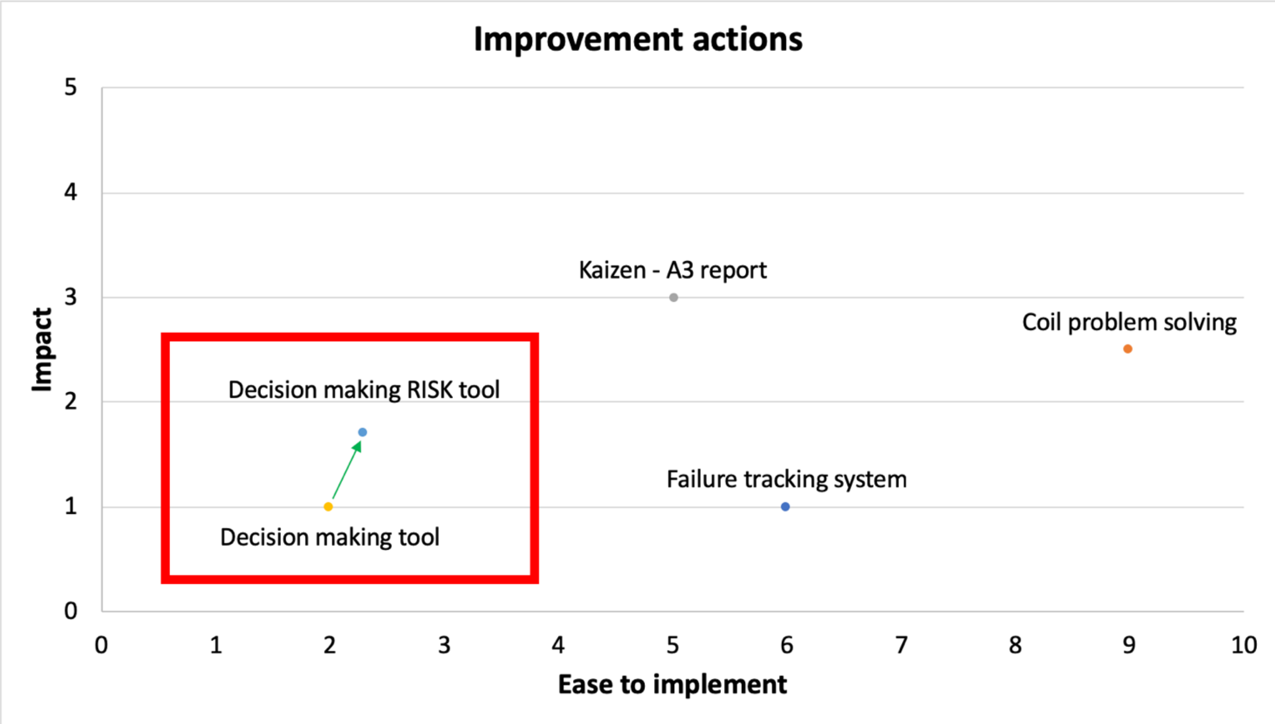

Figure 34: Effect of the Risk Assessment on the decision-making tool in the Impact-Ease graph of the improvement actions.

The improvement in the above graph is made semi-quantitively through the evaluation treatment sections. The numerical value attributed is due to the understanding and gut feelings of the author. The improvement of different actions, like kaizen and a more precise measurement system for data collection, will increase the understanding of the processes. Furthermore, a system for the reparation controlling can significantly increase the precision in the prediction of amount of material and time to perform a reparation, diminishing the level of uncertainty.

The Risk Assessment performed is shortened due to delimitations of the project. Furthermore, the holistic version of the Risk Management cycle has to be further considered and implemented in order to improve this assessment and other assessments with more qualitative and quantitative data.

7. Conclusion

The purpose of the study is to provide an improvement action to the company and to make it robust by executing a Lean Six Sigma project on the analysed production line and making the results reliable performing Risk Assessment. The objective of Vestfrost Solutions is to pursue a list of consistent solutions that can generate the best value for the business of the company.

The Lean Six Sigma process has been performed through interviews with managers from different departments of the organisation and with a database with a collection of data regarding claims and failures of the examined refrigerator. The improvement actions proposed are various. A list of the characteristics that need to be further studied has been prioritized using two indicators: the customer expectations and the company's performances. Furthermore, the production line has been analysed with the aim of reducing the costs derived from failures and quality performances. Thanks to the statistical analysis developed, it is possible to point at two main factors that played an important role in the expenditures during the production of the refrigerator: responsibility and item. These are recognised respectively in the machines and the coil. The root causes analysis and consequent improvements for these issues need to be further developed. Although, more wide-ranging actions have been proposed, in order to improve the whole business activities. In particular, a decision-making tool has been developed to support the operators when a defect is detected. The tool is an aid in the choice between dismantling or repairing a machine.

The Risk Assessment has been performed on the decision-making tool in order to assess the uncertainty in the choice. For its nature, the uncertainty emerges as unexpected outcome from the decision taken. To make the choice more reliable, a certain level of uncertainty has been introduced and to help the operator in taking the decision, three possible scenarios are estimated.

Risk Management takes into account delimitations and uncertainties associated with the information and expectations. The decision-making under risk uncertainty increases the confidence that the decision is the best with the current knowledge. Other treatment actions have been proposed to take into account the dynamic and variable nature of the process.

Based on the tools and data used, the application of Risk Management to Lean Six Sigma project shows that the impact of the project and the robustness of the improvement activities increase. This project is the first turn of a cycle developed with two management tools that systematically use statistics and assess the uncertainty to set strategy and make informed decision to improve business. More quantitative and cost analysis is necessary to estimate the extent of the improvement generated with the use of Risk Management in a LSS project. The author believes that the results obtained from this project can be applied to other production lines in Vestfrost Solutions. Furthermore, the author considers possible to use Lean Six Sigma combined with Risk Management in organisation with similar conditions. For more precise improvement plans, further investigations are necessary.

7.1. Future research and development

A complete control and review of the effectiveness of the results of the LSS project with Risk Assessment concerning the decision-making tool cannot be made yet. To do this, it is necessary to develop and implement the decision-making tool in the production system.

In order to make the tool more reliable, the first stage is to improve the system of collection of failures and claims. To do that, it is possible to involve more departments, including the IT, and use the analysis made in this report improved with information gathered from managers and employees to develop and maintain an effective solution. Other methods could be considered relevant for taking the decision, such as Monte Carlo simulation, and those must be investigated. Based on the observation that computerized stations are present in each stage of the process, the author suggests the development of an IT solution that includes the possibility to insert a picture in order to help finding the root cause of a failure.

For Vestfrost, to be able to improve the production line by reducing the cost of quality, many different actions from the Six Sigma project are proposed. The implementation of kaizen as an improvement action seems to be of a high value for the company from different perspectives. The involvement of all the employees in the continuous improvement implies the need of initial training sessions. This is a change in the culture that can bring many benefits to the company for current and future projects. As an example of kaizen event, the result from the study of the features in the Define and Measure chapters shows that it is necessary for the company to improve the communication between departments, setting and aligning the goals. Another example is using the kaizen A3 report to control the improvement of the problem solving in the coil production. The author suggests further education in this methodology, and to start solving in the beginning those problems that are considered "quick wins". [22]

Finally, the author recommends Vestfrost to review the Lean Six Sigma processes currently in act. With the involvement and education of more workers and the implementation of Risk Management methodology, the projects are expected to be more valuable, resilient and robust.

8. References

[1] IEEE, "IEEE Editorial Style Manual," [Online]. Available: https://www.ieee.org/content/dam/ieee-org/ieee/web/org/conferences/style_references_manual.pdf. [Accessed 7 January 2019].

[2] P. Hopkin, Fundamentals of Risk Management Understanding, evaluating and implementing effective risk management, London: Kogan Page Limited, 2017.

[3] F. Voehl, J. H. Harrington, C. Mignosa and R. Charron, The Lean Six Sigma Black Belt Handbook Tools and Methods for Process Acceleration, Boca Raton: CRC Press Taylor & Francis Group, 2014.

[4] Vestfrost Solutions A/S, [Online]. Available: https://www.vestfrostsolutions.com/.

[5] R. Woodard, "Project Management Methods & Ideologies," [Online]. Available: https://www.brighthubpm.com/methods-strategies/102279-history-of-lean-management/. [Accessed 9 December 2018].

[6] M. Grunow and H. Ott, "Six Sigma and Lean: Quantitative Tools for Quality and Productivity," EdX, Tecnical University of Munich, 2018.

[7] M. Holweg, "The genealogy of lean production," *Journal of Operations Management,* vol. 25, p. 420–437, 2007.

[8] Lean Enterprise Institute Inc., "Lean Enterprise Institute," [Online]. Available: https://www.lean.org/WhatsLean/History.cfm. [Accessed 9 December 2018].

[9] iSixSigma, "History of Six Sigma," [Online]. Available: https://www.isixsigma.com/new-to-six-sigma/history/history-six-sigma/. [Accessed 10 December 2018].

[10] N. Nayab, "Bright Up Project Management," [Online]. Available: https://www.brighthubpm.com/change-management/69148-the-story-of-six-sigma-and-ge/. [Accessed 12 December 2018].

[11] International Standard Organisation, "Quantitative methods in process improvement — Six Sigma — Competencies for key personnel and their organizations in relation to Six Sigma and Lean implementation," *ISO 18404:2015,* 2015.

[12] International Standard Organisation, "Quantitative methods in process improvement – Six Sigma – Part 2: Tools and techniques," *ISO 13053-2:2011,* 2011.

[13] International Standard Organisation , "Quantitative methods in process improvement – Six Sigma – Part 1: DMAIC methodology," *ISO 13053-1:2011,* 2011.

[14] International Standard Organization, "Risk Management - Guidelines," *ISO 31000:2018,* 2018.

[15] Study.com, Yolanda Williams, "Unstructured Interview: Definition, Advantages, Disadvantages & Example," [Online]. Available: https://study.com/academy/lesson/unstructured-interview-definition-advantages-disadvantages-example.html#lesson. [Accessed 08 January 2019].

[16] Oxford Dictionaries, [Online]. Available: https://en.oxforddictionaries.com. [Accessed 09 January 2019].

[17] W. Kenton, "Investopedia," 19 July 2018. [Online]. Available: https://www.investopedia.com/terms/r/robust.asp. [Accessed 09 January 2019].

[18] Powernoodle Inc., "Power Noodle - Better Quality Decisions," [Online]. Available: https://www.powernoodle.com/models-article/identify-prioritize-continuous-improvement-initiatives. [Accessed 6 January 2019].

[19] Bright Hub Project Management, "Six Sigma," [Online]. Available: https://www.brighthubpm.com/six-sigma/. [Accessed December 2018].

[20] A. Smalley and D. K. Sobek II, Understanding A3 thinking: A Critical Component of Toyota's PDCA Management System, Taylor & Francis Group, 2008.

[21] "Go Lean Six Sigma," [Online]. Available: https://goleansixsigma.com/. [Accessed 03 January 2019].

[22] Peak Denver Academy, "Impact Effort Matrix Reference Guide," [Online]. Available: https://www.denvergov.org/content/dam/denvergov/Portals/728/documents/Peak_Performance/Black_Belt/Reference_Guides/Guide_Impact_Effort_Matrix.pdf. [Accessed 7 January 2019].

[23] C. Martani, Risk Management in Architectural Design. Control of Uncertainty over Building Use and Maintenance, Cambridge: Springer, 2015.

[24] R. T. Clemen and T. Reilly, Making Hard Decisions, Mason: South-Western, Cengage Learning, 2014.

[25] J. A. De Feo and W. Barnard, Six Sigma Breakthrough and Beyond - Quality Performance Breakthrough Methods, Tata McGraw-Hill, 2005.

[26] Vestfrost Solutions - Biomedical Line, *Product Flyer - VTS 258,* 2018.

9. Appendix

9.1. Appendix A

AARHUS UNIVERSITET

Mini-udbud under Rammeaftalen for indkøb af basis apparatur og instrumenter til forsknings- og undervisningsbrug i Aarhus Universitets laboratorier, delaftale 12 – "Freezers from -40 °C to -86 °C"

Kære Rammeaftaleindehavere,

Aarhus Universitet inviterer til miniudbud under rammeaftalen for basis apparatur og instrumenter til forsknings- og undervisningsbrug i Aarhus Universitets laboratorier, delaftale 12 – "Freezers from -40 °C to -86 °C".

Aarhus Universitet Institut for Biomedicin udbyder køb af X antal -80 graders skabsfryser som skal kunne rumme 13.000 50 mm fryseæsker.

Mindstekrav og ønsker til skabsfrysere er anført i bilag 1.

Levering:
Levering og installation af skabsfryserne til Skou bygningen skal finde sted mellem den 01. september 2018 og den 31. december 2018. Den vindende tilbudsgiver vil få besked senest 1 måneder før leveringsstart. Efter afftalt levering skal de leveres inden for en periode på max 14 dage.

Forventet tidsplan:

Forventet offentliggørelse af miniudbud	25.april 2018
Tilbudsfrist	17. maj 2018
Indlevering til test	18. maj 2018
Test	uge 21-24
Evaluering	uge 25
Afgørelse sendes til leverandørerne	uge 25
Ordreafgivelse	uge 26 og frem
Levering	mellem 1. september og 31 december 2018

Leveringssted:
Aarhus Universitet
Institut for Biomedicin

Tilbud:
Fristen for indlevering af tilbud er fastsat til **den 17. maj 2018 kl. 12.00.**
Tilbud skal sendes elektronisk via e-mail til udbud@au.dk mærket "Sags.nr. 2017-152-000079, Miniudbud vedr. – 80 graders frysere".

Eventuelle spørgsmål skal indgives skriftligt til ovennævnte e-mail adresse.

Spørgsmål og svar vil blive sendt i anonymiseret form til samtlige rammeaftaleindehavere.
Spørgsmål indleveret tæt på tilbudsfristen vil ikke blive besvaret.

Tilbud skal omfatte:

- Udfyldt bilag 1 – Kravspecifikation og ydelsesbeskrivelse
- Tekniske specifikationer på de tilbudte skabsfrysere
- Evt. yderligere beskrivelse af kvaliteten af den tilbudte skabsfrysere
- Udfyldt bilag 2 – tilbudsbilag

Aarhus Universitet forbeholder sig retten til at annullere miniudbuddet, såfremt prisen på det vindende tilbud overskrider de disponible midler, eller der i øvrigt foreligger en saglige grund herfor.

Det indleverede tilbud skal være gældende i 3 måneder regnet fra tilbudsfristen.

Tilbudsgiver skal udover at indsende et skrift tilbud. Aflevere et test produkt til følgende testleveringssted.

Test leveringssted:

Testfryseren skal afleveres på følgende adresse senest den 18. maj.

FORCE Technology
Sandblæservejen 4
5330 Munkebo
Kontaktperson er Per Baunegaard With Jensen. Telefoner nummer 45 43 25 04 07.

Tidspunkt for aflevering af testproduktet aftales nærmere med Per Baunegaard With Jensen.

Tilbudsgiver skal ved aflevering af testprodukt vedlægge kontaktoplysninger for tekniske spørgsmål til testfirmaet. Så testfirmaet kan henvendes sig direkte til tilbudsgiver ved problemer. Derudover skal der vedlægges manualler og oplyses hvilken kølevandstemperatur fryseren skal køre ved. (gælder ved direkte tilsluttet køle/vand fryser).

Forbehold:
Tilbudsgivere, hvis tilbud, ikke lever op til alle de fastsatte mindstekrav, vil ikke kunne tages i betragtning.

Ordregiver er berettiget til at afvise tilbud, der indeholder forbehold af ikke-bagatelagtig karakter.
Såfremt Ordregiver accepterer et tilbud, der indeholder forbehold af ikke-bagatelagtig karakter, er Ordregiver forpligtet til at prissætte forbeholdet i forbindelse med evalueringen.

Kan forbeholdet ikke prissættes, er Ordregiver forpligtet til at afvise tilbuddet.

Såfremt Tilbudsgiver ikke udtrykkeligt, specifikt og klart tager forbehold over for Ordregivers udbudsmateriale, lægges det til grund, at Tilbudsgiver har accepteret dette.

Tilbudsgiver skal derfor være opmærksom på, at tilbud med forbehold løber en betydelig risiko for at blive afvist. Ordregiver anbefaler derfor Tilbudsgiver at stille spørgsmål til miniudbudsmaterialet og dermed belyse uklarheder eller uoverensstemmelser inden tilbudsfristen fremfor, at stille forbehold i tilbuddet.

Evaluering:

Evalueringen vil ske på baggrund af følgende underkriterier:

- Pris 60 %
- Kvalitet 40 %

Prisen evalueres ud fra en energiformel (bilag 3) Se afsnit om test af fryserne.
Tilbuddet med den laveste evalueringspris pr. fryseæske tildeles 100 point.

Prisevalueringen vil herefter ske på baggrund af nedenstående formel:

Tilbuddet med den laveste evalueringspris pr. fryseæske tildeles 100 point. Øvrige tilbudsgivere tildeles point i forhold hertil efter følgende formel: ([Bedste Tilbudsgivers evalueringspris] / [Tilbudsgivers evalueringspris]) * 100

Det tilbudte produkts kvalitetsniveau evalueres på baggrund af de tekniske specifikationer, der indleveres sammen med tilbuddet, og enhver anden kvalitetsbeskrivelse af de tilbudte frysere.

Der foretages en helhedsvurdering af det tilbudte produkts kvalitet, hvori indgår opfyldelsen af de i kravspecifikationen anførte ønsker samt resultatet af testen af de tilbudte frysere.

Ønsker vurderes og vægtes på følgende måde:

Ønske 10- Det vægtes positivt at det indvendige kabinet er af rustfrit stål. 20 %
Ønske 26 - Det vil vægtes positivt hvis følgende funktioner er mulige at tilgå på skærmen/displayet: 30 %
- styring bør være beskyttet af teknikere adgangskode.
- Se status for temperatur
- Se status for døråbninger
- Se status for alarmer

Ønske 24 - Det vil vægtes positivt at pulldown-tid er så kort som muligt. 30 %

Ønske 30 - Det vægtes positivt at skabsfryserne har et lavt støjniveau 10 %
Oplys støjniveau.

Ønske 34 - Beskriv indholdet af kurset 10 %

Energitest af -80 graders laboratoriefrysere.

Formål med energimålingen
Aarhus universitet lægger stor vægt på at nedbringe strømforbruget. Her er strømforbruget af de elektriske apparater en vigtig faktor, og derfor er det et mål i sig selv, at apparaterne er så energieffektive som muligt. Da der for nærværende miniudbud på – 80 graders frysere ikke findes egentlige standarder eller mærkningsordninger, vil Aarhus universitet sikre sig et godt sammenligningsgrundlag med afsæt i faktiske forhold på Aarhus universitet. Derfor vil leverandører, som afgive tilbud blive bedt om at indlevere frysermodeller, der indgår i tilbudsgivningen til en uvildig energimålingstest.

Energimålingens udførelse
Energimålingen forløber ved et eksternt uvildigt anerkendt testlaboratorie. Leverandørerne skal uden omkostninger for AU levere 1 eksemplar af hver af de tilbudte frysere til teststedet. Leverandøren skal afhente de testede frysere samme sted efter endt test. Aarhus Universitet afholder udgifterne til selve test og afrapportering. Forventet testtidspunkt se tidsplan. Fryserne skal indleveres til test den 14. maj-afleveringstidspunkt aftales mellem tilbudsgiver og den uvildige testcertifikat.

Testbetingelser og –indhold

Baggrund
Standarden "Køleapparater til husholdningsbrug – Karakteristika og prøvningsmetoder" EN/ISO 62552 danner baggrund for opsætningen af kontrolmålingerne. Dog vil ikke alle forudsætninger og målinger leve op til standarden, men vil tage udgangspunkt i standarden og vil være ens for alle kontrolmålinger.

Testen laves ved 25°C rumtemperatur mens selve Energiformellen beregnes ved 23 °C som er de faktiske forhold i det kommende fryserrum hos institut for Biomedicin. Der vil derfor være en fravigelse på maksimalt ca. 0,5%.

Metode
Alle målinger gennemføres i en periode på 24 timer for hver laboratoriefryser. -80 graders fryserne skal levere en target temperatur på -80 °C (± 5 °K).

Rapportering udføres i form af én testrapport pr. fryser. Ved hver fryser måles:

- Elforbrug
- Frysertemperaturstabilitet: ±5°K (MK i bilag 1)
- Energi afsat i kølevand
- Pulldown-tid (Ø i bilag 1)

Forudsætninger for kontrolmåling:

- Strømforsyning: 1 x 230 V(± 5 %) (Schuko-stik)

Leverandører på delaftalen:
Buch & Holm
Fisher Scientific
Holm & Halby
In Vitro
LH Laboratorie Service
Vibocold
VWR

- Rumtemperatur: +25 °C døgnmiddel(± 1,5 °K)
- Målinger udføres ved tom fryser.
- Fryseren holdes lukket under hele testperioden.
- En temperaturprobe monteres cenntralt i fryser før udførelsen af kontrolmålingen.
- Der udføres tætning omkring ledning til temperaturproben.
- Temperaturproben monteres i 25 g messinglodder jf. EN/ISO 62552 8.7.1
- Fryserne vil køre i minimum 24 timer inden målingerne udføres jf. EN/ISO 62552 §13.2
- Maksimalt en fryser vil blive testet pr. leverandør.
- Temperatur data indsamles under hele forløbet.
- Tilgængeligt kølevand: 12 til 20 °C.

Tolerancer for målinger

- Elforbrug: Målt elforbrug kWh pr. døgn (± 1 %)
- Frysertemperatur: Døgnmiddel(± 0,8 °K)
- Rumtemperaturen ved fryseren: Døgnmiddel (± 0,15 °K)
- Energi afsat i kølevand: kWh pr. døgn
- Pulldown-tid: Fra start af fryser til fryser temperatur på -80 °C i min.
- Varighed af målinger: 24 timer(± 10 minutter) jf. EN/ISO 62552 §8.10

Efter endt test sendes der er en rapport på fryser til Aarhus Universitet.

Testfryseren skal afleveres på følgende adresse senest den 18. maj.

FORCE Technology
Sandblæservejen 4
5330 Munkebo
Kontaktperson er Per Baunegaard With Jensen. Telefoner nummer 45 43 25 04 07.

Med venlig hilsen

Lasse Krongaard
Specialkonsulent
Mobil tlf.: 60202600
E-mail:lak@au.dk

AU Økonomi og Bygninger, Indkøb
Trøjborgvej 32-34
8000 Aarhus
http://www.au.dk

L

BILAG 1 -
KRAVSPECIFIKATION OG YDELSESBESKRIVELSE **April 2018**

Udbud af -80 graders skabsfrysere, til Institut for Biomedicin - Aarhus Universitet

Aarhus Universitet
Økonomi og Bygninger, Indkøb
Trøjborgvej 82-84
8000 Aarhus C
Sagsnr.: 2017-152-000079

1. Vejledning til bilag 1 – Kravspecifikation og ydelsesbeskrivelse

Tilbudsgiver skal udfylde denne formular med beskrivelse af opfyldelse af mindstekrav (MK) og ønsker (Ø).

Mindstekrav og ønsker

Tilbudsgivere skal for så vidt angår såvel mindstkrav (MK) som ønsker (Ø):

- Afkrydse den relevante rubrik i feltet "Er mindstekravet/ønsket opfyldt".
- Redegøre for hvordan kravet er opfyldt eller komme med en **præcis henvisning** til den del af tilbuddet, hvor tilbudsgiver fremkommer med en nærmere redegørelse for opfyldelsen eller den manglende opfyldelse af mindstekrav (MK) eller ønsker (Ø).

Redegørelsen for opfyldelsen eller den manglende opfyldelse af kravet danner grundlag for evalueringen af tilbuddet.

Tilbudsgiver **skal** vedlægge dokumentation for opfyldelse af mindstekrav samt dokumentation for beskrivelse af opfyldelse af ønsker.
Denne dokumentation **skal** omfatte:

- Produktbrochure/produktbeskrivelse
- Tekniske specifikationer

Tilbudsgiver er desuden velkommen til at vedlægge anden dokumentation, som denne måtte finde relevant.
Eksempler på sådan dokumentation fremgår af den ikke udtømmende liste straks nedenfor:

- Brugervejledning
- Vedligeholdelsesmanual
- Serviceaftaler/dokumenter
- Certificeringer o. lign.

Såfremt Tilbudsgiveren svarer "nej" til opfyldelsen af *mindstekrav* (MK), vil Ordregiver være forpligtet til at afvise tilbuddet i dets helhed, og således ikke tage tilbuddet i betragtning ved evalueringen af de indkomne tilbud.

I forhold til Tilbudsgiverens opfyldelse af et *ønske* (Ø), vil det blive tillagt vægt i forbindelse med evalueringen, og i det omfang et ønske ikke opfyldes, vil det kunne trække betydeligt ned.

Tilbudsgiver opfordres derfor til at være så specifik i sin beskrivelse og i eventuelle henvisninger til supplerende materiale (for eksempel eget tilbud, brochurer, tekniske specifikationer m.v.) som muligt.

2. Mindstekrav og ønsker til de udbudte skabsfrysere

Krav	Ydelsen	Mindstekrav/ Ønsker		Ordregivers beskrivelse	Opfyldt		Tilbudsgivers beskrivelse
		MK	Ø		Sæt kryds		
					Ja	Nej	
Generelle krav:							
1.	Skabsfryserne skal være CE-mærkede.	MK			X		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja, VTS258 er CE mærket.*
2.	Skabsfryserne skal overholde lavspændingsdirekivet 2014/35/EU.	MK			X		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja, overholder lavspændingsdirektivet 2014/35/EU.*
3.	De anvendte kølemidler skal være naturlige, miljøvenlige og må ikke indeholde CFC, HCFC eller andre freon-typer der skader ozonlaget (Jf. EU Forordning 2037/2000 er brug af freon-typer der skader ozonlaget ikke tilladt).	MK			X		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*

	Kølemidlerne må ikke være registeret på lister som står til at udgå eller skal udfases.						
4.	Skabsfryserne skal leveres, udpakkes, opsættes og idriftsættes (indreguleres til drift -80 grader). Alt emballage mv. skal fjernes.	MK			X		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*
5.	Levering og installation af skabsfryserne til Skou bygningen skal finde sted mellem den 01. september 2018 og den 31. december 2018. Den vindende tilbudsgiver vil få besked senest 1 måneder før leveringsstart. Efter afftalt leveringsdato skal de leveres inden for en periode på max 14 dage.	MK			X		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*
Dokumentation:							
6.	Tilbudsgiver skal med tilbuddet vedlægge datablade, brugsanvisninger, betjeningsmanualer og tekniske manualer herunder service- og vedligeholdelsesvejledning til de tilbudte skabsfrysere.	MK			X		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja, venligst se vedlagte specifikationer.*
Garanti:							
7.	Tilbudsgiver skal yde 5 års onsite garanti, inkl. 1. og 2. års eftersyn.	MK			X		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*

Kvalitet og design:							
8.	Skabsfryserne skal være en standard model og have samme modelnr.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja, standard model og samme modelnr.*
9.	Skabene skal fremstå sammenhængende visuelt i højde, bredde og dybde	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*
10.	Det vægtes positivt at det indvendige kabinet er af rustfrit stål.		**Ø**		**X**		*Tilbudsgiver bedes bekræfte opfyldelse af ønsket, samt beskrive hvorledes dette opfyldes:* *Ja.*
11.	Skabsfryserne skal kunne aflåses. Låsen skal være integreret i fryserne.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*
12.	Skabsfryserne skal have en adgangsport til ekstern føler.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*
13.	Ved luftkølet skabsfryser skal være konstrueret således at kondensatoren beskyttes mod støv/skidt. Kondensatoren skal være tilgængelig for rengøring, uden brug af værktøj.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*

14.	Skabsfryserne skal være konstrueret således at tilisning af forsegling/pakning minimeres.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*
15.	Skabsfryserne skal have genopladeligt back-up-batteri på styringen, således at styringen ved strømsvigt er funktionsdygtig i minimum 6 timer.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja, kan holde i 50 timer.*
16.	Skabsfryserne skal leveres med et CEE-stik, 230V/16A med jord samt 3 meter ledning. Testfryseren skal leveres med Schuko-stik.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*
17.	Skabsfryserne skal være med fastmonteret hjul til transport.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*
18.	Skabsfryserne skal have ben/fødder eller lås bare hjul til nivellering af skabene.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja, låsbare hjul.*
19.	Skabsfryserne skal have et håndtag, der kan åbne og lukke døren med én hånd.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*
Tekniske krav:							

20.	Ind transport målene må maksimalt være b x h 130 x 204 cm (maks. bredde er inkl. hængsler/håndtag).	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*
21.	Skabene skal kunne placeres i 3 rækker over for hinanden som vist på den medfølgende bilag 4 fryser tegning. Skabene skal enkeltvis kunne åbne døren så der er fri adgang til alle udtræksskuffer, uden at der er muglighed for kontakt mellem dør-dørhåndtag og skabet overfor. Der skal samtidigt være muligt at overholde producentens krav til ventilation omkring skabene.	**MK**					*Anders Larsen? Dette er ikke noget problem. Der er fint plads til både kabinetterne med åbne døre samt nødvendig ventilations afstand.*
22.	Fryserne skal kunne rumme 13.000 50 mm fryseæsker og skal være fordelt på x antal frysere som er nødvendig for dække 13.000 fryseæsker	**MK**		Tilbudsgiver skal oplyse antal af frysere som skal anvendes til at dække behovet.	**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja, 91 x VTS258 = 13.104 50 mm æsker.*
23.	Temperaturen i skabsfryserne skal som minimum kunne reguleres i området ÷60 °C til ÷86 °C.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*
24.	Skabsfryserne skal holde en temperaturstabilitet: ±5,0K	**MK**		Måles som en del af testen.			*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Anders Larsen? Ja*

25.	Det vil vægtes positivt at pulldown-tid er så kort som muligt.		**Ø**	Pulldown tid måles som en del af testen.			*Tilbudsgiver bedes bekræfte opfyldelse af ønsket, samt beskrive hvorledes dette opfyldes:* *Anders Larsen? Under 3 timer*
26.	Skabsfryserne skal have indbygget trykudligningsport, der tillader hurtig genåbning af lågen. Porten skal være konstrueret således at tilisning undgås.	**MK**					*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Anders Larsen? Ja*
27.	Det vil vægtes positivt hvis følgende funktioner er mulige at tilgå på skærmen/displayet: - styring bør være beskyttet af teknikere adgangskode. - Se status for temperatur - Se status for døråbninger - Se status for alarmer.		**Ø**				*Tilbudsgiver bedes bekræfte opfyldelse af ønsket, samt beskrive hvorledes dette opfyldes:* *Anders Larsen? OK til styring der er beskyttet med adgangskode til teknikere.* *OK til status for temperatur.* *Status for antal døråbninger ikke muligt.* *OK til status for alarmer.*
28.	Skabsfryserne skal have isolerende indvendige døre, som hjælper med til at holde temperaturen ensartet i kabinettet.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja, 2 indvendige døre.*
29.	Skabsfryserne skal have visuel og akustisk alarm, samt potentialfri udgang til ekstern alarm som starter, hvis:	**MK**					*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Anders Larsen? OK*

	- Temperaturen afviger fra det ønskede. - Der forekommer strømsvigt.						
30.	Skabsfryserne må maksimalt have et støjniveau på 60 dB(A). 1 meter fra skabet.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja, 60 dB(A).*
31.	Det vægtes positivt at skabsfryserne har et lavt støjniveau Oplys støjniveau.		**Ø**		**X**		*Tilbudsgiver bedes bekræfte opfyldelse af ønsket, samt beskrive hvorledes dette opfyldes:* *Ja, 60 dB(A).*
32.	Der skal være fri AU tekniker adgang til alle dele i fryserens styring. I garanti perioden kun efter aftale med leverandøren.	**MK**					*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*
Racks/indmad:							
33.	Der skal medfølge racks til standard 50mm fryseæsker, f.eks. Nalgene's cat.no. 5026-0909 (æskernes mål BxDxH = 133x133x50 mm). Racks skal fylde hele skabsfrysernes kapacitet og være af typen med udtræksskuffer. Racks skal være udført i rustfrit stål.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja, fra Tenak.*

34.	5 års garanti på de medfølgende racks	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* *Ja.*
Uddannelse:							
34.	Serviceteknikere kursus til 4 personer til uddannelse af teknikere.	**MK**			**X**		*Tilbudsgiver bedes bekræfte opfyldelse af mindstekravet.* Ja.
35.	Beskriv indholdet af kurset		**Ø**		**X**		Tilbudsgiver bedes bekræfte opfyldelse af ønsket, samt beskrive hvorledes dette opfyldes: *Ja, vil komme til at foregå på fabrikken i Esbjerg og vil omhandle alt omkring service, vedligeholdelse & fejlfinding af VTS258.*

Bilag 3 - Energiformel

$$\$ = \frac{A + (E * 10869{,}2) + (6{,}16849 * E * V) + (42{,}6182 * E * L)}{N}$$

$ = Total pris per 50mm æske [kr/stk.]

(over 15års levetid, med 1,6kr/kWh elpris med en prisudvikling på 3% pro anno.)

A = Anskaffelsers pris pr. fryser inkl. racks til 50mm æsker [kr]

N = Antal 50mm æsker i racks pr. fryser. [Stk.]

E = Fryserens døgnforbrug af el [kWh/døgn]*

V = Procentvise fordeling af fryserens energiafgivelse til vand [%][B]

L = Procentvise fordeling af fryserens energiafgivelse til luft [%][B]

Forklaring af energiformellens led:

$(E * 10869{,}2)$ = Elprisen for drift af fryseren (15år) [kr]

$(6{,}16849 * E * V)$ = Elprisen for fjernelse af varme via vandkøl (15år) [kr]

$(42{,}6182 * E * L)$ = Elprisen for fjernelse af varme via luftkøl (15år) [kr]

Med hensyn til den procentvise fordeling til vand og luft antages det at: Fryserens døgnforbrug af el er lig med den samlede energimængde der bliver afgivet til vand og luft. Af hensyn til rimligheden af testomfang måles energimængden der afsættes til vandet per døgn. Energimængden der afsættes til vandet **(Qv)** divideres med Fryserens døgnforbrug af el gange 100, for at finde den procentvise fordeling der afsættes til vand.

Qv = energimængden der afsættes til vandet [kWh/døgn]*

$$V = \frac{Qv}{E} * 100\ [\%]$$

For at finde den procentvise fordeling til luft findes ved differensen til 100% via Subtraktion med den procentvise fordeling til vand

$$L = 100 - V[\%]$$

* Findes ved test hos eksternt, uvildigt testorgan (Set punkt: ÷80°C, temperaturstabilitet: ±5°K, omgivelses temperatur: ens for alle, 25 oC døgnmiddel (+ 1,5 oC)

B Beregnes

9.2. Appendix B

Excel file with sheets to consult all databases and see how work is performed is consultable at https://drive.google.com/open?id=1_9isse4h87naIJFhgd1j_t0nEv8IQN1f