Sofie Kofoed Rødvei

Using Statistical Process Control (SPC) and Process Failure Mode and Effect Analysis (PFMEA) to Increase Overall Equipment Effectiveness (OEE) and Decrease Waste and Overweight in Consumer Goods Production Industry

Master's thesis in Mechanical Engineering

Supervisor: Bjørn Sørskot Andersen & Asbjørn Bonvik

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Sammendrag

Denne rapporten bruker ICCM (Identify, Control, Capability og Maintain) metoden, med noen av de tilhørende verktøyene, for å gjøre Conbar linjen på den Orkla ASA eide Nidar fabrikken mer effektiv og lean. De to hovedproduktene som har blitt sett på er New Energy og Småsulten barer siden disse er antatt å ha størst potensiale for forbedring. Analysene har blitt gjort ved hjelp av observasjoner på linjen, workshops med operatørene og analyser av dataen som har blitt innsamlet. Dataen har blitt innsamlet gjennom kontakt med operatørene og observasjoner. I tillegg har noe av dataen blitt logget av operatørene og lederne på linjen over tid.

Det var antatt før prosjektet at Conbar-linjen hadde unødvendig høye oppstarts og avslutnings tider, som igjen førte til lav Overall Equipment Effectiveness (OEE). Det var også antatt at vrakandelen var unødvendig høy for de to aktuelle produktene, og at overvekten også kunne reduseres for alle produktene på linjen.

Analysene er delt i tre hoveddeler: OEE, overvekt og vrakanalyse. OEE analysen presenterer flere tiltak som skal forbedre OEE, og besparelsene er beregnet til å være 0,70 årsverk årlig. Overvektsanalysen presenterer noen tiltak for å minke overvekten, og legger vekt på viktigheten av å ha fokus på overvekt. Tiltakene og det økte fokuset er beregnet til å føre til 26 tonn produkt spart årlig. Vrakanalysen viser detaljert hvor de største delene av vrak kommer fra på linjen, og presenterer i tillegg en liste med tiltak for å minke vraket for de to hovedproduktene. Totale besparelser fra vrakanalysen er beregnet til å være 44 tonn årlig. Dette viser totalt sett at det er et stort potensial for linjen da de totale besparelsene er beregnet til å være omtrent 0,70 årsverk og 70 tonn årlig.

For å klare å gjøre disse besparelsene burde tiltakene som har blitt presentert gjennomføres av Nidar. Et gjentagende tiltak er å stabilisere produksjonen slik at produktene har høyere og jevnere kvalitet. Hvordan produksjonen kan stabiliseres har blitt sett på i en Process Failure Mode og Effect Analyse (PFMEA). Denne analysen ser på ulike feilkilder, rangerer de, og lager et sett med tiltak for å sørge for at disse feilene ikke skjer. Denne analysen foreslo å innføre Statistisk Prosesskontroll (SPC) for å stabilisere produksjonen, derfor er også et forslag til bruk av SPC på flere ulike parametere presentert.

SPC med bruk av Process Behavior Charts (PBCs) viste at flere av parameterne kunne vært mer i kontroll, og derfor er det anbefalt å implementere SPC for å stabilisere de. I tillegg er det anbefalt at Nidar jobber med å iverksette e de forskjellige tiltakene presentert i denne rapporten. En prioritert liste over de foreslåtte overordnede tiltakene har blitt laget, og er som følger:

1. Forbedre oppstarts- og avslutningsrutinene
2. Alle vraktiltak på Småsulten produksjon
3. Implementering av SPC for å redusere variasjon og stabiliserer produksjonen
4. Gjøre spesifikasjonene for vekt av produkter mer realistiske
5. Gjøre overvekt til en Key Performance Indicator (KPI)
6. Alle vraktiltak på New Energy produksjon
7. Standardiserte rutiner og bedre opplæring av operatørene på disse
8. Lage tydelige regler for vektøkning/redusering ved undervekt/overvekt

Denne listen er basert på tiltakene med høyest fordel mot kostnad forhold. Flere workshoper og å gjøre PFMEA analyser på flere prosesser er også anbefalt siden dette førte til nyttige diskusjoner om produksjonsprosessen.

Summary

This thesis uses the ICCM (Identify, Control, Capability and Maintain) methodology, and some of the corresponding tools, to make the Conbar line at Orkla ASA's Nidar factory more efficient, effective and lean. Two main products have been looked at since these have the assumed highest potential. These products are the New Energy chocolate bar and the Småsulten nut bar. The research has been done by observations on the factory, workshops with the operators and by analyzing the corresponding data. Data has been gathered by interactions with the operators and observations on the line. In addition, some of the data used has been logged by the operators or the management over time.

The Conbar line was prior to the project assumed to have unnecessary high startup and shutdown times, which lead to low Overall Equipment Effectiveness (OEE). It was also assumed that the waste, including overweight, was high for the two main products. The amount of overweight was also assumed to be high for all the other products on the line.

The analyses are divided in three main themes: Overall Equipment Effectiveness (OEE), overweight and waste analyses. The OEE analysis presents several actions to improve the OEE, and the calculated savings are 0,7 Full Time Equivalent (FTE) yearly. The Overweight analysis presents some actions to decrease the overweight but is also describing the importance of being focused on overweight. The total savings are estimated to be around 26 tons yearly. Lastly, the waste analysis shows in detail where majority of the waste is located on the line and presents a long list of recommended actions for the two main products; New Energy and Småsulten bars. The estimated savings are respectively 27 and 17 tons yearly. This shows that there is a lot of potential on improving the line, which gives an estimate of 0,70 FTEs and 70 tons product in savings yearly.

In order to make these improvements, several actions have been presented. A repetitive action is to stabilize the production. This has been looked further into by a Process Failure Mode and Effect Analysis (PFMEA). This analysis is used to look into the failure modes, rank them, and make a set of actions to prevent these. The analysis led to the need of SPC, therefore a suggestion to use Statistical Process Control (SPC) on a set of different measures also will be presented.

SPC with Process Behavior Charts (PBCs) shows that several of the measures could be more in more control, and implementation of SPC is recommended to make the process more stable. In addition, Nidar is suggested to work on the actions mentioned in this thesis. A ranked list of the suggested overall main actions has been made, and is the following:

1. Improved startup and shutdown routines
2. All waste actions regarding Småsulten bars
3. Implement SPC to reduce variation and stabilize the production
4. Set the weight specifications more adequate
5. Overweight as a Key Performance Indicator (KPI)
6. All waste actions regarding New Energy
7. Standardized routines and better training of operators
8. Set clear action rules for weight increase/reduction

The list is based on the actions that has the highest benefit versus cost ratio. More workshops and making several PFMEA upon other processes are also recommended as this led to very useful discussions about the production process.

Preface

This thesis has been the written assignment in the course TPK4920 – Project and Quality Management, Master's Thesis at the Norwegian University of Science and Technology (NTNU) Trondheim. The thesis is the authors master's thesis and counts for 30 credits. It has been written in cooperation with Orkla ASA.

Working with this thesis has been very educational for me. I have learned a lot about production optimizing through different methods. I have also been able to interact with the operators at the line which was informative and educational. In addition to this, the project has almost been a job experience for me, which is useful as I will be finished with my grade when I deliver this thesis.

First of all, I want to thank my supervisor at NTNU, Bjørn Andersen, for the great support and help throughout this master thesis. He has especially been helpful making the project suit a master's thesis, and he has been available at any time for questions and support.

Further I want to thank my supervisor in Orkla ASA, Asbjørn Bonvik, for taking the time for the collaboration, and being available for questions at any time. He has been a big contributor when working with this master thesis. In addition, I want to thank the other members of the team at the project, Emelie Lysberg, Magnus Lantz and Mikael Andersson. They have assisted me with the analyses and been great support throughout the project execution.

Finally, I want to thank the entire staff I have been in contact with at the Nidar factory. Product developer Perny Emdal, quality engineer Thomas Smistad, maintenance engineer Finn Jarle Sørli, line manager Johnny Aker Hansen and the factory manager Anders Greiff has assisted me during the whole thesis writing, giving valuable information and being available for questions.

A special thank you to every operator on the Conbar line, that have used their time to explain processes to me, and logging data for me. This was crucial to complete the thesis.

Sofie Kofoed Rødvei

Trondheim, June 2019

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Abbreviations and Acronyms

A – Availability

CL – Central Line

D – Detectability

DMAIC – Define, Measure, Analyze, Improve and Control

PFMEA – Process Failure Mode and Effect Analysis

FTE – Full-Time Equivalent

ICCM – Identify, Control, Capability and Maintain

IDEF0 – Integrated Definition (diagrams)

KPI – Key Performance Indicator

LCL – Lower Control Limit

LSL – Lower Specification Limit

mR – Moving Range

NTNU – Norwegian University of Science and Technology

NV – Nominal Value

O – Occurrence

OEE – Overall Equipment Effectiveness

OGO – Orkla Group Operations department in Orkla ASA (earlier named Production Strategy & Development, PSD)

PBC – Process Behavior Chart

PE – Performance Efficiency

PFMEA – Process Failure Mode and Effect Analysis

Q – Quality

RPN – Risk Priority Number

RQ – Research Question

S – Severity

SD – Standard Deviation

SOP – Standardized Operating Procedures

SPC – Statistical Process Control

UCL – Upper Control Limit

USL – Upper Specification Limit

Chapter 1: Introduction

This chapter introduces the background and motivation of this thesis. To do this, the earlier project thesis of the author, Orkla ASA, Nidar and project Opal is briefly presented. Further the formal problem description and project scope, including the problem statement, corresponding Research Questions (RQs) and limitations are presented. In the end of this chapter the structure of the thesis is presented.

1.1 Background and Motivation

In the fall of 2018, the author wrote a project thesis in cooperation with Orkla ASA. That thesis was an introduction to this thesis – the master's thesis of the author. Orkla ASA is more than 350 years old and started out as being a mining company in Trøndelag, Norway. It was first in the late 20th century that Orkla started with consumer goods industry and have ever since gone more towards this field. (Orkla ASA, 2019a) Today Orkla ASA is one of the leading suppliers of consumer goods in the Nordic region, with a total of about 100 factories mainly in Europe, but also in India, Malaysia, China and Russia (Orkla ASA, 2019b). In 2018 Orkla ASA had revenue of over 40 billion NOK (Orkla ASA, 2019c). Being a company with such high revenue, it is clear that small savings for each product produced will be important in the big picture, and in the long term.

The Orkla ASA owned Nidar factory is an over 100 year old chocolate manufacturing company, that today produces candy in almost every form: chocolate, marzipan, jelly candy, licorice, toffee and pastilles (Orkla ASA, 2019d). One of the lines at Nidar is called Conbar and is producing many of the chocolates in bar-shape, such as Troika, Gullbrød, New Energy, Småsulten bars and Smash bar. Some of these bars have a complex production process, whereas some of them are less complex.

The project thesis of the author was about overweight in products at some of Orkla ASAs factories, including the Conbar line at Nidar. In the project thesis the author concluded with the need of better control of the weight of the products sold and that there was significant overweight of the Troika bar at the Conbar line. The author suggested that Orkla ASA implemented Statistical Process Control (SPC) or other methods to get better control of the process variation. This was then supposed to lead to the possibility to reduce the overweight. (Rødvei, 2018)

Orkla has initiated a project to reduce the process waste, including overweight, in this line at Nidar. The project will be executed in the first half of 2019 and is called project Opal. The project will be conducted by an internal consultant team from Orkla ASA, in addition to the author of this thesis. The author of this thesis is therefore in the spring of 2019 following project Opal and conduct several independent analyses, which will be presented in this thesis. During the project execution it was natural to look at the Overall Equipment Effectiveness (OEE), so this will also be a topic in this thesis.

This kind of waste reducing project is something that is relevant for all manufacturing companies. Project Opal is especially relevant for consumer goods production companies. This means that the thesis is not only of relevance at the Nidar factory. Orkla ASA may use some of the findings on other factories, and even other companies may use some of the findings.

1.2 Problem Description

The Conbar line at the Nidar factory, owned by Orkla ASA is assumed by the management to have unnecessarily high waste amounts, including overweight. The factory wants to get better knowledge of the amount of waste, where it comes from, and where to focus on waste reduction. Further they want to get help with actions to reduce this waste. In the process of doing this Nidar wants the project team to consider the Overall Equipment Effectiveness (OEE) at the line, especially looking at the startup and shutdown routines. The products assumed to have the highest value of waste is the New Energy bar and the Småsulten bars, therefore these are the only products that should be looked at regarding waste and OEE. When looking at the overweight all of the products on the line should be taken into consideration.

The project will be using the tools corresponding to the ICCM method (Identify, Control, Capable and Maintenance), which includes Process flow charts, IDEF0 Diagrams, Process Failure Mode Effect Analysis (PFMEA), Standardized Operating Routines (SOP) and Statistical Process Control (SPC). The first step to this project is to settle all relevant information about these tools, and to examine previous research about them. When this is done, a thoroughly description of the case has to be presented. Lastly all of the analysis, findings and discussions regarding these needs to be presented, prior to concluding on all of the findings.

1.3 Project Scope

The scope of the thesis will be presented in this subchapter, by first presenting the problem statement and the corresponding Research Questions (RQs). Then certain limitations will be presented and explained.

1.3.1 RQs and Problem Statement

From the problem description above, the following problem statement has been considered suitable:

> *"How may the Conbar line at Nidar increase their OEE and at the same time decrease the waste and overweight of their products using the tools included in the Identify, Control, Capable and Maintain (ICCM) methodology like SPC and PFMEA?"*

To be able to answer this problem statement, the three main parts of the thesis; OEE, Overweight and Waste, will be looked at separately. The RQs are settled from the hypothetical issues on the line, that will be presented in section 4.2 Todays Assumed Issues at the Conbar line. The corresponding RQs are therefore as follows:

- RQ1: Increase OEE
    - RQ1a: How may Nidar improve their Overall Equipment Effectiveness (OEE) at the Conbar line regarding startup and shutdown routines at the New Energy and Småsulten products
    - RQ1b: How much is it possible to save from these actions?
- RQ2: Overweight reduction
    - RQ2a: How much overweight does the Conbar line at Nidar have in total?
    - RQ2b: How may Nidar reduce their overweight at all the products produced at the Conbar line?
    - RQ2c: How high amount of overweight volumes are possible to save from these actions?
- RQ3: Waste reduction
    - RQ3a: How much waste does the New Energy and Småsulten products at Nidar have in total, and what is causing the waste?

- RQ3b: How may Nidar reduce their waste of the New Energy and Småsulten products?
- RQ3c: How high amount of waste volumes are possible to save from these actions?

1.3.2 Limitations

As previously briefly described, there are some limitations on this project and thesis writing. The project is only looking at two products on one line at one factory of Orkla ASA. This limitation has been made due to a tight timeline for the project execution. If the time limit were longer more products, more lines, more factories or even more companies could have been looked at.

The project could have looked at more factors than OEE, overweight and waste if there had been more time. These problems were the ones chosen as they were assumed to be the biggest problems on the line.

In addition, the economically calculations are not presented for the overweight and waste analyses as this is sensitive data for Orkla ASA. That is why the possible saved volumes are presented instead. All the findings have been calculated detailed into Norwegian Kroners but will not be presented here.

1.4 Structure of Thesis

The structure of the thesis, and a description of each of the sections are presented in Table 1.

Table 1: Structure of thesis

Chapter	Description
1. Introduction	Presents the background, motivation, scope and structure of the thesis. The formal problem description is presented. This is an introductory chapter that briefly explains the most important topics of the thesis and presents the problem statement and RQs.
2. Methodology	Mainly explains how the data collection and data analysis methods were done. In addition, the research design and the data verification are presented, and method evaluation is discussed.
3. Literature Review	This chapter present the main theory of this thesis, which is the literature review. The important concepts are presented and explained before different terms are looked at in relation to each other.
4. Case study	The case study sections explain the case in depth. The Conbar line, the project team and Nidar in general are presented. Then the assumed issues prior to the project is presented, and lastly the planned analyses are presented.
5. Analysis and discussion	This is the main part of the thesis. All the analyses done are presented and explained, before several stabilizing actions are presented in depth. The three main analyses. OEE, overweight and waste, are presented one after another. Then other smaller stabilizing actions are presented. Lastly special aspects of this project execution, that may differ from other optimizing production project, are presented.
6. Conclusion	This chapter sums up the whole thesis and concludes on the findings. The findings are connected to the RQs and problem statement. In addition, a summary of the total savings is presented. Lastly some further research is discussed.

As seen, the structure of the thesis follows a quite normal and logical structure. In the analysis and discussion part the three main analyzes are presented separately to make the section more structured. This means that the three main RQs are presented separately. Chapter 3: Literature review is the beginning of reflecting around the RQs but does not directly answer any of them. Chapter 4: Case study, explains the general case study regarding the actual line and the project. The assumed issues prior to the project is also presented in addition the planned analyses, which is important background information regarding the RQs. In the main part, Chapter 5: Analysis and discussion, all of the RQs has its own subchapter and these will be answered here. Chapter 6: Conclusion will sum up the main findings, and directly answer the RQs again.

As shown in Table 1 over, the next chapter, chapter 2, will go into the methodology of the thesis.

Chapter 2: Methodology

This chapter describes what research and analyses that have been done, and how it was done. The first subchapter is about the research design showing a timeline of the project. The next part of the chapter describes how the data collection and analysis was done. Lastly a discussion of the data verification and method evaluation is present.

2.1 Research Design

2.1.1 Overall Research Methodology

When settling the research design the author has to take some choices regarding several of the different stages in the research methodologies, corresponding to the so-called Research Onion (Saunders et al. 2007). This includes topics like research philosophy, research approach, research strategy, time horizons and data collection methods. The time horizon is described in the next part of this sub chapter. The data collection methods are explained in the next sub chapter. The rest of these topics will be presented here.

Research philosophy

The two ends of a research philosophy are the positivism and constructionism, which is based on empiricism and interpretivism respectively. Positivism is a philosophy that assumes that the reality is natural and independent of the researcher's values. This is in other words a research philosophy that is objective based. On the other end there is, constructionism, which is more based on knowledge gathered through human experiences. This means that the research is based on observations and is therefore more subjective. (Johannessen et al. 2016)

This thesis is of course using a lot of observations as this is a big part of the data collection. But on the other hand, the positivism philosophy is very present as the analyses are more scientifically and objective based. The research philosophy of this thesis is mostly based on positivism but has some aspects of constructionism.

Research approach

The research approach may be parted into deductive or inductive. Deductive research is using a research strategy to test a developed hypothesis, whereas the inductive approach uses observations to state theories. It is clear that this thesis is based on deductive reasoning, as there was a clear hypothesis list and RQs to be looked at. In other words, going from general to more particular in the research. The deductive reasoning match with the positivism philosophy. There has been done observations, but no general theory has been made from these, and therefore it could not be stated that the inductive research approach has been used.

In addition, there is a gap between quantitative and qualitative approach. As the name states, these are based on quantitative and qualitative data respectively. Quantitative approach could be based on a questionnaire or a datasheet with a lot of data that could be used in statistical analyses. It is clear that the great amounts of data logged by the operators and management is quantitative data, and therefore suits the quantitative approach. Qualitative approach could be based on in depth interviews or written articles or books. During the literature review, the qualitative approach has been used.

Research strategy

There exist several different research strategies, and several of these will be used in this thesis. Case study is of course used to investigate the special case of this thesis. Some experimental research has also been used, as the results has been compared to the expected results. Further ethnography has been used, as observations of the operators have been done. Lastly, a systematic literature review has of course been done to gather the needed knowledge and prior research about the terms.

2.1.2 Timeline of project

The formal startup date of the thesis was 15th of January 2019 (Tuesday week 3 of 2019), and the delivery date was 11th of June 2019 (Tuesday week 24 of 2019), which gives a period of 21 weeks. The official duration of a master's thesis at the Norwegian University of Science and Technology (NTNU) is 20 weeks, but since the Easter holidays are during the period, one week is added. In other words, the thesis is written over a period of 140 days in total, if the weekends are calculated as working days. The timeline of this thesis is presented in Figure 1.

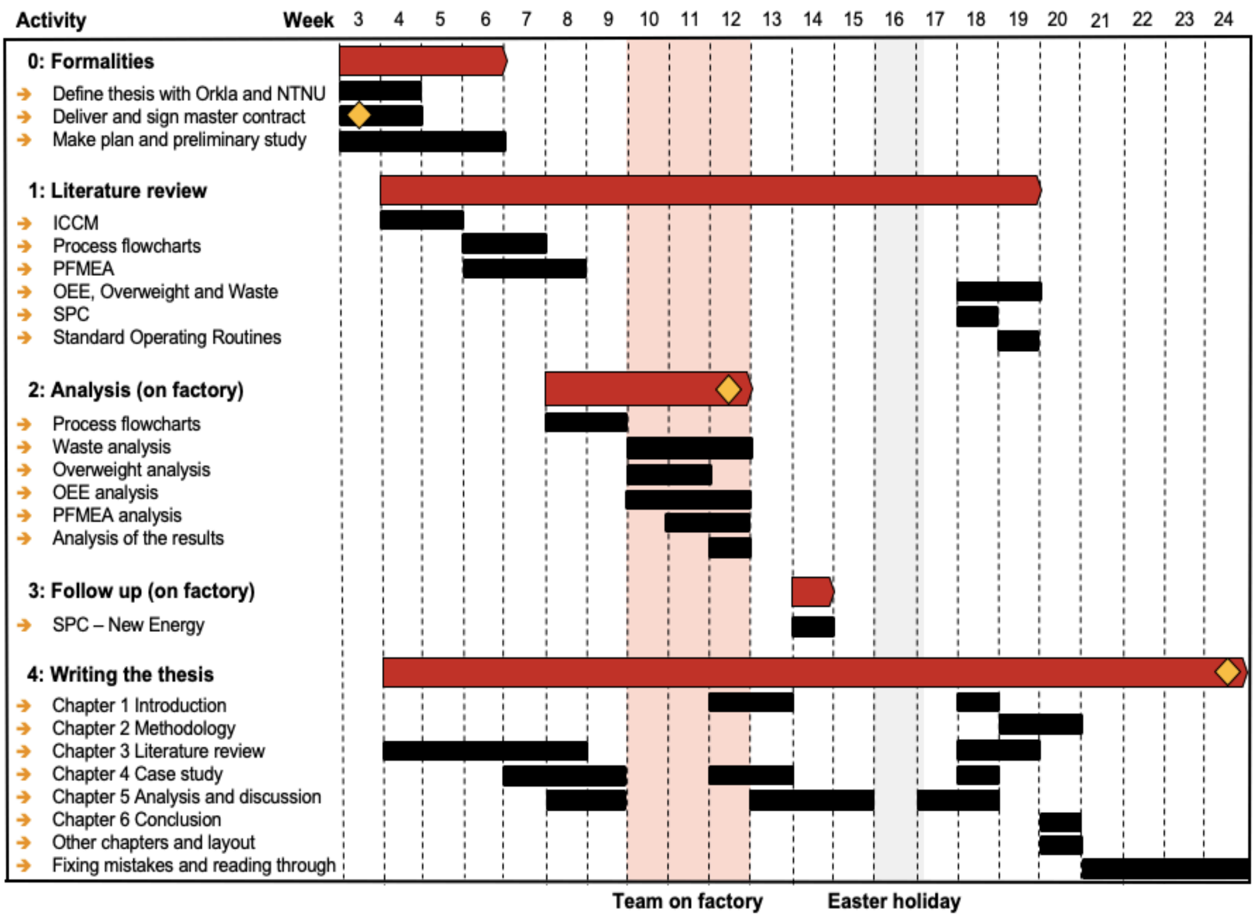

Figure 1: Timeline of the thesis

As seen from Figure 1, the first two weeks of the thesis writing (week 3 and 4 of 2019) was used mainly to formalities such as delivering the master contract, writing the preliminary study, and planning the research timeline including what to do at what time.

It was not until week 4 of 2019 that the author knew some methods and analyses that should be done during the project execution. She started with some literature review on the term ICCM, but it did not take long until she realized that this was a more company internal methodology, and that there did not exist much public literature on the term. Therefore, this term will be described in Chapter 4: Case Study, based on knowledge and documents gathered from Orkla ASA. In week 6 the author had a meeting with Orkla ASA to settle the project. This gave more clarity of the analyses that should be done, and she then started literature review on Process Failure Mode and Effect Analysis (PFMEA) and Process Flowcharts. After this meeting the author also started to write on Chapter 4: Case Study.

From week 8 to 12, in addition to week 14, the author was on the Nidar factory most of the time. Week 8 and 9 she was there to learn about the production and to make flowcharts. Up until this point the author did not work very intensive on the thesis, as she did not have much information. When the whole project team was present in week 10 to 12, this changed. In these intensive weeks all the analyses were done. After the project was done, all the analyses and discussions around these had to be written down. The author therefore focused mainly on Chapter 5: Analysis and Discussion for five weeks after the project was done.

In week 14 the author was supposed to implement Statistical Process Control (SPC) to the line. Therefore, she made logging charts to the operators and showed them how to log the data in a right way. After two shifts of New Energy running, she returned to the factory to make this data into SPC charts, and then follow the operators during a production run to show and teach them how to use SPC. Unfortunately, the day she returned, the production had to be stopped due to a raw material that unexpectedly run empty. New Energy was not on the production plan for a long time in the future either. This made it impossible to do this implementing. The SPC charts that should have been used, with the corresponding measures, is present in section 5.2.2 SPC instead.

The last weeks was used to write the rest of the thesis, in addition to doing some more literature review. Even if the framework of the whole timeline was done in the first weeks of the thesis writing, the planned timeline was updated every week. Week 14 was originally planned as a buffer week but was needed as the follow up on factory, due to the production plan.

2.2 Data Collection

This subchapter presents the different data collection methods and explains how these were done.

2.2.1 Literature Review

The literature review in this thesis has mainly been done by systematically searches on Oria, the database NTNU provides to their students for literature searches. Some of the resources were also suggested to me by the supervisors, some were used in the corresponding project thesis of the author, and some were found through lecture notes or lecture curriculums. Some were found though other resources as well. A presentation of how the literature review was done is presented in Table 2.

Table 2: Systematic presentation of the literature review

Term	Search word	Number of hits	References found and used	Other references used on the term
Overall Equipment Effectiveness (OEE)	Title: Overall Equipment Effectiveness AND Production OR Manufacturing	247	Hassani and Hashemzadeh (2012)	Nicholas (2011) from lecture curriculum
Overweight of products	All the literature used on this term was found in the corresponding project thesis. The directive about weight control (The Council of the European Communities, 1976) was found from the project proposal from the project thesis.			
Waste in production	Title: Waste AND Supply chain	7625	Peitz and Shin (2013)	Nicholas (2011) from lecture curriculum Markovitz (2012) found in the library shelf when picking up other resources
	Reduce waste AND Supply chain AND Food manufacture	2524	Pendrous (2017)	
	Lean AND waste	>80 000	Womack and Jones (2003)	
	Waste removal AND Taiichi Ohno AND Lean	22	Hines and Rich (1997)	
Process Flowcharts	Title: Flowcharts	289	Ellis (2001)	None
	Title: Process flowchart AND Production OR Manufacturing	23	Argent (2007)	
Standard Operating Procedures (SOP)	This reference was found during the waste literature review		Hunter (2004)	None
IDEF0 diagrams	IDEF0	2286	Marzouk and Elmansy (2018)	Some additional general knowledge gathered from

				insight of Orkla ASA's documents
Process Failure Mode and Effect Analysis (PFMEA)	Process failure mode effect analysis OR PFMEA	>400 000	Oakland (2014)	Stamatis (1995) found through other articles when doing the literature review Saux (2006) from supervisor
	Failure Mode and Effect Analysis FMEA production	4130	Ershadi and Ershadi (2018)	
Statistical Process Control (SPC)	All the literature used on this term was found in the corresponding project thesis.			

As seen from Table 2 some resources are from other sources than the searches on Oria. The acceptance criteria for the resources will be presented in section 2.4 Data Verification.

2.2.2 Case Study

Most of the data collection for the case study were datasets given to the project team by Nidar employees. During project Opal the team used the program Microsoft Teams as a tool to share data, and some of the data was directly gathered from here. Also, a lot of the observations and interaction with the operators on line, were data collection. A short description on the exact data collection for the different analyses and methods used are presented in Table 3. In addition, the degree of independence of the author, regarding the analyses and methods are presented in the table.

Table 3: Data collecting and independency of author

Analysis/ Method	Observations	Logged and other collected data	Independency of author
Flowcharts	The observations were done during week 8 and 9 at the Nidar factory. The author observed the production line regarding both New Energy and Småsulten production. In addition, she interacted with the operators on line to fully understand the line.	Nidar already has a flowchart of the whole Conbar line. This chart presents all products in one chart, and therefore had to be modified a lot. It was on the other hand very useful for gaining information about the different raw materials and the warehouse.	The observations and making of the flowcharts were done by the author alone.
OEE analysis	The startup and shutdown observation for Småsulten was done in week 10. Startup and shutdown for New Energy was observed in week 11. In addition, some of the observations from week 8 and 9 were used for the New Energy	To calculate the estimated earning of the improvement proposals several data was needed from Nidar. The data was gained from the factory manager and line manager.	The observations were done by the author and Emelie Lysberg. Most of the analyses was done by the author, with the input from

	analysis as well. The project team looked for inefficiency, like operators waiting, or routines taking longer than necessary.		Emelie's observations.
Overweight analysis	Some observations from the weight control in the production was done, looking at the routines and specifications on line.	Most of the data collection was done by getting a lot of historical logged weight data for all the products on line. Some of the products contained several thousand logged data, where as some had about hundred measures. The data was given to the project team by the quality manager.	All of the overweight observations and analyzes was done by the author.
Waste analysis	The observations were done mainly at the same time as the OEE analysis. Several bags for the operators to collect waste in was put along the line so that the project team could measure them to get a precise waste analysis. The operators were very helpful with filling the right bags.	Some historical data of earlier, not as precise, waste measurements on line were given to the project team by Nidar. This was used to scale the observed waste to a yearly waste amount.	All the waste observations and weighting were done by the author and Emelie. The analyzes of the yearly amount of waste was done by Emelie. The cost-benefit diagrams were made by the author.
PFMEA	Some of the observations the project team did during the other observation days were used here as well.	Most of the data and information collected to do the PFMEA were done through workshops with the operators on line, in addition to the project team and line, quality and maintenance managers.	Most of the PFMEA was done during the workshops, led by Asbjørn. The project team, including the author, was present and involved.
SPC	During the observations the other days, in addition to the input from the PFMEA workshop, the proposed measures to use SPC on were found.	The author made logging sheets for the operators and showed them how to do the logging. Then the data was filled out by the operators on line and collected again by the author.	All of the SPC data collection and analyzes was done by the author.

As seen, most of the data collection was done by observations and interactions with operators on the line, and data given by Nidar. The author did the flowchart, overweight and SPC analyses on her own, most of the OEE analysis alone, and was a part of the waste analysis and PFMEA.

2.3 Data Analysis

To analyze the collected data several different methods were used. These are presented in this section. An explanation on how the author used these methods are also present.

2.3.1 OEE Analysis

When the OEE data was collected, the author made an illustration of the shutdown routines as they appeared that day, regarding time used for shutdown at each position on the line. The figures for the two products are presented in section 5.1 OEE Analysis. The observations regarding inefficiency in the actual startup and shutdown routines were discussed with the team and settled as estimated minutes saved for each position on the line. From this information, the author was able to make proposals for new times for startup and shutdown routines by editing the illustrations that represented the observations for the day.

Further the calculations regarding the savings corresponding to the increased OEE were calculated as presented in section 5.1 OEE Analysis. The estimated savings are calculated in Full-Time Equivalent (FTE). The formulas used were made by the author, together with the project team, as they give the right calculations and information.

2.3.2 Overweight Analysis

The overweight analyses were done in Microsoft Excel and Minitab. All the data, for every product, was imported to one excel document. The average, standard deviation and average overweight for each product was calculated. Then the target weight, and corresponding Lower Specification Limit (LSL) for each product were found and noted down. Using this, in addition to the number of pieces produced yearly, the yearly overweight was calculated. The yearly cost of this overweight was calculated, but as this is sensitive information, it will not be presented here. An observant reader that also has read the corresponding project thesis will see that the overweight data from the project thesis and this thesis do not match completely. The calculations from this thesis is based on all the previous data Nidar has logged. The calculations in the project thesis is based on a few days production, and then scaled up to the yearly number of produced products. This makes the calculations in this thesis more accurate. On the other hand, if the production has changed over time, the calculations in this thesis may be based on data that is older, and maybe outdated and irrelevant.

Minitab is a program that gives the opportunity to easily present data in graphs, such as histograms. Minitab was used to present the behavior of the data for each product, using histograms with a suiting normal distribution trendline. The LSL, target value and Upper specification Limit (USL) were shown. USL were assumed to be the same distance over the target value, as the LSL is under the target. This made it easy to see the diversification of the data, in addition to the placement of the data compared to the target value.

2.3.3 Waste Analysis

As the yearly amounts of waste for the two products were not calculated by the author, the methodology of the calculations will not be explained here. On the other hand, the cost-benefit diagrams were made by the author. The estimated cost was plotted against the estimated benefit. The estimates were rough but was still done to try to say something about which actions to focus on. The estimated cost was a total of the price of the investment and time used on implementing the action. The benefit were the estimated possible savings, in volume, given that the actions worked as wanted, and the possibility that the action will work.

2.3.4 PFMEA

The PFMEA executions for the most critical processes from the two products were done through workshops where all of the operators on the Conbar line, the quality and maintenance manager, product developer, the project team and the line manager were invited. The workshop started with a walkthrough regarding the methodology. An IDEF0 diagram was made for each product, as this is a great tool to start discussions and to get an overview of the potential failure modes, control mechanisms and other relevant aspects needed in the PFMEA.

When the IDEF0 diagram was made, and the discussions stared, the PFMEA was settled with input from the participants. A lot of very useful discussions regarding exchange of ideas, views and opinions came up during these workshops.

2.3.5 SPC

The author was responsible of making the SPC charts. As previously mentioned in this chapter, it did not go as planned due to a situation with a lack of raw material. The plan was to gather data from the different measures that should be made PBCs of, then calculate the LCL, CL and UCL. When this was done the author was supposed to implementing these charts at the line, helping the operators with using the charts.

As the implementing part was not possible to do, the author gathered the data, and calculated the limits, as presented in section 5.2.2 SPC. The PBCs she made, in addition to the corresponding measures taken, are presented in the same section.

2.4 Data Verification

All the data and measures gathered from Nidar or Orkla ASA is assumed to be valid. That being said, there were some wrongly logged data regarding the overweight calculations. If the target value of the product is 50 grams, it is clear that the measure of 5000 grams is wrongly logged. Therefore, all the unnatural high, or low, data was removed during these analyses.

Regarding the literature review, when searching on Oria, there were some acceptance criteria used. First of all, peer reviewed articles were assumed to be valid. Further, books from NTNU's library were also assumed valid. In addition, the author tried to get a decent amount of newer literature. As seen from Table 2, most of the literature used is relatively new. 20% of the literature are less than two years old, and 60% of the literature in the table over is less than 10 years old. Most of the older literature is from books and is mostly used to gather the basic knowledge about a term. This is important to make sure the literature review and the thesis is up to date.

In addition to the literature found at Oria, the author also used literature from the supervisors and from curriculum from previous lectures. Also, literature from the previous project thesis was used. This literature is already verified by the author. All of these are assumed to be valid.

2.5 Method Evaluation

As mentioned, the SPC implementation did not go as planned. It is clear that this thesis would have much more depth, and Chapter 5: Analysis and Discussion would have a very appropriate discussion at the end, if this was done. Not only would it make this thesis stronger, but it would most probably had helped Nidar more too. On the other hand, it was not something the author had influence on and therefore it unfortunately had to be neglected from this thesis.

The timeline of the thesis is set up quite odd with little activity the first five weeks of the thesis writing, and a heavier workload from this point on. If it had been possible, it would be more convenient if the intensive weeks at the factory started in week 5 of 2019. Because of this, the workload at the end was increased significantly. The first weeks was used to read up on literature and such, which were useful, but these weeks were not very effective, as the terms and methods to read up on was a bit uncertain prior to the project execution.

Some of the data collection methods were somewhat hard to ensure the validity and reliability of. The data logged by the operators could be logged wrong or inconsistent as some of the operators may do the measures in different ways. Wrongly logged data lowers the degree of validity, whereas different measuring methods will make the data less reliable. Other than removing the clearly wrongly logged data from the data sets, there is not much to do to ensure that the logged data is correct and consistent. Therefore, the data had to be assumed right, even if that assumption may be somewhat vague.

The results, on the other hand, is more valid and reliable. The results of the analyses should be valid, and as they have been looked through several times of several different persons in the project team, there seems to be no mistakes regarding the analyses. This is given that the data collected is valid, which is discussable, as stated. The degree of reliability of the results is also discussable. The OEE analysis is based upon observations by the project team and could be different if they were done by other persons or other days. The same is the case for the waste analysis, as the waste is not the same for every shift. That being said, the waste was scaled up to the already measured yearly waste and should therefore be somewhat adequate. The waste analysis is possible to do in several different matters, but the way it is done in this project seems to be the most precise. All the possible waste areas on the lines has been measured. In addition, the approximately amount of the different raw materials from each waste was calculated, to give more precise knowledge of the economic degree of waste at each point on line. This is not shown in this thesis, as the raw material cost is sensitive data. Lastly the overweight analysis should be the same for everyone doing the analysis and is more reliable on the data logged by the operators.

The generality of this thesis is discussable. The project followed is of course a specific, and not that general project. Several of the findings are just relevant to the Conbar line at Nidar. That being said, making an OEE, overweight and waste analysis on a production line is general. It could therefore be stated that the methodology is general, but the suggested actions and result is somewhat specific to the line looked at.

Otherwise it seems like the methods chosen to use, and the use of them, seemed appropriate and adequate for this thesis, and project Opal, as they have been able to answer the RQs. The OEE analysis will be answering RQ1, overweight analysis will be answering RQ2 and waste analysis will be answering RQ3.

This will be further looked at in Chapter 5: Analysis and Discussion, but first a literature review that presents the most important terms and some relations will be presented.

Chapter 3: Literature Review

To be able to answer the RQs, some underlying literature review needs to be presented. The structure of the literature review, in addition to some relations among the terms are presented in Figure 2. First of all, the process mapping is presented, and as this is done by process flowcharts, some literature om this term is presented. Further the problems on the line needs to be analyzed, and the three main analyses; OEE, overweight and waste are therefore looked into. All of them are key terms to the RQs. Lastly several different stabilizing actions is presented, as these are suggested actions to help OEE, overweight and waste.

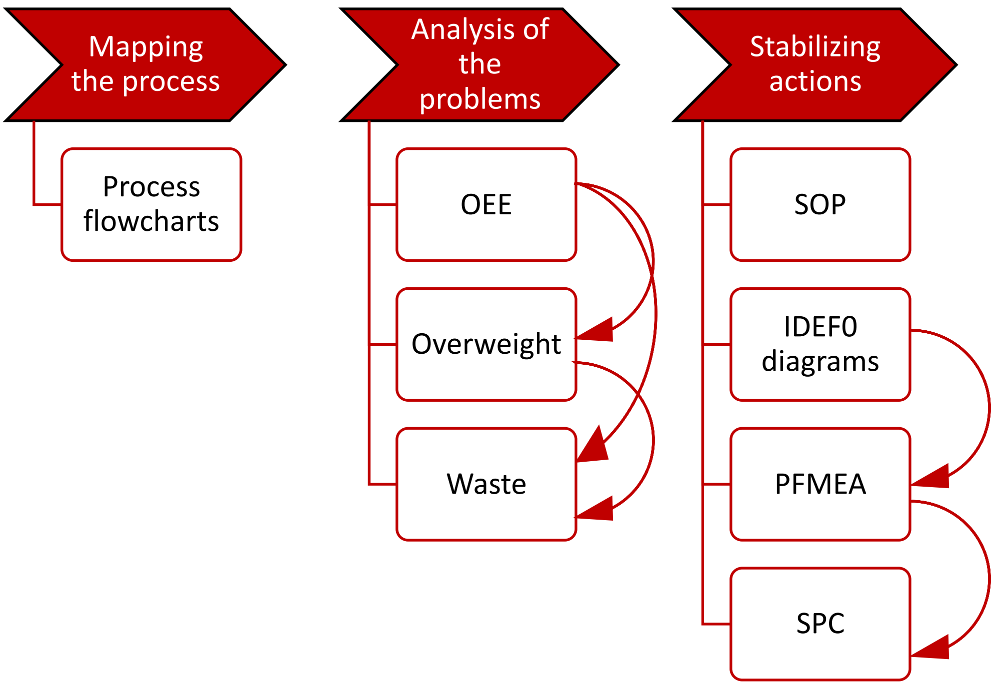

Figure 2: Structure of literature review

This chapter is first going into the concepts and terms illustrated in Figure 2. In addition, the relation between the different terms, as briefly presented in Figure 2, and will be discussed in the end of this chapter.

3.1 Presenting the Concepts and Terms

3.1.1 Process Flowcharts

Flowcharts exists in many different forms and may be made as detailed as preferred. As Ellis (2001) clearly describes: Flowcharts provide a visual representation of a process, identifying each step that's taken and each decision that's made. In a manufacturing process, the idea is to get a visual representation of the manufacturing line. Usually the different steps along the line is in boxes, and the connection between these are marked with arrows. Heat transfer, raw material movement and scrap may also be traced.

When establishing a manufacturing process flowchart, the boundaries of the process needs to be clear and consistent. It may also be useful to divide the process into macro parts, and then consult with the operators on the line, in addition to collecting paperwork belonging to this line, to get the micro parts of the macro processes. (Argent, 2007) Having process flowcharts present makes the understanding of the whole production process easier to understand, which is useful.

3.1.2 Overall Equipment Effectiveness (OEE)

According to Hassani and Hashemzedeh (2015), Overall Equipment Effectiveness (OEE) is one of the most popular methods of evaluation of the performance in a manufacturing process to identify and eliminate the causes of production losses. It is usually used as a Key Performance Indicator (KPI)[1] in manufacturing sites.

OEE is, as the name states, a measure on the effectiveness of the equipment. It includes Availability (A), Performance Efficiency (PE) and Quality (Q) and is therefore possible to calculate by Formula 3.1.

$$OEE = A \times PE \times Q \tag{3.1}$$

A, PE and Q may be calculated by Formula 3.2, Formula 3.3 and Formula 3.4 respectively

$$A = \frac{Actual\ running\ time}{Planned\ running\ time} \tag{3.2}$$

$$PE = 1 - \frac{Time\ for\ interruptions}{Actual\ running\ time} \tag{3.3}$$

$$Q = 1 - \frac{Defective\ output}{Actual\ production\ volume} \tag{3.4}$$

[1] KPI = Key Performance Indicator, the most important set of Performance Indicators. Performance Indicators are specific measurement of performance, in or example a manufacturing site (Andersen and Fagerhaug, 2001)

Formula 3.1 shows that if A, PE or Q are increased, the OEE is increased. Formula 3.2, Formula 3.3 and Formula 3.4 then shows that an increase in actual running time and actual production volume, as well as reducing the time for interruptions and defective outputs will give an increase in OEE, which clearly is wanted. In other words, OEE is a measure that says something about a factory's productivity. (Nicholas, 2011)

An increase in OEE is not only helping with the productivity, but also helping with reducing the variation in the production schedules and the products produced. This again leads to less overtime for the operators and less rework, or waste of bad quality products. (Nicholas, 2011)

3.1.3 Overweight of Products

Every prepackaged consumer goods product must have a volume or weight printed on its packaging that shows the customer the weight or volume of the product, according to The Council of the European Communities (1976). To have this exact weight or volume in every product produced is impossible, as every production process has some degree of variation. The excess unnecessarily weight that a company give away to customers for free is called the overweight of the products. Having too much overweight may cost a lot in the long run but having too little, or more correctly none, is not allowed. The goal for the production companies is to minimize the overweight but keeping it high enough to pass the weight-tests in the directive (Faulkner, 1993). That being said, having too little, even if following the directives, may lead to bad publicity as Solset (2018) has shown recently.

The actual deeper meaning of the directive will not be presented in this report as it is not a large part of this thesis but may be read about in Rødvei (2018). On the other hand, a brief introduction of the requirements will be presented. To be clear; the underlined text in the following three requirements is exactly how the requirements are formulated in the directive, and therefore the references to sections, tables and annexes is not the same as the ones in this thesis. According to the directive (The Council of the European Communities, 1976) the objectives of the weight control is that the prepackaged goods need to satisfy all the following three requirements for every batch:

1. <u>"The actual contents shall not be less, on average, than the nominal quantity"</u>
   This means that the average weight of a certain batch of a product cannot be lower than the nominal quantity of the product.

2. “The proportion of prepackages having a negative error greater than the tolerable negative error laid down in Section 2.4 shall be sufficiently small for batches of prepackages to satisfy the requirements of the tests specified in Annex II”
   There is a tolerable negative error, often called T.1 (Tolerance limit 1) that depends on the nominal weight of the product and is given in Section 2.4 in the directive. Products under T.1 are called defective products. The number of defective products needs to be small enough to satisfy a specific test in Annex II of the directive. The directive does not state what number of defective products is acceptable, just that the test needs to be satisfied. The test is a double sampling plan test, and it depends just on the batch size, and gives some room for imprecise measurements. Section 2.4 from the directive is presented in Appendix 1: Excerpt from the Weight Directive.

3. “No prepackage having a negative error greater than twice the tolerable negative error given in the table in Section 2.4 may bear the EEC sign (℮)”
   The last requirement states that none of the products in the batch may be under a limit, T.2 (Tolerance limit 2), which is two times T.1. The EEC sign is a sign that may be used when these requirements are fulfilled. In some EU countries these requirements are already put into that country’s law and is therefore not mandatory to use by the companies in such cases. For the countries that these requirements are not granted, the EEC sign may be used as an indication of good quality regarding waste.

This means that every company producing pre-packaged consumer goods needs to sample measure the weight of their products, usually every hour. Doing this gives good amounts of data that may be used to calculate the actual overweight of the products. The value of the overweight can be calculated to give an indication of the scale of the problem to make the prioritizing easier to the company.

It is useful to look at the degree of variation in the measured data. A product with a lot of variation is much more unsafe regarding the directive and its requirements. This means that with products that has high variation it is harder to minimize the overweight. Having as little variation as possible is the first step in reducing the overweight. After the variation is made smaller, the average of the weight may be pushed down as low as the company dare to minimize overweight.

3.1.4 Waste in Production

Waste is a well know problem in production companies (Peitz and Shin, 2013). Most companies are striving to get as little waste as possible, some focusing more on it than others. If the wasted product, time or money is of small economic significance to the company they may actually decide not to do anything about the waste issue, as it not will be economically beneficial for them to spend the time. On the other hand, many of the types of product waste is not beneficial for the environment. The food distribution industry stands for a significant part of the total wasted food in the world, and the companies should therefore be even more motivated to reduce their product waste, than just the economic benefit it gives (Pendrous, 2017).

Having a lot of waste is anyways not suiting the Lean ideology and should therefore be reduced. This is exactly that lean production is about; reducing the waste to be able to increase quality and efficiency and to minimize the costs (Markovitz, 2012). Lean production was introduced by the Toyota Motor Company right after World War II (Womack and Jones, 2003). The Lean ideology includes a lot of different tools to reduce the waste.

According to Womack and Jones (2003) waste is defined as any activity that consumes resources but creates no value. Waste exists in many different forms and is parted into categories differently by different persons. Canon's Nine Wastes and Lean to green programs are mentioned by Nicholas (2011). Taiichi Ohno (1912 – 1990), one of the Lean production fathers, identified a set of seven different types of wastes, which seems to be the most used sets of waste types. The types of waste he defined are: overproduction, waiting, transport, inappropriate processing, unnecessary inventory, unnecessary motion and defects (Hines and Rich, 1997). Several different types of waste have been presented in the later years, in addition to these. (Womack and Jones, 2003).

In this thesis, waste is defined as the weight difference between the input material and the product on customer invoice, or in other words, the activities that consumes physical product, but does not end up in being a product sold to customers. This kind of waste may be several different types, such as: Dosing errors, product on floor, discarded products, startup or shutdown losses and overweight, and is mainly related to the inappropriate processing and defects as the waste types Ohno defined.

3.1.5 Standard Operating Procedures (SOP)

In every manufacturing process there should exist operating routines in parts of the processes. Having these standardized, optimized and written down is useful to gain an effective and Lean production. The Standard Operating Procedures (SOP) tells the operators precisely what to do at what time, and possibly how it is done. Having these SOPs present for the operators may increase the effectivity at startup and shutdown of productions, as an example. This again may lead to longer production runs or a reduction in manpower, which again is economically beneficial to the factory, as it increases the OEE. (Hunter, 2004)

SOPs may also be used to ensure good quality products. Having the routines standardized gives less room for variation and therefore a more stable production. This means that all of the products produced are more alike each other, which increases the chance of detecting a bad quality product. Having less bad quality products sold to the customer is essential to the factory, as bad quality products may lead to compensation issues or bad reputation. (Hunter, 2004)

3.1.6 Integrated Definition (IDEF0) Diagrams

Integrated Definition (IDEF0) diagrams needs to be explained briefly before going into PFMEA, as these diagrams may be used as a tool to settle the different failure modes in a PFMEA. IDEF0 diagrams are used to analyze a process, present or in the future, and the corresponding Input, Output, Controls and Conditions, as shown in Figure 3. (Marzouk and Elmansy, 2018)

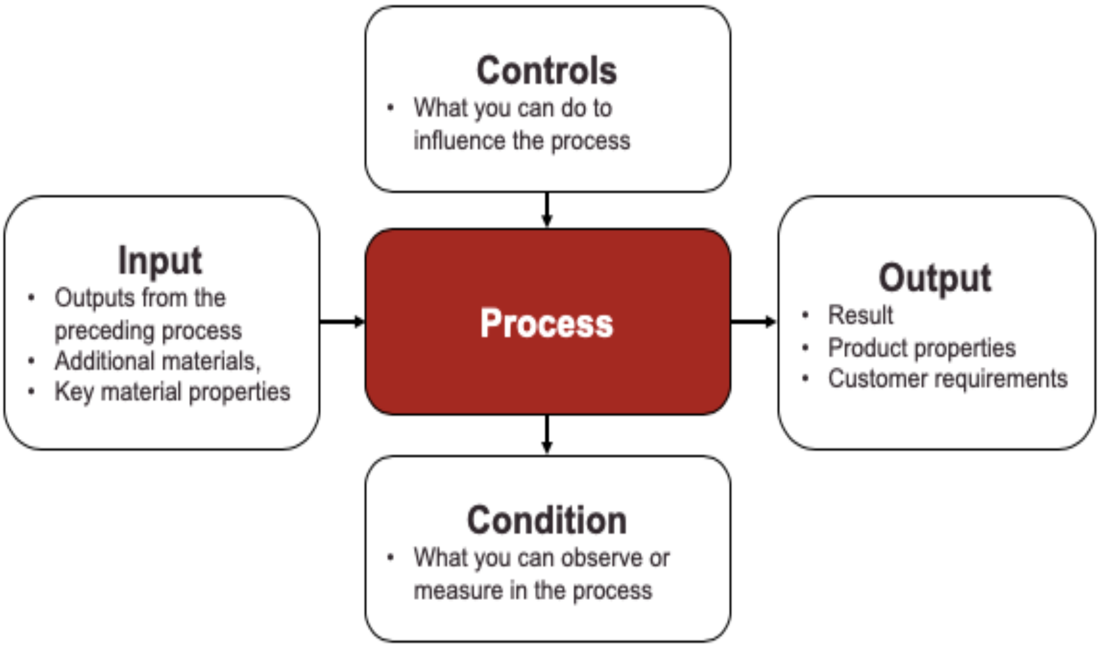

Figure 3: IDEF0 model

IDEF0 diagrams may be used in series, as one process' output, could be the next process' input. This is useful when analyzing and presenting a whole line, to see the relationship of the different processes. (Marzouk and Elmansy, 2018)

3.1.7 Process Failure Mode and Effect Analysis (PFMEA)

Process Failure Mode and Effect Analysis (PFMEA) is a method used to define, prioritize and reduce potential process failures. This is done to increase the quality of the process and to maximize the satisfaction of the customers. The Occurrence (O), Severity (S) and Detectability (D) of the failure modes are multiplied to give the Risk Priority Number (RPN) of the failure mode. This is done to make it easier to prioritize the failure mode. PFMEA is used to define and optimize quality, reliability, maintainability, cost and productivity of the process. This means that all of these factors should be optimized as a total, not looking at them separately. As an example, the increase of quality should not have a too big negative impact at the cost. PFMEA charts are usually dynamic documents that changes as the process changes. (Stamatis, 1995)

Oakland (2014) describes the seven steps in a FMEA as follows:

1. Identify the product or system components, or process function.
2. List all possible failure modes of each component.

3. Set down the effects that each mode of failure would have on the function of the product or system.
4. List all the possible causes of each failure mode.
5. Assess numerically the failure modes on a scale from 1 to 10. Experience and reliability data should be used, together with judgement, to determine the values, on a scale 1–10, for:
    - O: the occurrence or probability of each failure mode occurring (1 = low, 10 = high).
    - S: the severity or criticality of the failure (1 = low, 10 = high).
    - D: the difficulty of detecting the failure before the product or service is used by the consumer 1 = easy, 10 = very difficult).
6. Calculate the product of the ratings, RPN = O x S x D for each failure mode. This indicates the relative priority of each mode in the failure prevention activities.
7. Indicate briefly the corrective action required and, if possible, which person, department, function or group is responsible and the expected completion date.

Step 1 and 2 are typically done by using IDEF0 diagrams. When these seven steps are done the failure modes should be sorted after the RPNs to give a prioritized list. If the failure mode has high RPN it is critical. Low RPN indicates less criticality. The result is a prioritized list of different failure modes, and corresponding actions to prevent these. This makes which failure modes to be aware of clearer, and what to look for. It also gives a set of prioritized actions and settles the responsibility.

When implementing PFMEA there are several stages that should be followed so that the implementation is easily done. Collecting all the important information and determinate all the potential risks correctly are important in the beginning stage, to make the PFMEA efficient. To be able to do this, involving of all parts on the line are important. This includes the operators, product developer and line, quality and maintenance managers. Involving all parts of the line early on also makes the parts understand the need of the PFMEA, which will make them more open minded to it. The discussions that occur between the different persons is very useful to get all the potential risks and failure modes on the table. (Ershadi and Ershadi, 2018)

As with most other tools like this, follow up is important. Is the responsible person looking at the actions delegated to them? Are the actions done in time? Is the target completion dates realistic? What happens when the actions are done? Did it help? Someone should have the responsibility to do this follow-up. Also, the PFMEA is a dynamic tool that should be revised. When the actions are done, the PFMEA should be revised with new potential failures, new RPNs and a new prioritized list. (Saux, 2006)

3.1.8 Statistical Process Control (SPC)

Statistical Process Control (SPC) was first introduced by Walter A. Shewhart in the early 1920s. SPC is a statistical method for controlling a process to make it more efficient and of better quality. SPC are a great tool to try to predict the future of a process and is therefore very suitable when you want to say something about leading indicators. This ability is highly needed in a production process, especially in the quality department, which makes SPC an useful tool in a production process. One of the SPC techniques used in production is called Process Behavior Charts (PBCs). These charts are supposed to make it easier to distinguish between common and special causes of variation, and to determine if the process is under control or not. (Darestani and Nasiri, 2016)

The PBCs exists in many different forms, and measures different thing, such as X bar – R charts, X bar – S charts, XmR charts, np charts and so on. Some that are commonly used when looking at weight of products in a manufacturing is X bar – R charts and XmR charts. These plot X bar (the average) and R (range) of each subgroup, and if the "subgroup" just consists of one measure, the moving range (mR) is measured instead. If an X bar chart shows deviations it is a sign of change in position of the measures. But if the R or mR chart has deviations it is a sign of variation in the process. This means that you can distinguish between these two factors when using these charts. When making a PBC an upper control limit (UCL), lower control limit (LCL) and Central Line (CL) needs to be calculated based on the previous measures. (Wheeler and Chambers, 2010)

According to Wheeler and Chambers (2010), the formulas for LCL, CL and UCL for X bar – R and XmR charts are as presented in Table 4.

Table 4: Formulas for LCL, CL and UCL in PBCs

Chart type	LCL	CL	UCL
X bar	$\bar{\bar{X}} + A_2\bar{R}$	$\bar{\bar{X}}$	$\bar{\bar{X}} - A_2\bar{R}$
R	$D_4\bar{R}$	$\bar{R}$	$D_3\bar{R}*$
X	$\bar{X} + 2{,}660\overline{mR}$	$\bar{X}$	$\bar{X} - 2{,}660\overline{mR}$
mR	$3{,}268\overline{mR}$	$\overline{mR}$	Does not exist

*= does not exist for subgroup sizes smaller than 7

A2, D3 and D4 are constants that depend on the subgroup size n. These values can be found in Appendix 2:Scaling Factors for PBCs.

PBCs are continuously used in the production. Every time new measures are taken, they are plotted into the charts. The position of the measures is then used to try to distinguish between unusual and normal variation in the process, and therefore when to adjust the process, and when to not adjust. There are several different detection rules that may be used to do this. The one that Wheeler and Chambers (2010) suggest are the Western Electric Zone Test. When using this test the two sigma and one sigma limits needs to be shown in the charts as well as UCL, LCL and CL. All of these lines then part the charts into six different zones. The detection rules presented by Wheeler and Chambers (2010) are as follows:

1. Detection rule one: Look for a dominant Assignable Cause whenever a single point falls outside the three sigma limits.

2. Detection rule two: Whenever two out of three successive values are both on the same side of the central line and are both more than two sigma units away from the central line, you should look for the cause of intermediate sized shifts in the underlying process. This detection rule cannot be used in a moving range chart.

3. Detection rule three: Whenever four out of five successive values are on the same side of the central line and are also more than one sigma unit away from the central line,

you should look for the cause of a moderate shift in the underlying process. This detection rule cannot be used in a moving range chart.

4. Detection rule four: Whenever eight successive values all fall on the same side of the central line, you should look for the cause of a small but sustained shift in the underlying process. This detection rule cannot be used in a moving range chart.

As seen, just the first detection rule may be used in a mR chart. It is important not to combine too many detection rules. This would increase the sensitivity of the tests but would at the same time rapidly increase the chance of false alarms. Using just detection rule one a false alarm for every 370 subgroups will be present. Using all four detection rules give a false alarm for every 92 subgroups. These four detection rules combined gives a good balance between high sensitivity and low degree of false alarms. (Wheeler and Chambers, 2010).

When the charts have been used correctly for a while the variation in the process should decrease and new limits should be calculated. The new limits will then be even tighter and force the process to be adjusted more centered towards the wanted nominal value.

Implementation of SPC in production may be hard, as the operators need to know how to use SPC properly. If the operators do not know this, the use of SPC may be unnecessary. In addition, this will probably seem like extra work for the operators, so they need the right motivation to start using it. According to Evans and Mahani (2012) there are some barriers to a smooth implementation of SPC in a manufacturing process:

1. Lack of commitment and involvement of top management.
2. Lack of training and education in SPC tools.
3. Failure to interpret control charts and take proper action.
4. Lack of knowledge about product characteristics and process parameters.
5. Invalid and incapable measurement systems in the workplace.
6. Lack of understanding of customer requirements.

If these factors are kept in mind, and ensured to not be present, the use of SPC may be much more efficient.

Lim et al. (2014) has written a paper on SPC in the food industry. Here they state that the implementation of SPC in food industry mainly is motivated by the laws and regulations regarding the food industry, and not that much actually just to improve the internal process. The paper concludes with the fact that the use of SPC to control a process seems to become more and more usual, and as this paper is 5 years old, it is reasonable to think that this is more usual for the food industry these days. Lim et al. (2014) also states that the main reasons for the lack of SPC use is food industry may be the lack of statistical thinking, lack of practical SPC guidelines customized for the food industry, and the perception that SPC is too advanced to be applied. Therefore, this should also be worked at as implementing SPC.

3.2 Relations Among the Terms

As seen from Figure 2 in the introduction of this chapter there are some relations among the different terms presented. First of all, it is clear that the OEE is decreased if there is a lot of waste or overweight in a production. This is because of the increase of defective products, and the decrease in produced products. This means that reducing the waste and overweight of a production will also increase the OEE.

Further there is a clear relation between waste and overweight. As described, overweight is one form that waste may be present in production. As the way waste is defined in this thesis, overweight is one of the main waste-sources. The overweight is generated during the production but will first be defined as overweight when it is sold to customers, whereas the rest of the waste will be present during the production run.

Waste from production is defined as the waste from raw material picked up from the warehouse, until the finished product is packed, palletized and transported to the warehouse. Overweight is the weight that is excess when the product is sold to the customer, as shown in Figure 4.

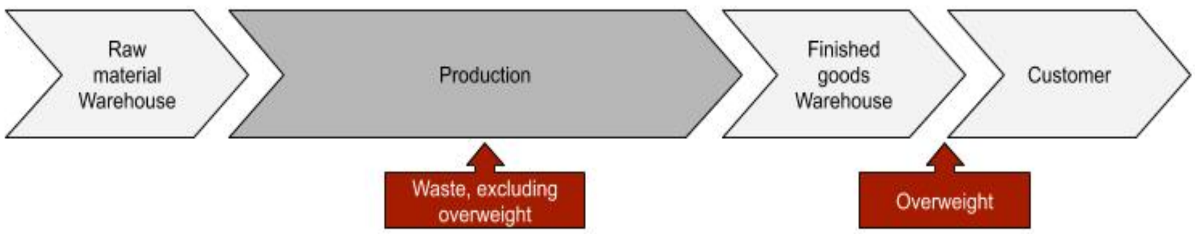

Figure 4: Illustration of where waste and overweight are present in the value chain

Overweight is assumed to be a big part of the waste in project Opal and is therefore calculated by its own in section 5.2 Overweight Analysis. The waste analysis will just briefly mention the results from the overweight analysis, as it is a part of the total waste.

Further there is a close relation between IDEF0 diagrams and PFMEA, as IDEF0 diagrams often is used as a tool to settle the different failure modes in the PFMEA. These two tools are therefore often used together. PFMEA and SPC also do have some relation. SPC gives information about the process' adaptability to changes, which is useful when suggesting a set of actions in the PFMEA. SPC may be used as an action in the PFMEA, to stabilize the process. In other words, SPC may both be used as a tool to learn more about the process, as well as improving the process, regarding the PFMEA. In addition to this, both PFMEA and SPC are tools that may be used to control and improve a process. Where PFMEA focuses on the failure modes and potential risks of a process, and SPC is looking more on how different values vary, regarding normal or special causes of variation. SPC may also show operators when to act in a production. (Stamatis, 1995) You could say that PFMEA is more an overall view at a process, that the managers will use to know the risks and to reduce these. SPC looks more on a specific problem at the line with data that has high degree of variation to be able to reduce the variation, and to act in the right moment. PFMEA may be a good tool to know where to use SPC.

All of these relations will be clearer in Chapter 5: Analysis and Discussion, but first the case study needs to be presented.

Chapter 4: Case Study

This chapter is going into the case description, both regarding the Conbar line and the project Opal. Then the hypothetical issues at the Conbar line prior to the project execution is presented, and lastly the planned analysis methods are explained. This chapter is not directly answering any of the RQs, but are presenting the hypothetical issues on the line, which are closely linked to the RQs. In addition, the planned tools and methods to answer the RQs are presented.

4.1 Case Description

4.1.1 The Conbar Line at Nidar

As already mentioned in section 1.1 Background and Motivation the Conbar line produces chocolates in bar form. In addition, they produce some bite-size products such as Troika bit and Gullbrød bit. As these bite-size products are internally transferred to other departments in the factory, and not directly sold to the customer, they are not taken any further into account in this project. Calculating overweight on these products would as an example be misleading as it is not actually product lost to the customer.

The line consists of four main parts, the cooking, top, middle and packaging position. The cooking position is responsible for cooking of caramel, binder and jelly, and therefore has no task on the actual line. The operators working at the cooking is supposed to provide the finished caramel, binder or jelly to the line. The top position is where the product is mixed and put onto line and is defined as all that happens on the line before the first cooling canal. The middle position is mainly between the two cooling canals, and is where the product is cut, separated and chocolate covered. The job at the middle is to pick out bad quality product to ensure that all of the products that comes to the packaging is of good quality. The packaging is, as the name states, responsible for the packaging at the end of the line. This includes packing the single products, cartooning and palletizing. On some products a separate operator is present, to do all the transportation on the line. The task of the transporter is to transport finished goods to the warehouse and to give the top and cooking position necessarily raw materials.

The chocolates produced in biggest volumes at the Conbar line are New Energy, Troika, Smash bar and Småsulten bars. They are respectively produced in about seven, six and three million pieces a year. As already mentioned, the New Energy and Småsulten bars are the only one considered in this thesis. In the authors project thesis, the Troika bar was considered. The reason for the change of product is the high amount of estimated waste on the other two products, and the value of the waste. In the project thesis Troika was looked at as at it was estimated to be one of the biggest problems regarding overweight. New Energy and Småsulten bars are both produced in high quantum, and the New Energy is assumed to have very high amounts of waste. The Småsulten bars also have high amount of waste, and is in addition made of nuts, which is an expensive raw material, so the waste is extra expensive. Småsulten bars are produced in two types, and to several different countries. The two types are the nuts and seeds bar and the nuts and berries. These are mainly the same and will be considered as the same bar for most of this thesis. The product delivered to different countries are the exact same product, just with different packaging, so these are considered the same in this thesis as well.

Using flowcharts to understand the two main products that will be looked at is useful to get an in depth understanding of how the process is. Including all the decisions done in the flowchart would be overwhelming as decisions regarding the different parameters are made continuously during the production. Therefore, just the different parts of the process are presented, including the flow of the product, raw material, heat and main scrap positions. Flowcharts of the production of these two products are presented in Figure 5 and Figure 6.

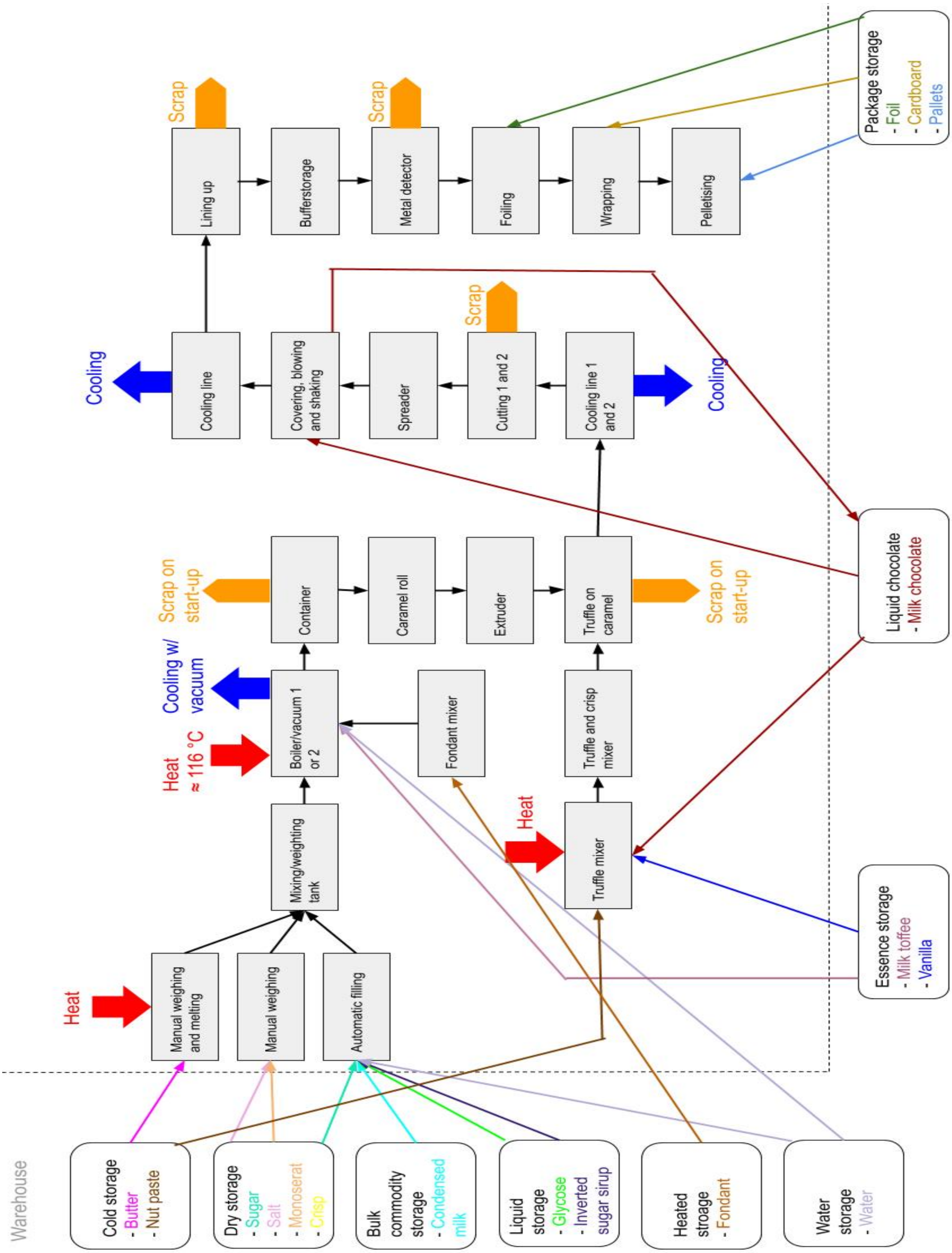

Figure 5: Flowchart of New Energy production

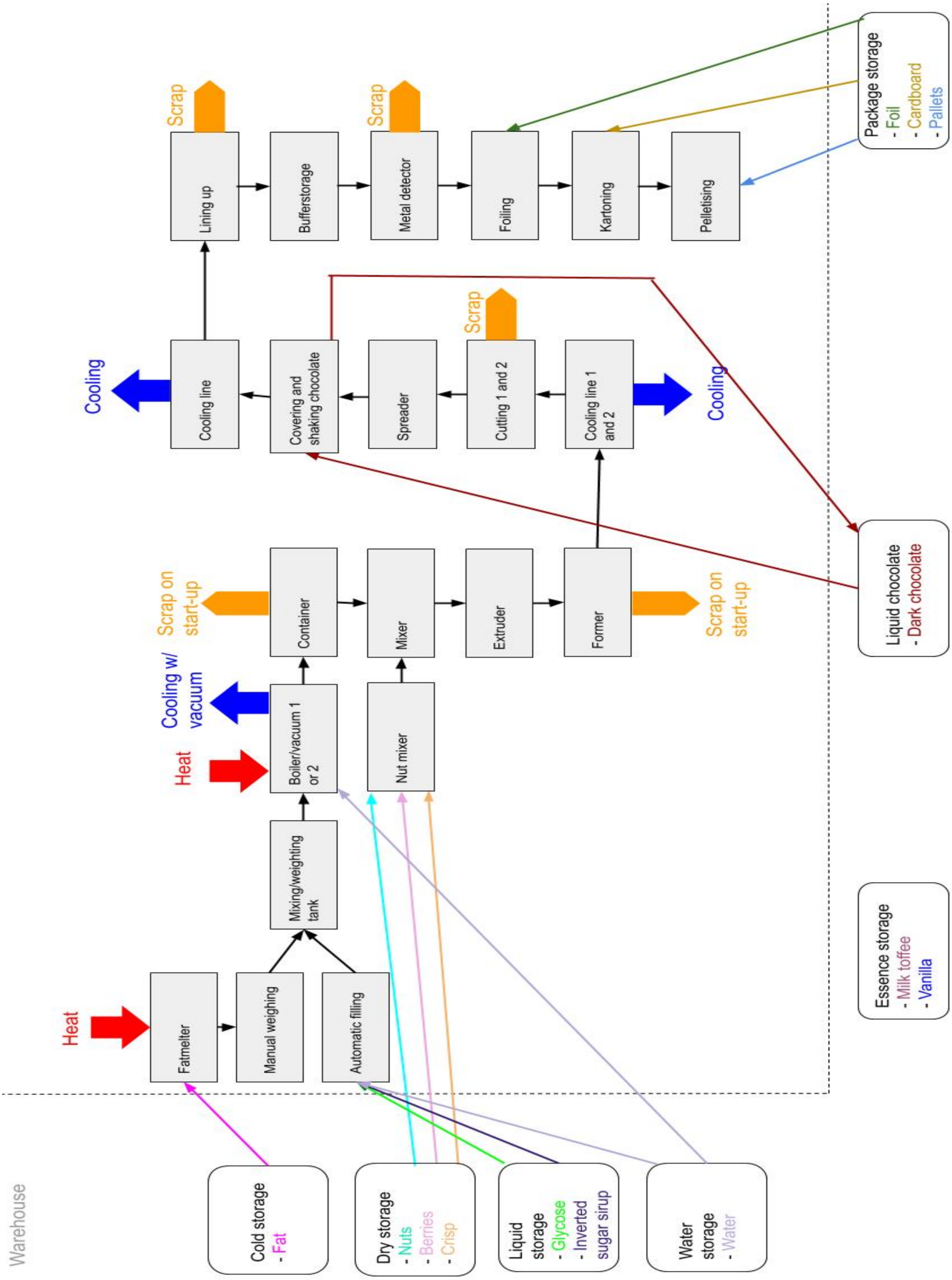

Figure 6: Flowchart of Småsulten production

As seen, the two flowcharts do have many of the same aspects. The flowcharts after cooling 1 is almost the same, this means that the biggest deviation from product to product is in the cooking and top position of the production. Another quite big deviation is that New Energy is made of two layers in addition to the chocolate cover, whereas the Småsulten bars just has one mixed layer in addition to the chocolate covering. From this it seems like the New Energy bar is more complex and probably has more variation.

4.1.2 Project Opal

As described in Chapter 1: Introduction this thesis is a further research from the project thesis the author wrote in the Fall of 2018. Rødvei (2018) stated that there was need for an improved weight control at the Conbar line at the Nidar factory, owned by Orkla. Orkla is in the Spring of 2019 conducting a project – project Opal, which is looking at this problem including others. The project is examining two of the lines at the Nidar factory, where the author will just follow the line called Conbar. This is one of the production lines she looked at in the project thesis. The project execution will be done by Orkla Group Operations (OGO) which is a department in Orkla ASA with internal consultants. This department was earlier called the Production Strategy & Development (PSD) department. The organization of the project is presented in Figure 7.

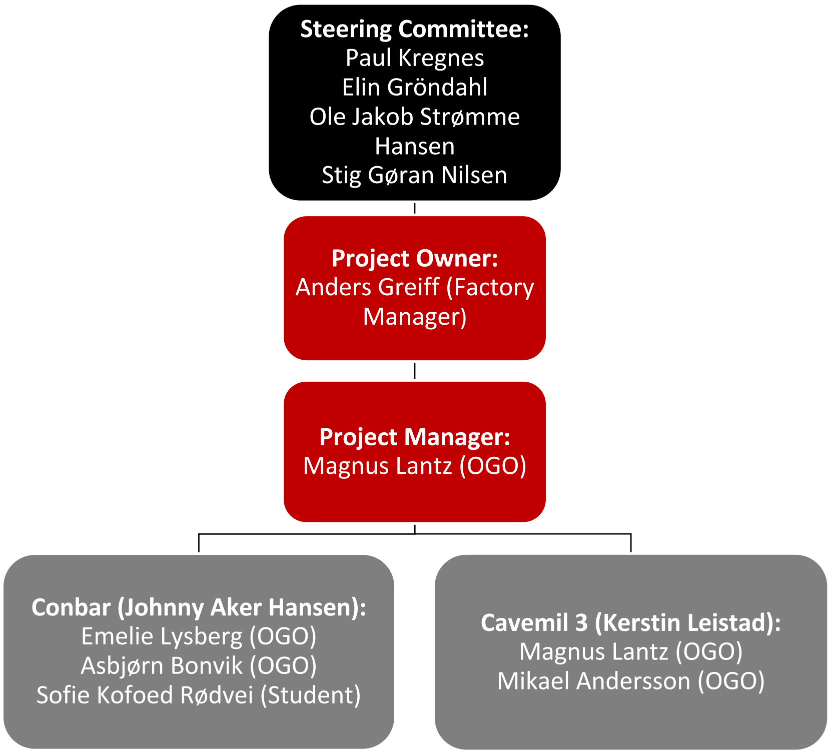

Figure 7: Organization of project Opal

As seen from the figure, there are two project teams, where the author will follow the Conbar line. The project owner is the factory manager Anders Greiff, and the project manager is Magnus Lantz from OGO. The Conbar line manager is Johnny Aker Hansen, with whom the project group will work closely with. In addition, there is a steering committee of the project.

The project will mainly take place at the Nidar factory for three intensive weeks in the Spring of 2019, with preparation work prior to that, and some follow up afterwards. The main focuses on the Conbar line during project Opal will be Waste, Overweight and OEE. OEE includes a brief look at the manpower, but the focus will be on shortened startup and shutdown times.

4.2 Todays Assumed Issues at the Conbar line

The line manager had prior to the project made a hypothesis list of the different issues on the line, that he hoped the project Opal would help with. The hypothesizes for project Opal are presented in Table 5. The data from the descriptions is from the line manager.

Table 5: Hypothesis list on project startup

No.	Hypothesis	Description
1	Reduce the startup times	**OEE:** The startup stands for 33% of all the stops on the line. This should be possible to reduce with products of better quality and with better startup routines
2	Reduce the shutdown times	**OEE:** The shutdown times stands for 10% of all stops on the line. This should be possible to reduce with better quality products and with better shutdown routines
3	Reduce the overweight	**Overweight:** The overweight of certain products is estimated to be relatively high according to the author's project thesis. This should be investigated on all the products on the line.
4	Reduce the waste on the line, especially on New Energy and nut bars production	**Waste:** The waste on the Conbar line stands for 43% of the total waste at the Nidar factory. New Energy and the Nut bars are some of the biggest waste-products on the Conbar line and should therefore be possible to reduce.

As seen the hypothesis number one and two is about OEE, three is about overweight and the fourth is about waste, which matches the RQs.

4.3 The Planned Analyses and Methods

The project will follow the project execution method called Identify, Control, Capable and Maintain (ICCM). This methodology includes a lot of effective tools, were some of them will be used in this thesis.

4.3.1 ICCM

There does not exist much public literature on ICCM, as it is a method used mostly internally in companies. In addition, it is hard to look up the topic in databases because of the general name. The author has therefore used information she has gained access to from Orkla ASA to describe this methodology.

The method was originated with Alcoa which is a metal production company. Alcoa and Elkem have cooperated in Norway (Alcoa, 2019), and as Elkem was owned by Orkla ASA until 2011, this may be the origin of why Orkla ASA is one of the companies using this methodology today (Orkla ASA, 2011). The four phases, Identify, Control, Capable and

Maintain, are used to stabilize a process. It is also a methodology that focuses on using leading indicators rather than lagging indicators.

First the different parts of the process need to be identified and prioritized. Then the process needs to be fully understood and brought into control. Further the variation needs to be as small as possible, and lastly the process needs to be stabilized and maintained. The methodology is summed up in Table 6. The tool examples marked in red are used in the project.

Table 6: Description of ICCM

Name	Focus	Tool examples
I **Identify** & Prioritize	Prioritize: - Identify most critical processes - Link these to business impact	- A3 - Process flow charts - Customer/supplier interfaces - SIPOC
C Understand & bring into **Control**	Process knowledge: - Document detailed process knowledge - Bring critical processes into statistical control	- IDEF0 diagrams - Process mapping - Statistical Process Control (SPC) - Out of Control Action Plan (OCAP)
C Make the process **Capable**	Reduce variation: - Understand and reduce sources of variation - Establish procedures and standards	- PFMEA - Design of Experiments (DOE) - Measurement System Analysis (MSA) - Incoming Material Control Plan - Process Control Plan (PPCP)
M **Maintain** and Improve	Stabilize: - Develop systems to maintain the process in control and capable - Improve the process	- Standard Operating Procedures (SOP) - Internal Process Audit - Reliability Centered Maintenance (RCM)

As seen from the figure, there is a focus on fully understanding the process (Identify and Control) prior to improving the process (Capable and Maintain). This is important to be able to prioritize the right processes and gain as much benefit from the analyzes as possible. This is also important to be able to choose the right leading indicators, as it is needed to have a lot of knowledge about the process prior to this.

It is important to mention that the tool examples are not strictly used at just one of the phases, but rather at several. For example, PFMEA may be used as a tool in all the three first phases, and even in the last. But as the main overall purpose from the method is to reduce the variation, the tool is linked to the Capable phase here. The same is the case for SPC as this is both a tool to gain process knowledge, but also to reduce the variation.

The process flow chart was made by the author prior to the intensive weeks at the factory. She observed the factory for two days to make these. The IDEF0 diagrams was made in the same workshop as the PFMEA, with all the operators at the line. This was during the project execution. SPC with PBCs has been made at several different measures to reduce variation of the process. Lastly, implementing SOP has been suggested by the project team to the factory to improve the quality of the products produced, after the project execution is done.

ICCM vs. Six Sigma

The ICCM method is similar to the more familiar Six Sigma methodology, but where Six Sigma focuses on DMAIC problem solving (Define, Measure, Analyze, Improve, Control), ICCM focuses on the four phases described; Identify, Control, Capable and Maintain. (Shankar, 2009). Both has the Control phase, but ICCM goes two steps further; making the process capable and maintaining it. This means that the ICCM method includes the after-work of the actual project execution, which Six Sigma does not include. Six Sigma focuses on the problem and solving it, and ICCM is more focused towards follow-up and maintaining.

They both use many of the same tools, but the work process is quite different. Six Sigma is more focused towards expert-driven analyses and project, ICCM focuses more on including the operators to keep the process capable and in control, even after the project is finished. As mentioned above, ICCM goes two steps further, but the actual problem solving, and the corresponding tools are on the other hand very similar between the two. It is therefore reasonable to assume that the ICCM methodology is a methodology developed from factories using Six Sigma and improving it in the way suitable or their project.

As one of the important aspects of project Opal execution is operator involvement, ICCM is a more suiting methodology to use than Six Sigma in this case. In addition, it is important to the project team that the actions are followed up and maintained, which is of bigger focus in the ICCM methodology.

4.3.2 Other Planned Analyses

Some of the tools used in the project are described over. In addition, there was three planned main analyses; OEE, Overweight and Waste, as mentioned earlier. The OEE analysis will be used at the startup and shutdown routines at the factory and look for actions to make these more efficient and effective. The manpower will briefly be looked at. The recommended actions will be presented, and the corresponding money saved yearly will be calculated. Further the overweight analysis will look at all the overweight at the line, using logged data from the line. Some actions to improve the overweight will be presented. Lastly the waste analysis will be done and will look at where the most waste from the line is located. There will be presented different actions to reduce the waste, and the amounts of product that is possible to save from the actions will be presented.

All of the analyses done will be presented and discussed in the coming chapter.

Chapter 5: Analysis and Discussion

This section goes into depth with the actual analyses done on the Conbar line. First the observations and analyses that were done to map and identify the issues are presented. Then the suggested actions to improve these issues are presented and explained. In the end of this section some aspects that are special to this project are discussed. This section is the main part of answering the RQs. RQ1, RQ2 and RQ3 are analyzed, answered and discussed respectively in section 5.1 OEE Analysis, 5.2 Overweight Analysis and 5.3 Waste Analysis. Some parts of the RQs are even answered some in 5.4 Stabilizing the Production.

5.1 OEE Analysis

As shown in Table 5: Hypothesis list on project startup, one of the issues at the Conbar line today is that startup and shutdown of the line is inefficient regarding stops on the line. In addition, the time used to prepare for production at startup and clean the line at shutdown is assumed to be unnecessarily high. There is in other words an unnecessary high time for interruption and defective output, but a lower running time, which leads to lower OEE.

The first step to increase the OEE, by increasing A, PE and Q, was to observe the startup and shutdown routines. This was done to investigate where these issues come from, the potentials and how to make the startup and shutdown more efficient and effective.

In this subchapter RQ1a will be answered, and RQ1b will be calculated, meaning the whole RQ1 will be presented in this section.

5.1.1 Observations

The observations were done for both New Energy and the Småsulten nuts and seeds bar. It is assumed that the observations for the Småsulten nuts and seeds bar are adequate to use for Småsulten nuts and berries too as the process is basically the same, just with some deviations in the raw materials. Startup and shutdown observations for Småsulten was 6th of March. Startup observation for New Energy was done both on the 20th of February and 12th of March. Shutdown of New Energy was looked at 13th of March. Both startups began at 5 am and shutdown of Småsulten began about 10 pm and New Energy about 9 pm. The overall observations are presented in Table 7.

Table 7: Observations and reflections from startup and shutdown of the production

	New Energy	Småsulten nuts and seeds
Startup	• 7 operators • The caramel cooking is the bottleneck • Unnecessary error message is present at the display in the cooking position, as it is just valid for other products. This makes the actual error messages harder to detect. • The startup lists were not followed in the right order. • Not an optimal cooperation between the operators, useful to change the startup lists to each person instead of each position. • Problems with the automatic dosing especially the inverted sugar syrup • Problems with both tempering of chocolate and the line	• 8 operators • The binder cooking is the bottleneck • Unnecessary error message is present at the display, as it is just valid for other products. This makes the actual error messages harder to detect. • The startup lists were not followed in the right order. • Not an optimal cooperation between the operators, useful to change the startup lists to each person instead of each position. • The dosing of nuts/seeds/berries is hard to control – may not be dosed right and faults are hard to detect for the operators. • Manual dosing of the melted fat was time consuming and not very precise
Shutdown	• 7 operators • The shutdown at the cooking was the bottleneck. • Not an optimal cooperation between the operators, useful to change the shutdown lists to each person instead of each position. • The packing had most time left after shutdown. • The shutdown lists were not followed in the right order. • The operators in cooking does sometimes need to wait on each other to finish tasks and cleaning to be done. Using more correct and better shutdown lists could decrease this unnecessarily time used on waiting.	• 9 operators • The shutdown at the middle of the production was the bottleneck. • There is one operator extra throughout the evening shift placed at the middle only to be able to do the shutdown in time. There is no need for an extra person the rest of the shift. • Not an optimal cooperation between the operators, useful to change the shutdown lists to each person instead of each position. • When finished with the shutdown tasks most of the operators took a break instead of helping the other operators that was not finished with their tasks. • The packing had most time left after shutdown. • The shutdown lists were not followed in the right order.

Startup

The startups for both products have many of the same problems. The caramel and binder cooking are the bottlenecks to get the products on the line in time. This is depending a lot on the unstable process of the cooking, especially for New Energy caramel cooking. If the caramel cooking process were more stable, the yearly startup times could probably be significant lower. The cooperation between the different positions does not seem optimal. In addition, the startup lists are not for each person but for each position on the line. This makes it hard for multiple persons at the same position to cooperate in an effective way. Another important aspect is the problems that are outside the influence of the operators, for example mechanical problems with the line or the tempering machine. These problems are mostly based on bad maintenance or old machines and is not something that the operators are able to reduce significantly on their own. On the other hand, these problems seem to be detected late, and results in unnecessarily high downtimes.

From the observations it was clear that the hypothesis about unnecessarily high startup times, from section 4.2 Todays Assumed Issues at the Conbar line, was confirmed.

Shutdown

The shutdown routines have many of the similar problems for the two products, but the bottleneck is not at the same place. The bottleneck for New Energy production is the cooking position, but for the Småsulten bars the bottleneck is the middle position. This difference is due to the different properties of the two products. For example, the Småsulten bar leaves a sticky layer on the line which take some extra time cleaning. This results in extra time needed at the middle position and have been solved by putting an extra operator at this position during the whole evening shift.

It was observed that the cooperation between the different positions, and the shutdown lists for the positions were not optimal, as with the startup routines. Illustrations of how the operators are placed along the line and the time they use for shutdown on the observation days is shown in Figure 8 and Figure 9. The figures are made by the author as a way to visualize the time used regarding shutdown routines. The gray area is where the production is still running. The white, blank squares is where the operators still are at work but does not have anything to do. One colored horizontal line represents one operator. The excess time is the total excess time for all the operators on the same position on line.

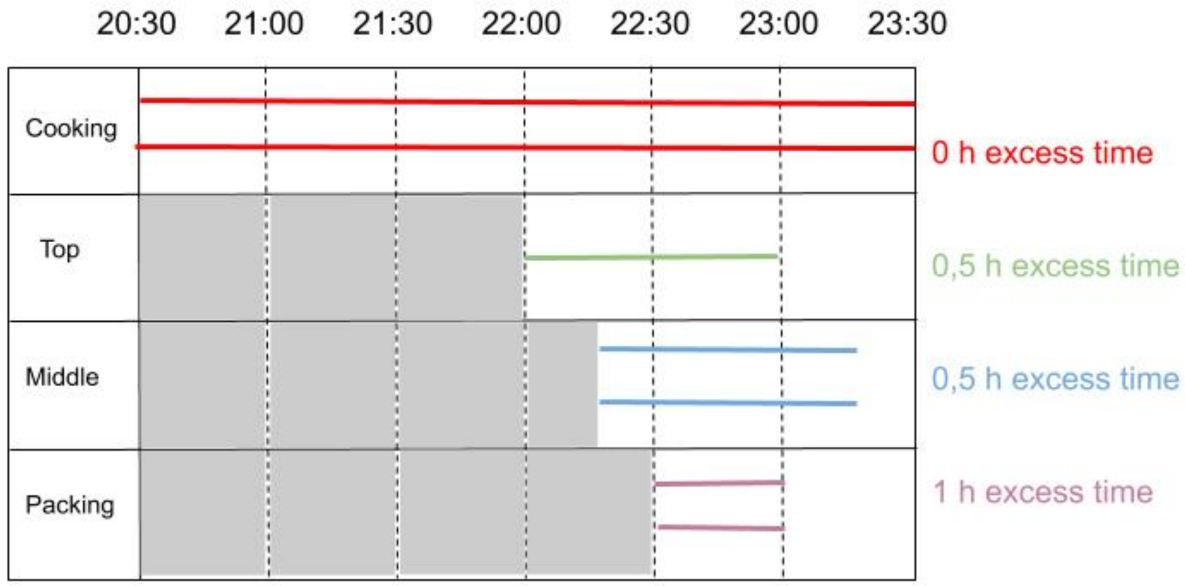

Figure 8: Visualization of the shutdown routine for New Energy production

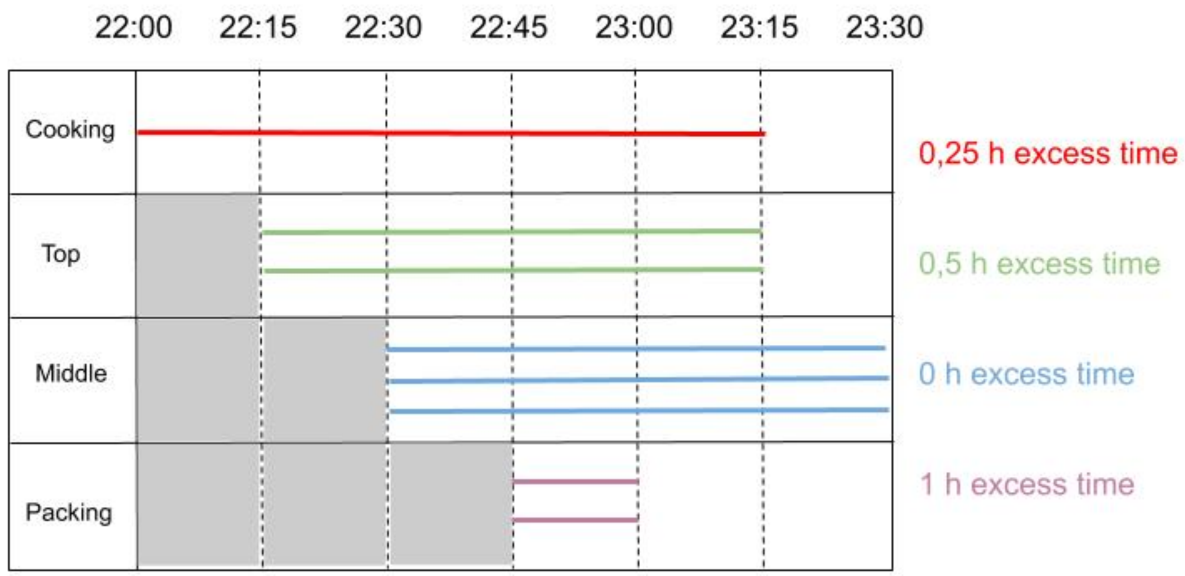

Figure 9: Visualization of the shutdown routine for Småsulten production

It is clear that there is some unnecessary excess time at the end of the shutdown for both productions, as stated in the hypothesis list in section 4.2 Todays Assumed Issues at the Conbar line. The New Energy production has a total of 120 minutes excess time and Småsulten production has a total of 105 minutes excess time. This fact combined with the observations described in Table 7 shows that there is potential of reducing the shutdown time for both products. Also seen from the figures over, the shutdown starts one and a half hour earlier for New Energy than for the Småsulten bars.

5.1.2 Improvements for Startup

The faults that are based on lack of maintainability or old machines is not directly something that the operators can do anything about. The focus on line, regarding these problems, should be that the operators are well aware of what to do when these faults happen. In addition, it is important to detect these faults early so they can be fixed as soon as possible to reduce down time on the line.

Another aspect that is important to be able to reduce the startup times, is to have more optimal and clear startup routines regarding both the startup lists and cooperation between operators. The line already has SOPs regarding startup and shutdown, but these may be much more precise to increase the efficiency. The startup and shutdown times of each task should be addressed more precise. The observations from project Opal should then be used to make more efficient startup and shutdown lists that belong to each operator at the line. The SOPs could be optimized in a way that the operators do not need to wait for each other.

The last aspect is to have less variation in parameters in the cooking and top position to make the product more stable. This will make the products less variable, which will make the operators have more control of the product. This should lead to less waste of product. As startup time is measured in the packing, this means that the product will be at this starting position earlier and will therefore mean saved time on startup. Having less wasted product and faster startup time will give an increase of actual production time, and a decrease in defective output. This will increase A, PE and Q, which again will increase the OEE.

Through discussions between the project team, the line manager, the quality engineer at the line and the maintenance engineer at the line it is assumed that the startup times may be reduced to about half of today's time if the suggestions over are followed.

New Energy

To calculate the possible earnings of this increase in production, only the salary of the workhours of this production are calculated. This is not the only earnings that a shorter startup time will give but calculating the earnings of the products produced in the saved time can be imprecise as there may not be a demand for this extra production. To calculate the earned salary in Full-Time Equivalent (FTE), the yearly hours of one FTE and the total yearly startup time needs to be known, and this is given by Nidar. The values are respectively 1721 hours/FTE and 93,5 hours. In addition, the number of operators on the shift and the estimated percentage of improvement needs to be known. The numbers of operators are found in Table 7 and the estimated percentage of improvement is as already stated 50%. The following formula is used:

$$Yearly\ savings\ startup = \frac{Total\ yearly\ startup\ time \times (1 - Estimated\ percentge\ of\ improvement)}{Hours\ in\ one\ FTE} \times Number\ of\ operators\ on\ shift \quad (5.1)$$

Using Formula 5.1 and the corresponding data above over this gives:

$$Yearly\ savings\ startup_{New\ Energy} = \frac{93{,}5\ hours \times (1-0{,}5)}{1721\ hours/FTE} \times 7 = \mathbf{0{,}190\ FTE}$$

This means that it should be possible to reduce the startup times so that it saves Nidar almost 0,2 FTE yearly, for just this single product. This is of course given that it is possible to reduce the startup times with 50%, which is a rough estimate. On the other hand, if the startup times is reduced, the operators could in the long run come later on work, and therefore start their working hours later. These early hours are more expensive for Nidar than the average salary cost. The estimate is rough, but an indication that it is recommended to focus on reduced startup times for Nidar, as many of the suggested improvements could be used on other products as well.

Småsulten bars

To calculate the yearly savings for Småsulten bars the same formula as for New Energy is used. The only changes in the data is that the total yearly startup time is 106,8 hours and that there are 8 operators on the shift. Using Formula 5.1 and this data gives

$$Yearly\ savings\ startup_{Småsulten} = \frac{106{,}8\ hours \times (1-0{,}5)}{1721\ hours/FTE} \times 8 = \mathbf{0{,}248\ FTE}$$

The same discussion as for the New Energy bar is valid and shows that this is a rough estimate. It shows that it is clearly of value to focus on reducing the startup times for the Småsulten bars. Mainly because of the increased number of operators on the shift, there is more potential on the Småsulten bars startup than or the New Energy one.

5.1.3 Improvement for Shutdown

It is not possible to reduce the manpower on the evening New Energy production as they need to be 7 operators during the shift. This is on the other hand possible for the Småsulten production as described in Table 7. If the shutdown is more effective, the whole shift may be reduced with one operator. Therefore, there is one suggestion on how to reduce the shutdown time at New Energy production will be presented, but two suggestions for the Småsulten production; one with reduced manpower, and one with reduced shutdown time.

New Energy

From the observations the project team concluded that there should be room to reduce the shutdown time in the cooking position at New Energy production with a total of 60 minutes. This could be done if the shutdown lists were more precise and separated to persons not positions to increase cooperation. This will decrease the time the operators need to wait on each other or washing programs to be done. It should also be possible to shorten the actual cleaning of the pipes and containers. If this is done, combined with a better cooperation between the operators, it would be possible to increase the production time with 30 minutes, as shown in Figure 10.

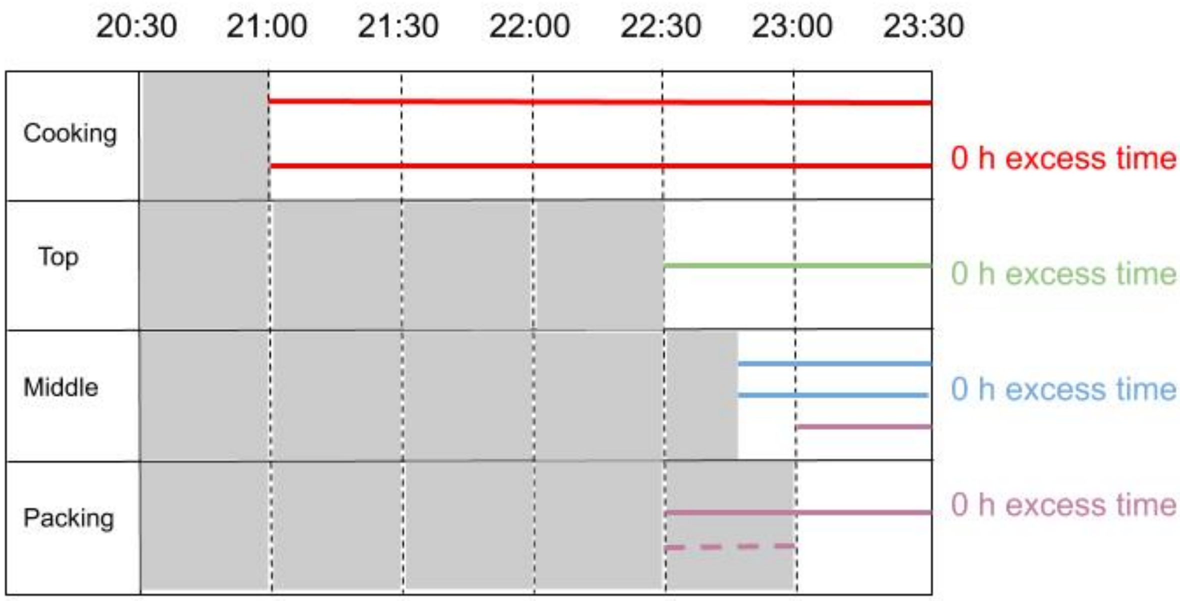

Figure 10: Visualization of improved shutdown routine for New Energy production

The bottleneck when increasing the production with 30 minutes, is now the middle position. Therefore, it is suggested that one person from packaging helps the middle with the shutdown routine. This makes the shutdown time at the packaging tighter. Further it is assumed that one of the packaging operators is able to start the shutdown during the last 30 minutes of the production. Many of the tasks for the packaging operators are actually transportation tasks as there are no certain transport position at this shift. Several of the transportation tasks are possible to begin with prior to production stop, and it should be possible for one person to control the packaging position for a while. The dotted purple line indicates a packing operator that is moved to the production line during production, whereas the whole line in the grey area indicates the operator that has already started the shutdown routine while the production is running. This setup gives a total of 0 minutes excess time, which indicates an effective shutdown routine with a tight schedule and less room for mistakes or inefficient work.

To calculate the savings of reduced shutdown time, the saved hours each shift, number of shifts yearly, and number of operators on shift needs to be known in addition to the already known hours in one FTE. These numbers are respectively 0,5 hours/shift, 39 shifts and 7 operators. The total savings is calculated with the following formula:

$$Yearly\ savings\ time = \frac{Saved\ hours\ each\ shift \times Number\ of\ shifts\ yearly}{Hours\ in\ one\ FTE} \times Number\ of\ operators\ on\ shift \qquad (5.2)$$

Using the right data in Formula 5.2 gives us:

$$Yearly\ savings\ time_{New\ Energy} = \frac{0{,}5\,\frac{hours}{shift} \times 39\ shifts}{1721\ hours/FTE} \times 7 = \mathbf{0{,}079\ FTE}$$

The potential for the shutdown of New Energy is not as high as for the startup, but these calculations is more precise and realistic, as the estimated time saved is looked further into than just a rough estimate. Therefore, it is suggested for Nidar to improve their shutdown routines and lists, and make the operators collaborate more than they do today. The best way to do this is probably to make the shutdown lists that are meant for each person instead of each position on the line, as already mentioned. This will make it clearer for the operators how to cooperate in an efficient way. In addition, several actions have to be made to make the actual shutdown time of the cooking shorter. This includes the use of a pressure washer and investigating if it is possible to shorten the washing programs.

Småsulten bars

The observations showed that there was potential to reduce the shutdown time or manpower. There were no clear actions to reduce the actual shutdown time of each position at the line, but with better cooperation between the operators, and better shutdown lists (as with the New Energy production) there should be some potential on the total shutdown routine. As already mentioned, the possibility to reduce the whole evening shift with one operator should be looked at as well as the possibility to reduce the shutdown time. The two possibilities are shown in Figure 11 and Figure 12 respectively.

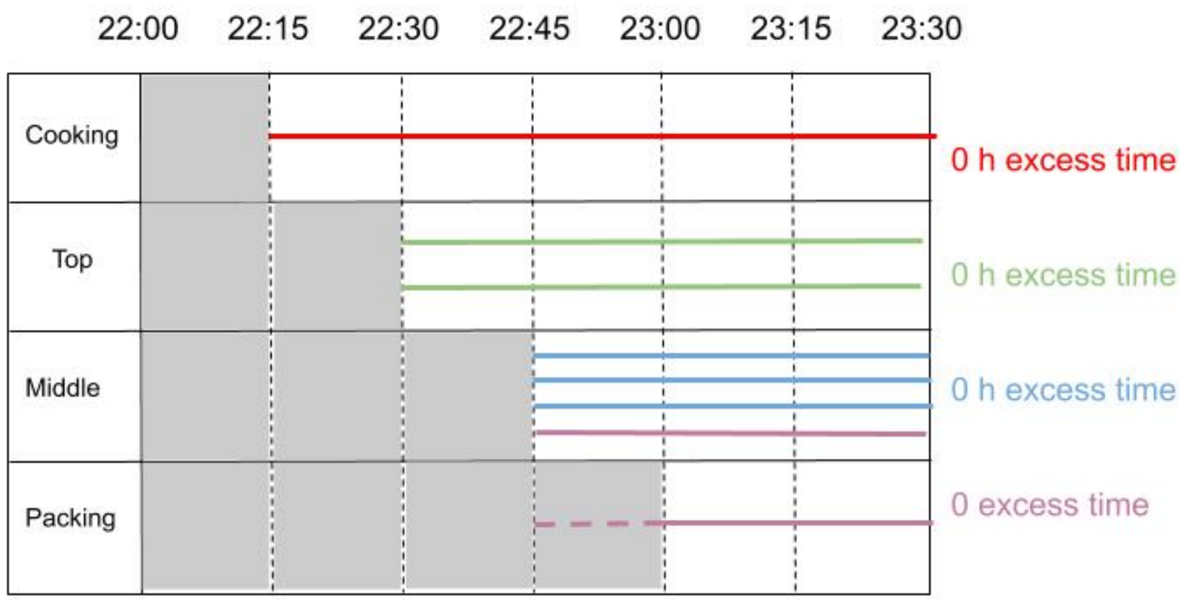

Figure 11: Visualization of alternative 1 of improved shutdown routine for Småsulten production

<u>*Alternative 1*</u>: This alternative reduces the total shutdown time with 15 minutes, which gives 15 minutes longer production. The clear bottleneck here is the middle position, and therefore this position needs help from packaging. As with the New Energy the packaging operator is needed at the middle position before the actual shutdown of the line, so it is assumed that the other packaging operator is adequate to do the last 15 minutes of the production alone. Alternative 1 has zero minutes of excess time, which again indicates an efficient and effective shutdown. Zero minutes excess time gives less room for mistakes. The possible yearly savings can be calculated with the same formula as for the New Energy savings. For Småsulten bars the yearly shifts are 37 and the operators at the shutdown is 9. Using Formula 5.2 with the extra data given from Nidar:

$$Yearly\ savings\ time_{Småsulten} = \frac{0{,}25\,\frac{hours}{shift} \times 37\ shifts}{1721\ hours/FTE} \times 9 = \mathbf{0{,}048\ FTE}$$

The calculations here, as with the New Energy calculations, are more precise and realistic than the estimated savings for startup. On the other hand, a reduction of less than 0,05 FTE is not very significant and should not give too much attention. This is because of the few shifts yearly.

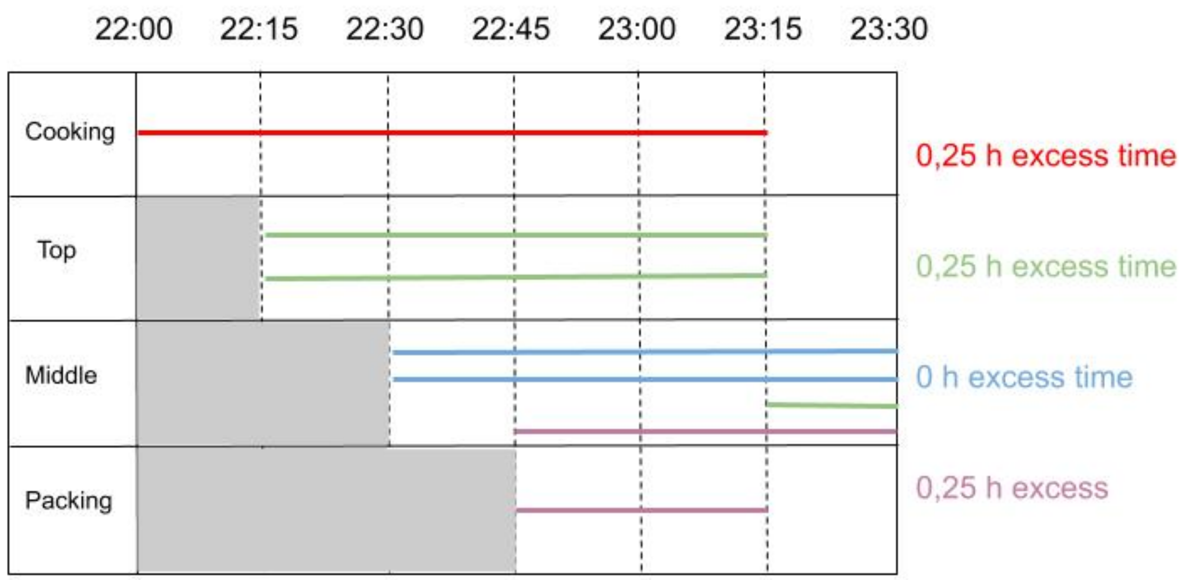

Figure 12: Visualization of alternative 2 of improved shutdown routine for Småsulten production

Alternative 2: This alternative reduces the manpower at the middle position with one operator the whole shift. The bottleneck is therefore the middle position regarding the shutdown. Both packaging and the top position need to help the shutdown in the middle. The result of alternative 2 is 45 minutes of excess time. This indicates that there could be potential to reduce the shutdown time a little in addition to the reduced manpower, or just gives more room for mistakes in the shutdown process.

To calculate the yearly savings of the reduced manpower the following formula may be used:

$$Yearly\ savings\ manpower = \frac{Hours\ in\ the\ shift \times Number\ of\ shifts\ yearly}{Hours\ in\ one\ FTE} \tag{5.3}$$

The shift is from 3pm to 11:30pm, so the number of hours in the shift is 8,5. Using Formula 5.3, and the data given in alternative 1, this gives:

$$Yearly\ savings\ manpower_{Småsulten} = \frac{8{,}5\,\frac{hours}{shift} \times 37\ shifts}{1721\ \ hours/FTE} = \mathbf{0{,}183\ FTE}$$

It is clear that alternative 2 is much more economical beneficial than alternative 1. With this second alternative there is even room for more ineffective work or mistakes as there is a total of 45 minutes excess time. This may later result in the possibility to shorten the shutdown time in addition to the reduced manpower. The project team is suggesting Nidar to cut one position on the middle of the line at evening shifts of Småsulten production. To be able to do this, better shutdown lists that focuses on the person, not the position, should be present to make the shutdown more effective and make cooperation easier for the operator as some of the operators now is working on different positions of the line.

That being said, all of these improvements may give less slack to the operators, that may be strained, and therefore not be as accepting from them. It is very important to focus on the suggested actions to the improvements at first and explain how this could be more efficient and effective for the operators. Simply introducing this as “We will cut one person at the evening shift” or “We shall start the shutdown time 30 minutes later than usual” will most probably seem impossible and unrealistic to the operators. It is therefore suggested to work through the startup and shutdown SOPs together with the operators and make the procedures more efficient. This could improve the way the operators do their job, which again will lead to shorter shutdown times.

The improvements suggested are the answer to RQ1a, and the corresponding savings is the answer to RQ1b.

5.2 Overweight Analysis

Looking at the hypothesis list in Table 5, the overweight of the products at the Conbar line is assumed to be fairly high by the project thesis of the author (Rødvei, 2018). To investigate the scope of the overweight, long-term logged data is analyzed. The historical data was collected each hour for each product, and logged into excel by the operators, then collected by the quality manager. This subchapter answers the whole RQ2. RQ2a is presented in 5.2.1 Observations. RQ2b and briefly RQ2c is presented in 5.2.2 Improvements.

5.2.1 Observations

Looking at all the historical data, the averages and standard deviation were calculated. Then these values were compared to the nominal value and the specification limits given by The Council of the European Communities (1976), found in Appendix 1: Excerpt from the Weight Directive. Lastly the total number of products produced yearly was then multiplied by the average overweight to get the total yearly overweight. The data is summarized in Table 8, where NV is the nominal value, LSL is the lower specification limit from the directive (T.1) and SD is the standard deviation of the historical data.

Table 8: Summarized overweight data

Product	NV (g)	LSL (g)	Average of historical data (g)	SD	Average overweight: Average – NV (g)	High variation 2*SD > NV-LSL?	Total yearly overweight (kg)
New Energy	45	40,95	46,46	1,125	1,46	No	9 882,6
Småsulten nuts & seeds	40	36,40	42,43	2,210	2,43	Yes	4 197,0
Småsulten nuts & berries	44	40,04	45,12	2,430	1,12	Yes	1 496,9
Gullbrød	65	60,50	66,67	2,312	1,67	Yes	3 135,6
Troika	66	61,50	67,01	1,700	1,01	No	5 689,4
Mokkatrøffel	42	38,22	42,88	1,262	0,88	Yes	237,6
Smash bar	34	30,94	35,20	1,541	1,20	Yes	4 012,6
Krokantrøffel	42	38,22	42,89	1,241	0,89	No	143,6
Vill nøttebar	40	36,40	41,01	1,528	1,01	No	724,1
Troika appelsin	66	61,50	67,11	1,825	1,11	No	970,4
Total							**30 489,8**

As seen from Table 8 the total yearly overweight at the Conbar line is almost 30,5 tons, and almost 10 of these tons are just from the New Energy production. All the nut bars in total stand for about 6,5 tons, but as nuts are an expensive raw material this is assumed to be a lot economically.

One method to state if the process variation is high or low is to look at the standard deviation versus specification ratio. More specifically; if two times the standard deviation is higher than NV minus T.1, tolerance limit 1, it is a rule of thumb that the variation is high. This is OGO's way to tell if the variation is high or not and has been decided through calculations the author has not gained insight in. It is clear that the relationship between standard deviation of the data, and specifications from the customer has something to do with Process Capability[2].

All the data have been logged into histograms with the corresponding normal distribution shape, target or nominal weight and Lower Specification Limit (LSL). An Upper Specification Limit (USL) which is the same distance from the target as the LSL is shown. The histograms from the New Energy, Småsulten nuts and seeds and Småsulten nuts and berries is presented here, in Figure 13, Figure 14 and Figure 15 respectively, as these are the main products looked at in this thesis. The rest of the histograms can be found in Appendix 3: Minitab Histograms of Overweight on other Products on the Conbar line.

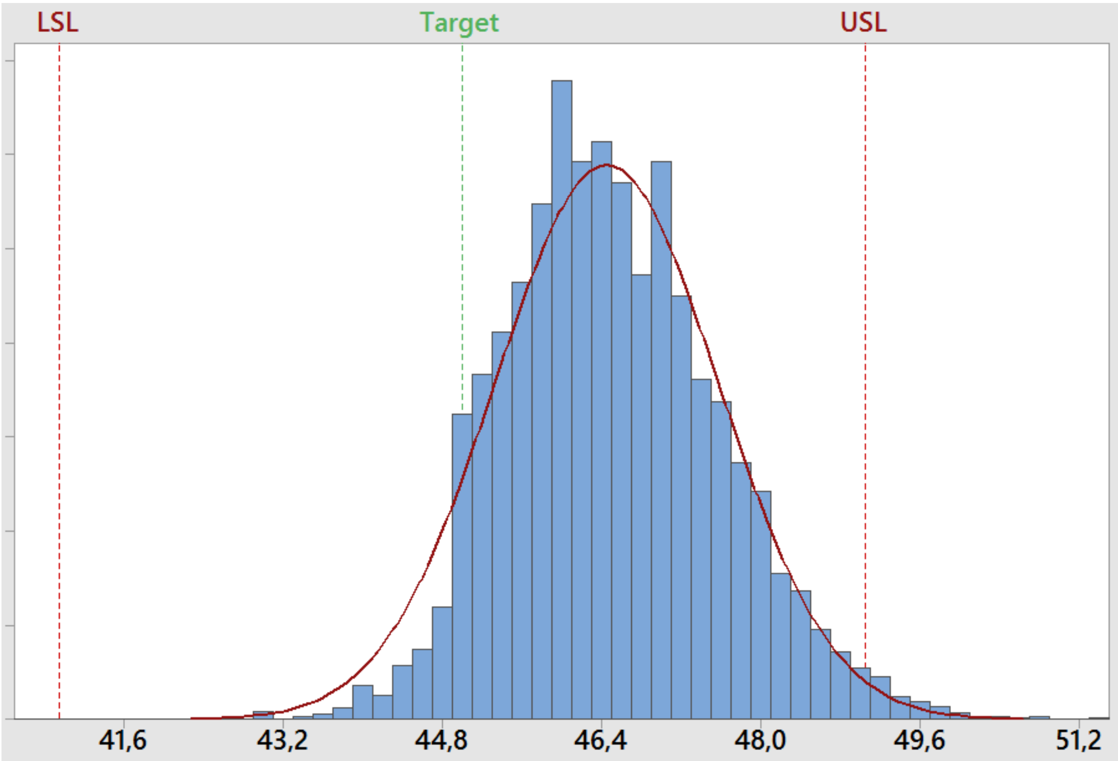

Figure 13: Histogram of New Energy overweight data

[2] Process Capability = Voice of the customer/Voice of the process = USL – LSL/6 SD. Says something about the output of a process versus the specifications, and if the process is capable (Wheeler and Chambers, 2010).

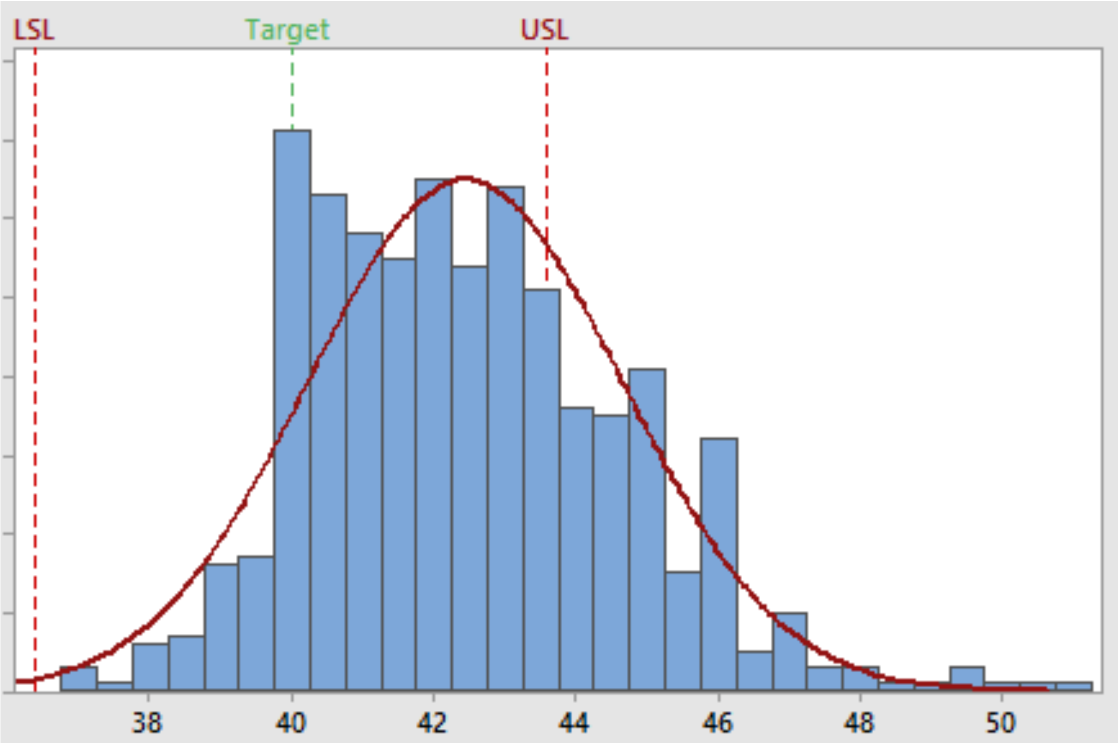

Figure 14: Histogram of Småsulten (Nuts and seeds) overweight data

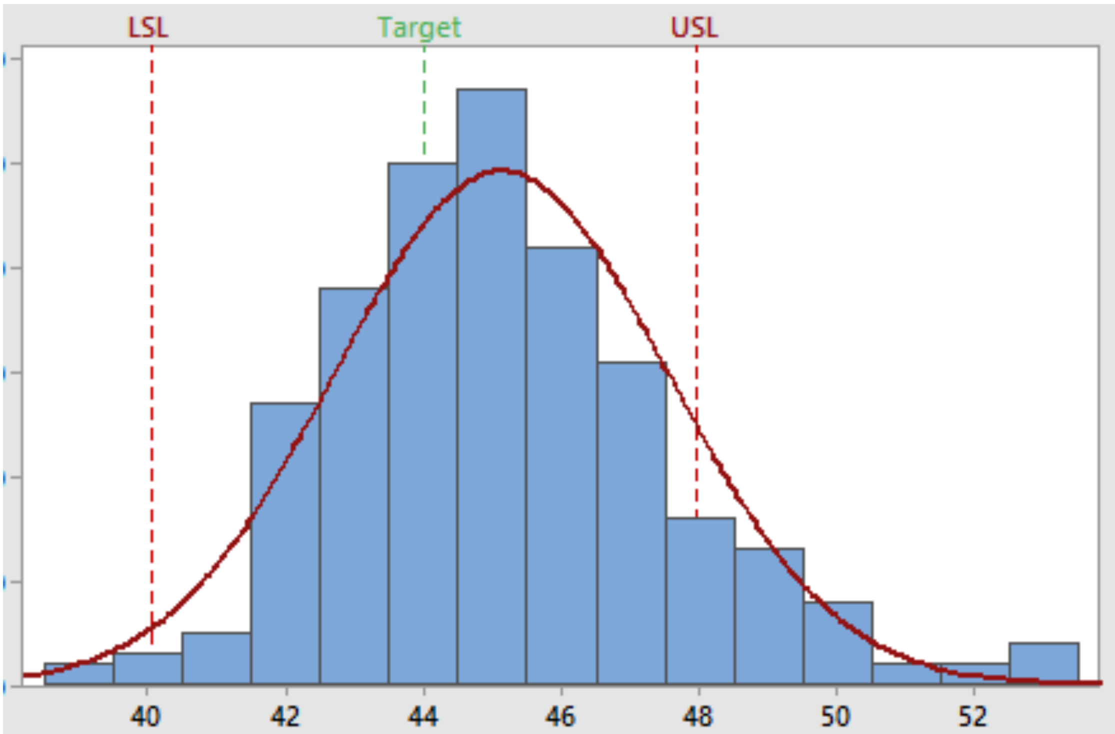

Figure 15: Histogram of Småsulten (Nuts and berries) overweight data

The figures show that Conbar products weights more than the requirements from the directive. From these three products, only Småsulten Nuts and berries has a single sample product under LSL, which is allowed to some degree. None of these three main products are close to have products near T.2 (which is two times lower than T.1, compared to the target value). On the other hand, many of the products are over the USL. This may indicate that there is a much bigger focus on making sure the weight is not to low, than keeping the weight as low as possible.

As seen from Figure 14, there seems to be an unnatural high amount of sample measures on the target value. This is also the case for several of the histograms in Appendix 3: Minitab Histograms of Overweight on Other Products on the Conbar Line. This may indicate wrongly logged data from the operators. It seems like the logging may be a bit biased regarding the target value. This makes the data somewhat incorrect and makes the use of such logging of data less valid and useful.

Looking at the histograms above and in Appendix 3: Minitab Histograms of Overweight on Other Products on the Conbar Line, and Table 8, many of the products have an unacceptable high variation, with two times SD higher than NV minus LSL. This is the first step in reducing the overweight for each product; the variation needs to be as low as possible, and at least acceptable. When the variation is acceptable it is possible to work with the centering of the process, which means moving the average closer to the NV. From the histograms and the data in Table 8 it is clear that reducing the variation should be the first focus on many of these products for Nidar, for example the Småsulten bars. For some of the products, and in the long term when the variation is reduced, moving the average closer to the target should be the focus.

When observing the weight control process, it was clear that some of the product specifications is set very unnaturally. For one product the LSL was set as the NV of the product and the USL was set to 10 kilograms. This is very unrealistic limits, that basically states that everything above NV is an acceptable weight. This makes it hard for the operators to know when to act to reduce the overweight and will automatically lead to excess overweight. From the other products specifications, it still seemed like they were a bit too conservative. Usually T.1 was treated as a T.2, saying that none of the product may be under the T.1 limit. This may be Orkla or Nidar being afraid of a bad reputation, and therefore wanting the weights of the products to higher than necessary. If that is the case, reducing the overweight significantly may be difficult, as there will be a need of some overweight, since there will always be some variation in every process.

There may be some limitations to these observations as the measures are based on about ten measures every hour of production. This is not a very big part of the produced product. On the other hand, this is acceptable by the directive, and the measures should therefore be good enough to do these analyzes.

5.2.2 Improvements

To be able to reduce the variation it is important to have a stable process on the cooking and top position of the production, as with the OEE analysis. This includes better and more equal understanding about weight control between the operators, which again largely depends on better specifications on the line. If the operators fully know how the procedure of weight control should be, and also know the specifications of the product, one important factor for the weight control will be less uncertain, which should reduce the variation to some degree.

An aspect to get a more stable weighting process is to have clear action plans and instructions for when and how to act when there are deviations in the weight control. To be able to know when to act, clear instructions that all of the operators follows could be implemented. SPC could also be used on the weight of the measured bars. This will be a lagging indicator, therefore it would be useful to use SPC to stabilize the process in the top of the line, to get a leading indicator for the weight of the product. This will be further discussed in section 5.4 Stabilizing the Production. Action plans for what to do if there actually are deviations should be made and be made specifically for each product. In the end it is the operators that adjust the weight of the products, so they should know the actual specifications and limits for the products. They also need to have a clear and uniform understanding of how and when to act if there are deviations in the weights.

One last improvement proposal is to include overweight as a Key Performance Indicator (KPI) at the line. This is an easy step to give more focus to overweight, and to have better continuous knowledge about how the overweight situation is. It is easy to get the total overweight from a batch when the measures are logged. In addition is the number of products produced known, so the overweight of the previous day could actually be presented every day at the morning meeting when the OEE data is presented.

On some products the reduction of the overweight should be achievable. For example, the New Energy bar, which stands for the biggest overweight, does not have high variation, and the products is therefore just laying too high on the weight scale. The chocolate cover of this product is going through a machine that blows off the excess chocolate to make the cover thinner and rougher. It is easy to adjust this blowing, and this could be used to increase or decrease the weight of the products more precise. This step is also the last step of the production of the bars, so the lagging time is not that long from detecting a deviation in weight till fixing the problem. It is therefore assumed by the project team, and line manager, that with the mentioned improvements, that the New Energy overweight should be possible to be reduced by about 95%, which is a yearly reduction of over 9 tons.

This is the case for other products too, to some degree, and the overweight of all the products is assumed to be possible to be reduced by about 50% to 95% depending on the product. Summarizing the total estimated saved weight gives a total reduction of about 84%. This is a reduction of almost 26 tons yearly at the line, which is significant. The estimated savings are very rough estimates, and should not be used very specific, but it is clear that there is a great potential to reduce the overweight at the line. That being said, the overweight could never be all the way down to zero kilograms because of the way the weight directive is set up. This makes the assumption of 95% reduction on New Energy somewhat unrealistic, as none variation in the process is impossible, especially if Orkla and Nidar wants to be safer on their weight than the directive states. This is on the other hand the goal that the manager on line though was an appropriate goal to work towards, but this does not mean that it is possible to achieve.

All of this being said; there is some clear potential to reduce the overweight. A thought review of the specifications, in addition to being more aware of the amounts of overweight, for example by introducing it as a KPI, would probably help a lot.

5.3 Waste Analysis

The last hypothesis in Table 5 is that it is possible to reduce the total waste on line. Waste at the Conbar line is a big problem, and according to Nidar it stands for 43% of all of the waste at the Nidar factory, where New Energy and the nut bars are the biggest waste producing products. Regarding the environmental issue about waste in production, presented in section 3.1.4 Waste in Production, it is appropriate to state that Nidar actually send most of their wasted products to animal food. The production of the chocolates is more energy and time consuming than just producing the animal food, but the product is at least used instead of wasted. RQ3 will be answered in this subchapter. RQ3a will be answered in 5.3.1 Observations. RQ3b and RQ3c will be presented in 5.3.2 Improvements.

5.3.1 Observations

A proper waste analysis was needed as it detects what is causing the waste. Nidar have been logging their waste for some time, but this is not very precise as it has only been from a few points at the line. To do a proper waste analysis the team followed the production both at startup, shutdown and a whole shift to try to detect several additional waste points to get a clearer picture. The measures were scaled up with the historical waste data collected by Nidar to get an approximately amount of waste, at each point, for a whole year. The amount of overweight is added, as this is a kind of waste, but improvements for overweight is not discussed here as this was done in section 5.2 Overweight Analysis.

The waste analysis has only been done with the New Energy and Småsulten bars as these are assumed to be the biggest waste problems at the line. That being said, many of the actions and improvement proposals found for these two products is possible to use on other products as well. When the analysis was done the actual price for each kind of waste was calculated based on the amount of caramel, binder, nuts, truffle and chocolate ratio. This data is sensitive and is therefore not presented in this thesis. Doing the waste analysis in this way presented some surprising aspects, as the points on line with the highest volumes of waste not necessarily are where most money are lost.

New Energy

As already stated, New Energy is the product estimated to have the highest amount of waste at the Conbar line. The Conbar team thinks this is because of variation in the quality of the caramel. The variation sometime leads to wasted product as the quality is too bad. The texture of the caramel is also of big importance when the wafer is cut into bars, as it may cause trouble on the line. Both of these issues make big amounts of waste and happens on a regular basis at the line. According to the data from Nidar there is produced about 6,8 million New Energy bars yearly, which makes it clear that small wastes for each product produced adds up to a lot of waste over a year.

An illustration of the measured total waste scaled up to a yearly perspective is shown in Figure 16.

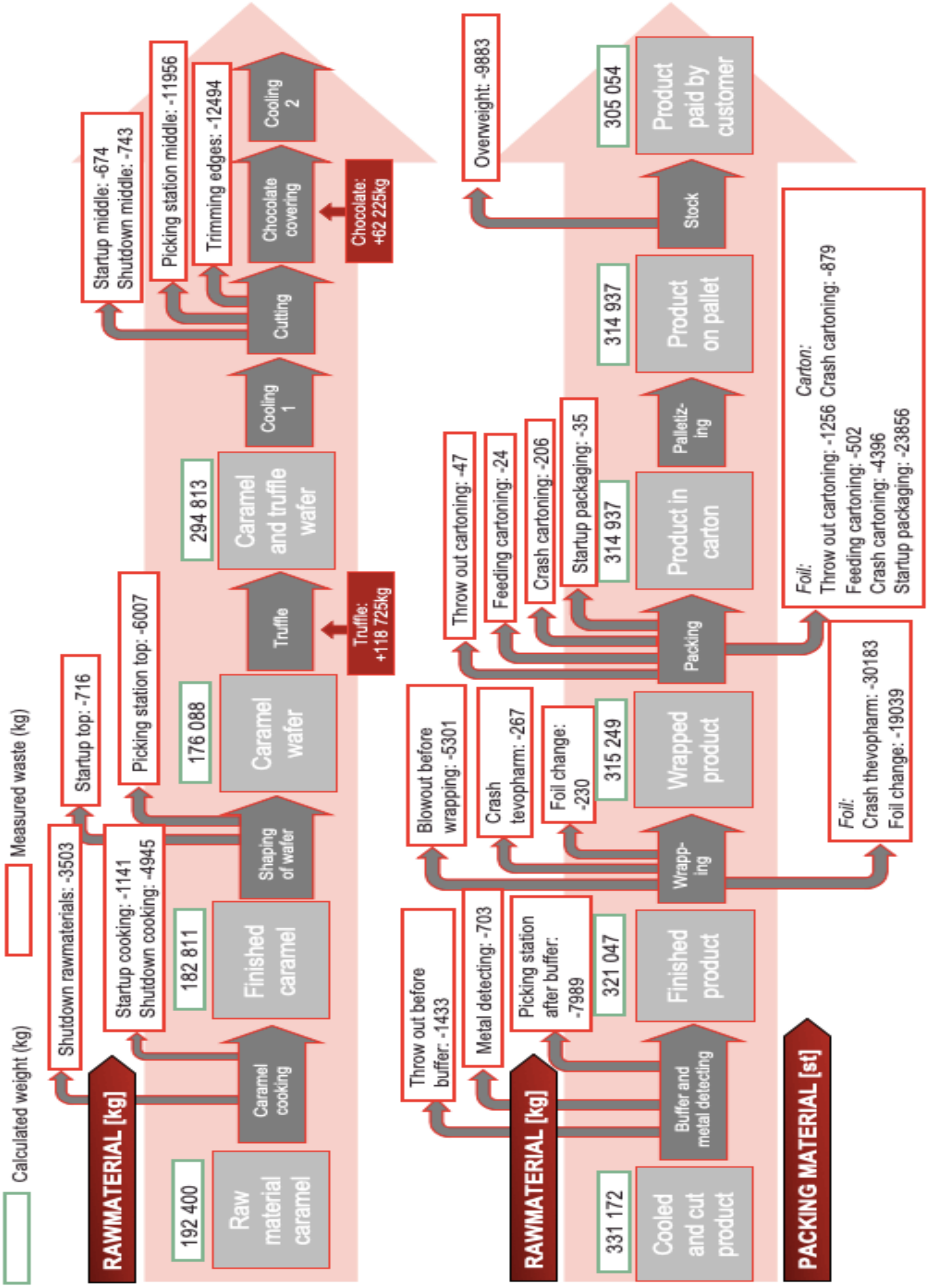

Figure 16: Waste analysis New Energy

This figure gives a clear picture of where the biggest amounts of waste comes from in the production. As seen, there is about 20 measuring points of waste on the line, which gives a good understanding of where the waste is coming from. Using the definition of waste that was defined in section 3.1.4 Waste in Production, waste is the total input minus the output paid for by the customer. This is the first green square, added to the truffle and chocolate input, minus the last green square. As seen from the figure, the total waste is, with this definition, just below 70 tons of product yearly, and includes about 10 tons of overweight. This gives a production yield of about 82% and is the product paid by customer versus raw material input ratio. It is therefore calculated by dividing the product to customer by the total raw material input. In addition to this there is waste of almost 80 000 pieces of foil and 1000 cartons yearly.

It is clear that high amounts of the waste come from the middle of the production, where the pickings station and the trimming of the edges stands for the biggest amount. These two places on line, in addition to the overweight, stands for about 50% of the total waste. All of these waste points depend a lot on having stable production processes, as already discussed. This means that if the production is less variable, and more stable, it will lead to a lot of benefits regarding both wastes, including overweight, and startup times.

Småsulten bars

The Småsulten bars do not have that much overweight compared to New Energy, and is not produced in very big quantum, but it is assumed that the yield of the product is bad, and that the raw material is expensive as it includes nuts. According to the data from Nidar there are produced about 3,1 million Småsulten bars yearly including both Småsulten nuts and seeds and Småsulten nuts and berries. Both of these products are also produced to other countries with other names, and these are included here as the product itself is the same. This is still, in total, less than half of the amount of New Energy bars produced yearly.

A presentation of the calculated overweight on the line, with the total yearly waste at each point, is shown in Figure 17.

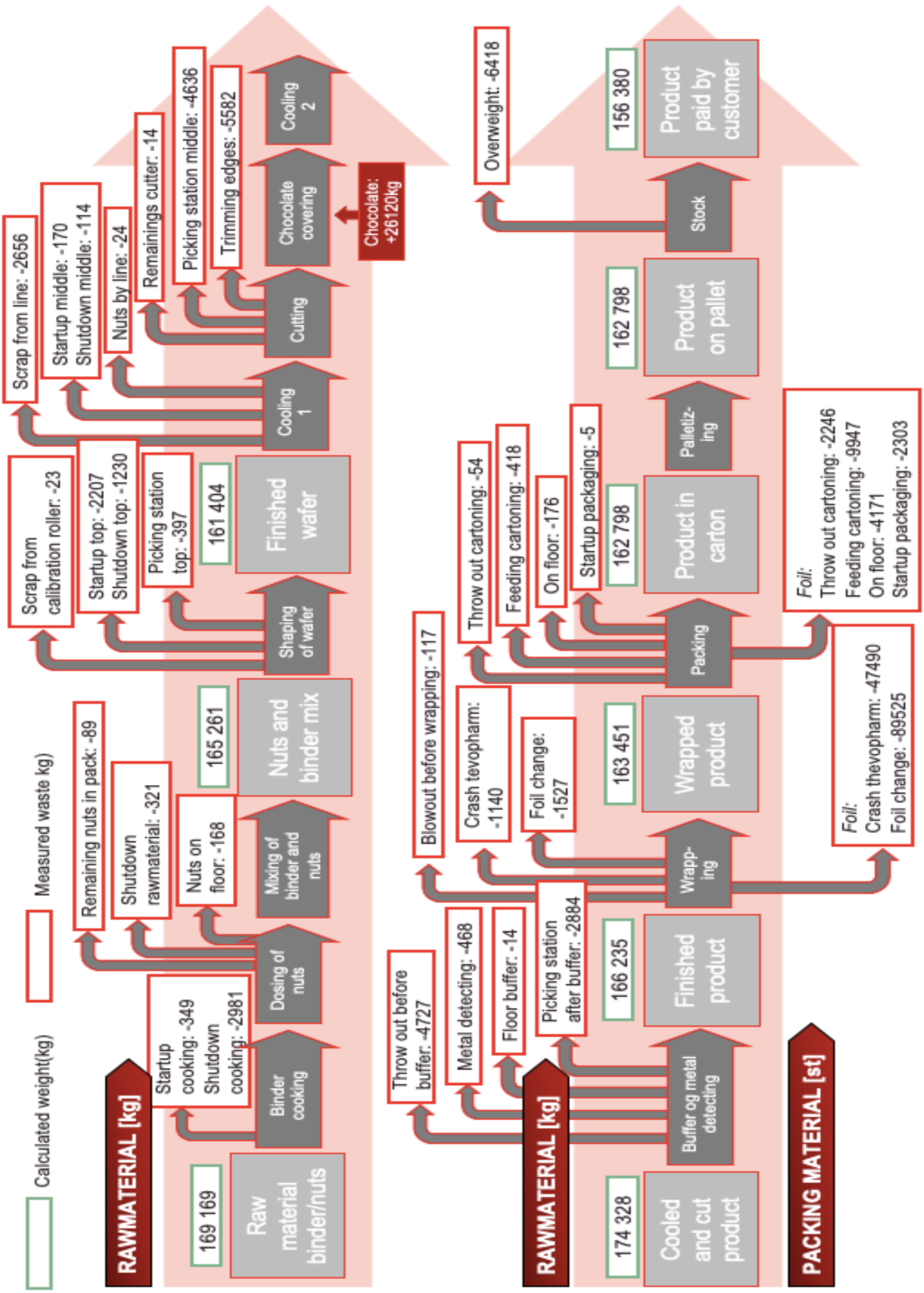

Figure 17: Waste analysis Småsulten

Looking at the waste in the same way as with the New Energy bars, it is seen from the figure that the total waste is just below 40 tons yearly included the overweight of about 6 tons. This gives a production yield of about 80%. In addition to this there is a waste of over 155 000 pieces of foil yearly, which is almost the double of the waste of New Energy foil, even if the amount of Småsulten bars produced are less than half of the New Energy bars. The biggest amount of wasted foil is from foil change, and crash in the Thevopharm, which is the wrapping machine. The foil waste is not considered any further in this thesis, but it is clear that this should be possible to reduce, as the New Energy has significantly less foil waste.

It is clear that both products have high amounts of waste, as suggested by the hypothesis list in section 4.2 Todays Assumed Issues at the Conbar line. Having a yield of about 80% is not very lean and means that if you buy a chocolate of 80 grams, there have actually been used 100 grams of raw material to make it, including the overweight. This should be focused on to try to reduce it.

5.3.2 Improvements

The first step in reducing the waste is, as already done; investigate where the waste actually is located. The next step is to look at where the biggest volumes or costs of the waste is. In this thesis only the volume will be presented due to sensitive data regarding raw material cost. Lastly it should be suggested actions to improve these problems. To find actions and to estimate how much waste that should be possible to reduce, the project team had a meeting with the line, quality and maintenance managers.

New Energy

The information gathered from the meetings with the Conbar managers is put together. The problems that lead to waste, where on the line these occur, the total waste of the problem, suggested actions and estimated savings are presented in Table 9. In addition, the author has estimated the effort or cost and benefit linked to this problem. These are rated on a scale from one to ten, where high numbers mean high effort or high benefit. This gives an idea of the cost benefit ratio and shows which problems to prioritize.

Table 9: Summary waste New Energy

Problem	Where on line	Total waste (kg)	Suggested actions	Estim-ated savings (%)	Estim-ated cost (1-10)	Estim-ated benefit (1-10)
1. Bad quality product	• Picking station top • Picking station middle • Picking station after buffer • Blowout before wrapping	31253	• Stabilizing actions (SPC, PFMEA, logging changes in parameters, laser measurer on top of the line to get the height of the wafer) • Investigate if the caramel cooking is optimal (cooking temperature, amount of fondant, amount of emulsifier) • New tempering machine for truffle (planned 2019)	50%	6	6
2. Too much trimming on edges	• Trimming of edges	12494	• Investigate optimal adjustment for extruder • Investigate possibility to change the format of the bars and wafer to be more optimal	30%	3	4
3. Startup and Shutdown inefficiency	• Shutdown raw materials • Startup/shutdown cooking • Startup top • Startup/shutdown middle • Startup packaging	11757	• Stabilizing actions for more efficient startup (SPC, PFMEA, logging changes in parameters, laser measurer) • Reduce the overlap of truffle on caramel on startup and shutdown • Reuse caramel • Better startup and shutdown routines in the cooking	50%	4	4
4. Quality and food safety	• Metal detecting • Overweight	10586	• Reuse good product from metal detector • Overweight discussed in section 5.2 Overweight Analysis	95%	2	4
5. In-line error	• Throw out before buffer • Crash Thevopharm • Foil change • Throw out cartooning • Feeding cartooning • Crash cartooning	2207	• Reuse good products • Investigate best practice foil change, and give training to the operators • This problem is also dependent on having a stable process.	50%	1	3
Total		**68297**		**36413**	**53%**	

As seen from the table, the biggest problem is that bad quality product is made. This gives high amounts of picking waste and blowout before wrapping. This may be improved mainly by having a more stable, less variating production. It is estimated that over 50% of the total waste is possible to save by the actions mentioned, which means about 36 tons saved yearly. Trimming of edges is also a big problem, but this is harder to do something about. It is estimated that it is possible to save about four tons here by optimizing the extruder, and possibly adjusting the bar or wafer size. Startup and shutdown waste should be possible to halve with more stable production, better startup and shutdown routines and by reusing leftover and wasted caramel. It should be possible to save about six tons by this. Quality and food safety, where overweight is the biggest problem, should be possible to almost remove totally. Overweight actions are already discussed, but the metal detecting waste should be possible to reuse to some degree. This accounts for 10 tons savings. Lastly the in-line errors waste should be possible to reduce by reusing some of the waste, implement better routines for foil change and having a more stable process. This accounts for a saving of one ton. This sums up to 36 tons saved, which gives an estimated total savings of 53%.

The cost-benefit diagram of the New Energy waste problems is shown in Figure 18. The problem numbering is the same as in Table 9.

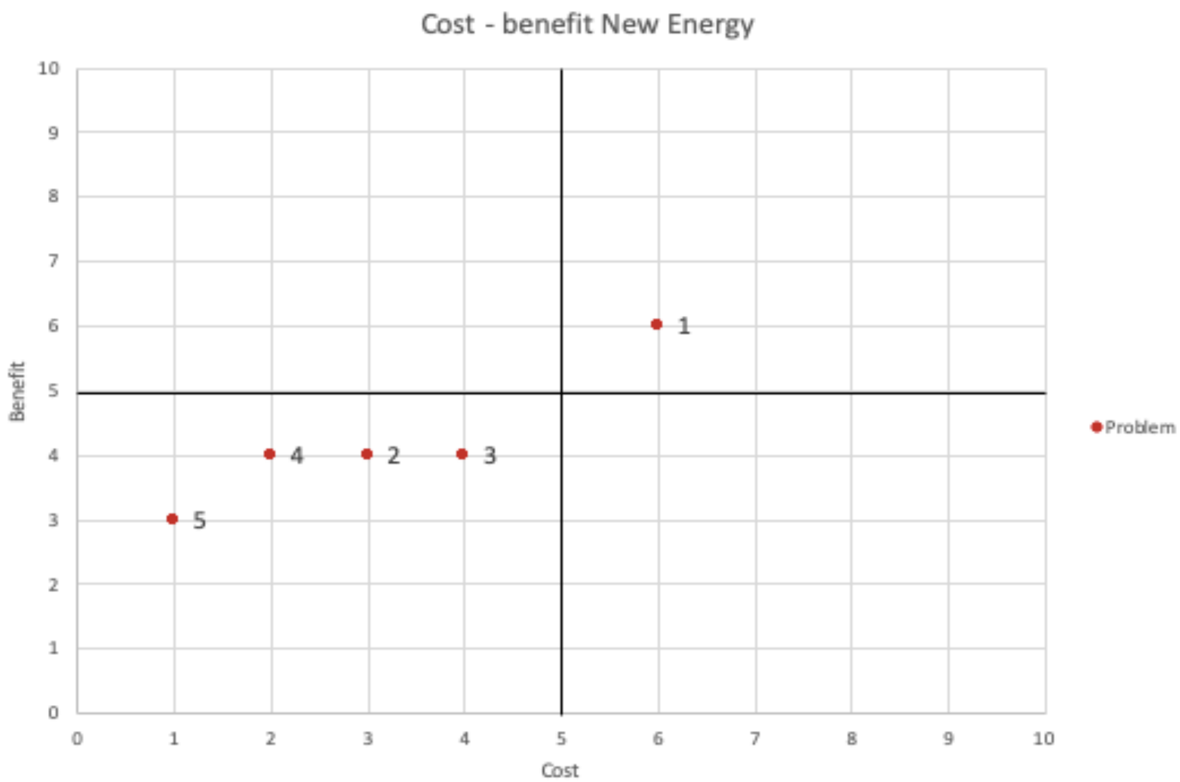

Figure 18: Cost - benefit for New Energy waste

As seen from the figure all of the problems lie approximately at the diagonal line from (0, 0) to (10, 10). This means that they all do have almost the same cost-benefit ratio. Problem 2, 4 and 5 has the best estimated benefit versus cost and is therefore the actions that should be prioritized first. That being said, having a stable production is as already mentioned a suggested action for many of the problems, and is therefore important to investigate further.

Småsulten bars

Table 10 is set up the same way as Table 9 for the New Energy.

Table 10: Summary waste Småsulten bars

Problem	Where on line	Total waste (kg)	Suggested actions	Estim-ated savings (%)	Estim-ated cost (1-10)	Estim-ated benefit (1-10)
1. In-line error	• Remaining nuts in pack • Nuts on floor • Scrap from calibration roller • Scrap from line • Nuts by line • Remainings on cutter • Throw out before buffer • Floor buffer • Crash Thevopharm • Foil change • Throw out cartooning • Feeding cartooning • On floor	11030	• Reuse good products • Investigate best practice foil change, and train the operators • Make the operators more aware of the value of nuts in pack and on floor • Making the processes more stable • Investigate the possibility to use line lubricant to get less scrap from line	30%	2	2
2. Bad quality product	• Picking station top • Picking station middle • Picking station after buffer • Blowout before wrapping	8034	• Stabilizing actions (SPC, PFMEA, logging changes in parameters, laser measurer on top of the line to get the height of the wafer) • Investigate if the binder cooking is optimal (cooking temperature, amount of emulsifier) • Investigate the possibility to reuse scrap from the top. This will decrease the amount of scrap on the top, but also	50%	3	5

			decrease the scrap on the rest of the line as the product that gets sent from the top is of better quality • Make it easier for the operators to see if the product is good from the top (alarm if nuts are not dosing right)			
3. Startup and Shutdown inefficiency	• Shutdown raw materials • Startup/shutdown cooking • Startup/shutdown top • Startup/shutdown middle • Startup packaging	7377	• Stabilizing actions for more efficient startup (SPC, PFMEA, logging changes in parameters, laser measurer on top of the line to get the height of the wafer)) • Investigate the possibility to reuse the scrap from the top. • Better startup and shutdown routines in the cooking	50%	3	4
4. Quality and food safety	• Metal detecting • Overweight	6886	• Reuse good product from metal detector • Overweight discussed in section 5.2 Overweight Analysis	70%	2	4
5. Too much trimming on edges	• Trimming of edges	5582	• Use metal edges to make the wafer smaller • Investigate the possibility to reuse the scrap of the trimmings	95%	1	5
Total		**38909**		**21138**	**54%**	

As seen from the table the biggest problem is the in-line errors. This gives high amount of waste in packing and along the line. This may be improved by having better routines for foil change, reusing more products and also having a more stable process. It is estimated that 30% of the waste is possible to save by the actions mentioned, which gives about 3 tons saved yearly. Bad product is also a big problem and is, as with New Energy production, most dependent on having a stable process. It is also possible to reuse more of the waste, as the nut-binder mix is reusable. It is estimated that it is possible to save about four tons on the bad product actions. Startup and shutdown waste are mainly the same as for the New Energy production, and it should be possible to save about four tons from this as well. Further Quality and food safety, where overweight is the biggest problem should be possible to reduce a lot. The estimated savings is lower here as the overweight on Småsulten bars is more difficult to control than for the New Energy production. The metal detection waste should be possible to reuse 100%, as the Småsulten bars are fairly durable. This gives about five tons savings yearly. Lastly the trimmings on edges should be possible to reduce by use metal edges that force the wafer to be a better size, and then use the scrapping again. It should be possible to save five tons from this. This sums to 21 tons saved yearly, which gives an estimated savings of 54%, which is almost the same saving ratio as for the New Energy bars.

The cost-benefit diagram of the Småsulten bar waste problems is shown in Figure 19.

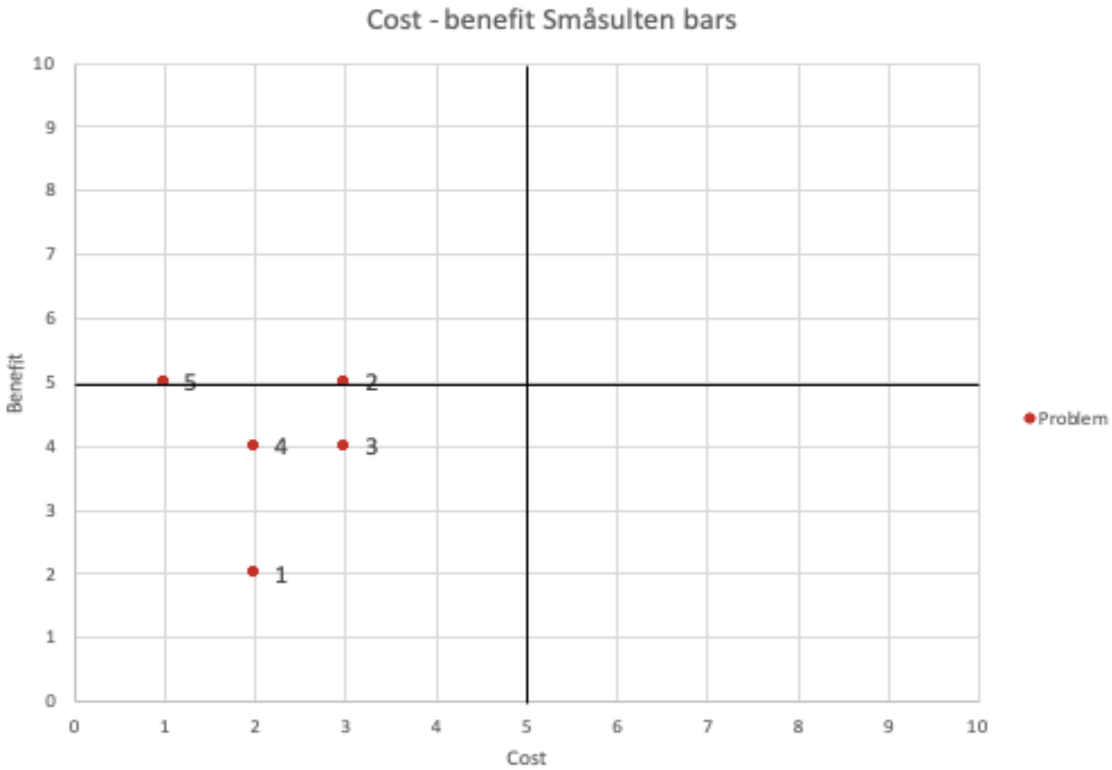

Figure 19: Cost - benefit Småsulten waste

The figure shows that most of the problems lie at the low cost, low benefit quadrant. Problem 2, 4 and 5 has the best estimated benefit versus cost and is therefore the actions that should be prioritized at first. That being said, having a stable production is a suggested action for many of the problems, and it is therefore on its own very important to look deeper into, as with New Energy.

5.4 Stabilizing the Production

As seen from both the overweight and waste analysis, having a stable production process is key to a lot of the issues at the line. In addition, a stable production process could reduce the startup times as most of the startup issues is because of bad product that is wasted in the startup. There are several different actions to stabilize a process. The ones chosen to be used in this project is PFMEA and SPC, in addition to several other smaller actions that have already mentioned.

5.2.1 PFMEA

As described in section 3.1.7 Process Failure Mode and Effect Analysis (PFMEA), PFMEA is a tool used to address and prioritize failure modes and list corresponding effects. This is used to figure where the focus of failures should be, and to discuss possible actions to prevent these. A PFMEA analysis was done for both New Energy caramel cooking and Småsulten binder cooking as these processes are assumed to be the biggest problems to get a stable production of these products. The analysis was done by having workshops with all the operators that work on the Conbar line, in addition to other important persons such as quality and maintenance managers. The project team led the workshop, and it started with giving the operators some background information about PFMEA. IDEF0 diagrams for the process were made, and lastly the PFMEA was filled out, all with input from the operators, managers and the project team.

When filling out the IDEF0 diagram and PFMEA several important discussions occurred between the operators and the managers. Many of the discussions were not directly relevant to this thesis, and will not be discussed further here, but one example will be presented: The operators explained that they had problems with measuring the water content of the binder because the fat in the product often separates from the binder and lays on the top. The Product Developer then explains that the fat should not separate from the product, and that it is an indication of too little emulsifier in the receipt. This makes the binder non-homogenous which may be one of the reasons for an unstable production. The amount of emulsifier therefore needed to be looked at, and the operators need more information about the product so these problems can be reported earlier. It also shows the importance of the management talking to, and listening to, the operators on the line. It seemed like this problem has been a case for a long time without anybody knowing.

The presence of these discussions may indicate that Nidar have not had adequate discussions about having a stable cooking process with the operators and managers together in a group before. This on its own part was very useful to address problems related to the PFMEA, and Nidar is suggested to have similar workshops more frequently. Most of the operators gave very positive feedback from participating in the workshops, as they found it useful, and they felt listened too.

New Energy

As already mentioned, the focus of the PFMEA was the caramel cooking. To be able to address the critical processes that stands for the variation an IDEF0 diagram is used. The IDEF0 diagram has the input and output of the process in addition to factors that may be controlled and observed. The IDEF0 diagram was made with input from the operators, managers and the project team. The IDEF0 diagram of the New Energy caramel cooking is presented in Figure 20.

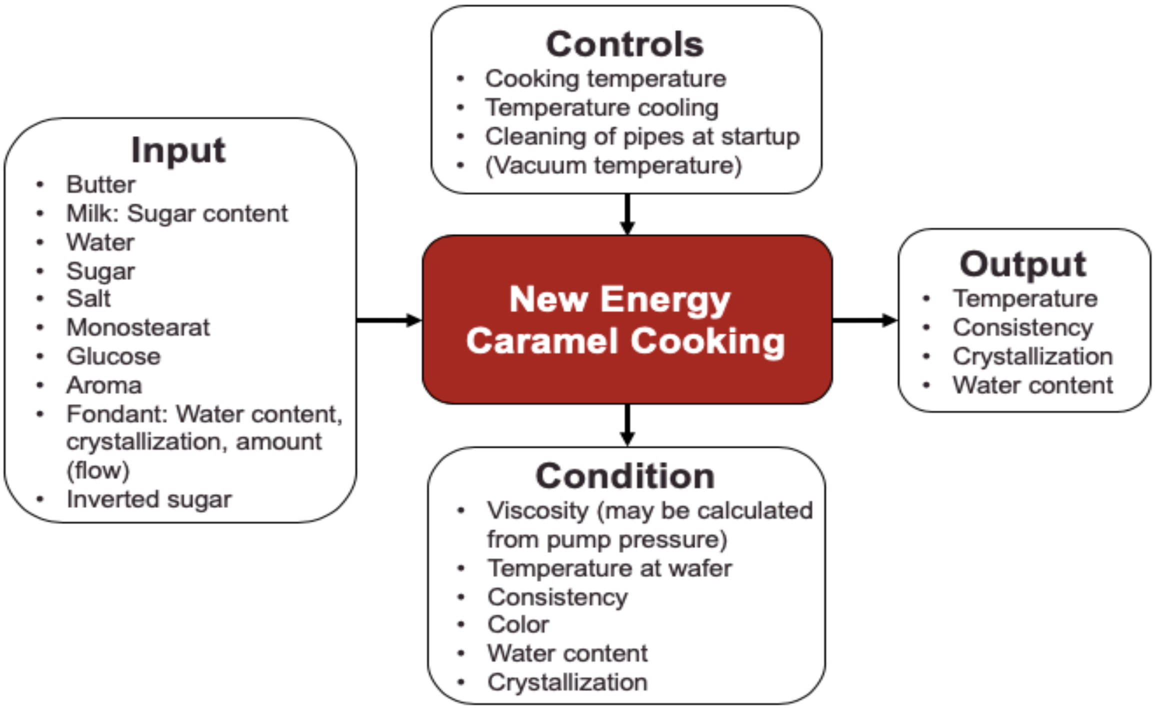

Figure 20: IDEF0 diagram for New Energy Caramel Cooking

As seen from the figure there are a lot of input parameters, but not that many control parameters. This may be challenging when trying to have a stable production. On the other hand, there are some conditions that may be checked to review the quality of the product, which is positive. These are the lagging indicators. If the caramel that comes as an output is bad, the caramel may need to be wasted. As seen in the figure, there are a lot of factors that may stand for the variation in the process, and some of them seems extra important. As an example, the temperature is a factor that is important through the different parts of the IDEF0 diagram.

The different failures were taken from this IDEF0 diagram put into a PFMEA, as shown in Figure 21.

Potential
Failure Mode and Effects Analysis
(Process FMEA)

Item: Conbar cooking
Process: New Energy Caramel cooking
Core Team: Operators, quality, maintenance

Process Responsibility : Johnny Aker Hansen
Key Date : 2019-03-18
FMEA Number : 1

Prepared by : Asbjørn Borvik
Revision Date: 2019-03-19
FMEA Date (Original): 2019-03-11

Process Step / Function	Require-ment	Potential failure mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) of Failure	Current Process: Controls Prevention	Current Process: Occurren	Current Process: Controls Detection	Detection	R.P.N.	Recommended Actions	Responsibili-ty & Target Completion Date
Caramel cooking	Right consistency	High cooking temperature	Too hard caramel, damage to equipment (mixer and cutter)	8	Too high temperature at first cooking in the morning	There exists startup routines, but these are not followed perfectly	6	The operators choose different startup cooking temperatures and from how the first caramel is, they adjust the next batches. Problems is detected at line.	6	288	Agree with a good start temperature that every operator follows. Better to start too low than too high, less potential to damage on equipemnt. Consider if it is possible to have the startup cooking with just water to stabilise the temperature.	Thomas, next New Energy run
Caramel cooking	Getting caramel to the line	Caramel splashes at level sensor because of spills at evacuating	Process stops, wrong temperature at evacuating	7	Overcooking at vacuuming, caramel on level sensor		6	Often at the start up cooking, the display shows an alarm when the problem already have occoured	6	252	Root cause analysis, is other sensors possible to use? Have less product in the container.	Finn Jarle, next New Energy run
Caramel cooking	Right consistency	Crash in cutter	Accumulation of product, possible damage to cutter	8	Too hard caramel, too soft truffle	There exists startup routines, but these are not followed perfectly	5	The consistency of the caramel may be observed by pump pressure from container	5	200	Update limits for acceptable pressure and set standarized action plans for whent there are deviations. When should product be wasted already at the top of the line? When should the cooking temerature be adjusted?	Thomas, next New Energy run
Caramel cooking	Getting caramel to the line	When the line stops the caramel that stands still in container and pipes hardens	Caramel boiled too long, possible stop at line	7	Stop at line	Buffer before packaging, operators is supposed to notify if there is a long stop at	5	May be detected too late if the communication is good	5	175	Agree on a routine for notifying. Alarm, display. Agree on when to stop production.	
Caramel cooking	Right consistency	Wrong dosing of fondant	Wrong consistency of caramel, possibly following failures	7	Wide tolerance limits of flow from pump, new pump may dose a bit different than earlier	Tolerance limits exists, but are probably too wide	5	The pumps are adjusted if they are outside the limits	5	175	Calibrate by setting the flow to 600 and measure the amount that goes out. Set a smaller acceptet toleraence limit.	Thomas, next New Energy run
Caramel cooking	Getting caramel to the line	Dry boiling	No product as expected, possible stop	5	Unknown	The dosing is automatic	4	Detected when the cooking is done	5	100	Look at the possiblity to have an alarm that prevents this	
Caramel cooking	Getting caramel to the line	Wrong dosage of raw material because of clogged pipes	Delayed startup	4	Clogged pipe, empty pipe		4	Detected if thee is no product coming to container	5	80	Know the condition before startup	

Figure 21: PFMEA diagram for New Energy caramel cooking

The table is sorted from highest RPN to lowest. This means that the factory should ideally look at the top failure mode and the corresponding actions first. That being said, smaller actions, that has a relatively high RPN should also be prioritized. It is shown from the RPN calculations that the temperature is as important as it seemed from the IDEF0 diagram. It is also of importance that most of the actions recommended are the responsibility of the management. This may implicate that when gathering the operators to discuss different problems within a process, the managers get some new information that they have not had before. This shows that the operators have some experiences and knowledge about the process that managers should facilitate the operators to share, for example by having these workshops more often.

Most of the actions were not investigated further until the next New Energy run as noted in the last column in the diagram. This may indicate the need of better follow up of the responsible person, or that the target completion dates were too short and unrealistic. It is important for the factory to follow this up further along the line, and probably set some more realistic target completion dates.

Småsulten bars

The connection between the IDEF0 diagram and the PFMEA is the same for the Småsulten bars as for the New Energy one. The IDEF0 diagram for the Småsulten binder cooking is shown in Figure 22.

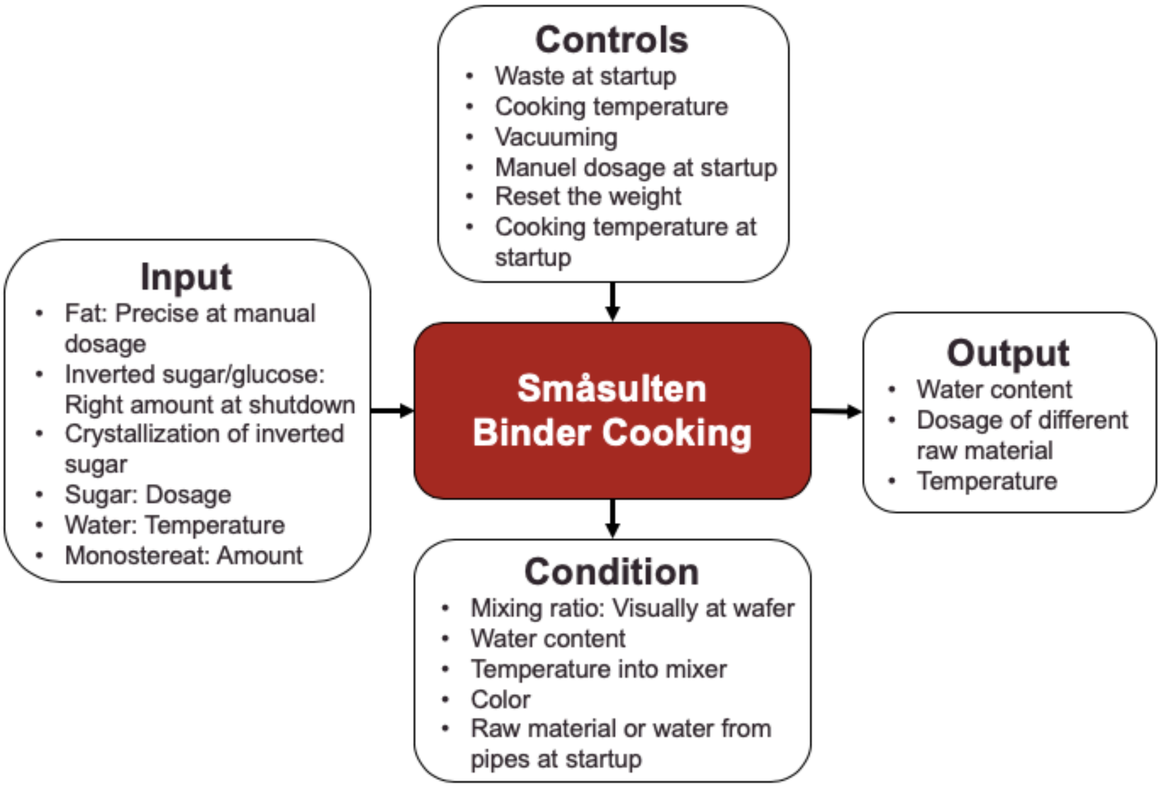

Figure 22: IDEF0 diagram for Småsulten Binder Cooking

As seen, from the figure, Småsulten bars have a better control parameter versus input parameter ratio compared to the New Energy cooking process. This may indicate that the process is easier to control, but also that there are room for a lot of operator driven variation. As seen from the last point at input, monostearate (emulsifier) amount is noted. It was at this point that the discussion between the operators and the product developer started, as mentioned earlier. This information is put into the PFMEA as shown in Figure 23.

Potential
Failure Mode and Effects Analysis
(Process FMEA)

Item: Conbar cooking	Process Responsibility : Johnny Aker Hansen	Prepared by : Asbjørn Bonvik
Process: Binder cooking Småsulten	Key Date : 2019-03-11	Revision Date: 2019-03-19
Core Team : Operators, quality, maintenance	FMEA Number : 1	FMEA Date (Original): 2019-03-11

Process Step / Function	Requirement	Potential failure mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) of Failure	Current Process: Controls Prevention	Current Process: Occurrenc	Current Process: Controls Detection	Detection	R.P.N.	Recommended Actions	Responsibility & Target Completion Date
Binder cooking	Good binder	Non-homogenous binder	Separation of fat, uneven quality	7	Wrong dosage of emulifier (monostearat) i recipe	None	10	Visual inspection, but no actions that will help	7	**490**	Consider changing the recipe, start a routine for inspection and adjusting if the fat has separated	Perny, next Småsulten run
Binder cooking	Wrong dosage into container	Unprecise manual weighing of raw material	Bad quality, different characteristics	7	Unprecise weighting method, unprecise operators	Aim for as precise dosing as possible	9	Visual weight of container	6	**378**	Investigate if the method is right	Thomas, next Småsulten run
Binder cooking	Good binder	Wrong water content into mixer	Bad quality, different characteristics	7	Wrong measurement method, raw material, cooking time	Check lists	8	Measured at startup	6	**336**	Agree on the right measuring method and set it as a standard, SPC for each cooking	Thomas, next Småsulten run
Binder cooking	Good binder	Incorrect startup lists	Bad quality, different characteristics, delays	7	Not updated based on newest experience	Tecnician has the responsibility	6	The same error is found at the next production day	7	**294**	Clearify the responsibility for updates and follow up in daily meetings	Thomas, next Småsulten run
Binder cooking	Good binder	Change of temperature in pipes if the line stops	Bad quality, different characteristics	6	Binder is cooled in pipes if there are stops on line	Have stops as seldom as possible	6	Visually after mixing, but no actions that will help	7	**252**	Return pipe for binder with continiously circulation back to container	Geir, Next Småsulten run
Binder cooking	Good binder	Wrong cooking temperature at startup	Bad quality, different characteristics, following failures at line	7	Unprecise standard, operator makes mistakes, deviations in raw material, deviations in weather	Visually on display, check lists	5	Detected when the first cooking is done	7	**245**	Investigate right startup cooking temperature, start with water cooking to stabilize the temperature, clearify the responsibility for updates and follow up in daily meetings	Thomas, next Småsulten run

Figure 23: PFMEA diagram of Småsulten binder cooking

As seen, the emulsifier problem is ranked highest with a RPN of 490. This is mostly because of the occurrence, that is 10, because it happens for each run. The manual dosing is also a big problem as it is hard for the operators to dosage the fat precise with today's methods. Also, here the temperature is of importance. Småsulten bars is not produced that often, so it is unknown if the actions were taken by the next run.

5.2.2 SPC

SPC is a suggested method to gain more information and control about variation in the process, as mentioned in the PFMEAs. There are several different factors that SPC may be used on, for example viscosity of caramel or binder, temperature different places at the line, water content, height of wafer and weight of finished bar to mention some. Weight of finished bar is a lagging indicator, and as the ICCM methodology is mainly using leading factors, this will not be looked at here. In addition, this was a topic in the project thesis of the author and may be read more about in that project report (Rødvei, 2018). Height of wafer is hard to measure with the tools at the line. It has been a suggestion to invest in a laser measurer to do this, which would be very useful. The viscosity, water content and temperature on the other hand has been logged by the operators and is therefore made into Process Behavior Charts (PBCs).

The temperature and viscosity were only logged at a New Energy production, and the water content at the Småsulten production. The factory does not have the opportunity to measure viscosity directly at the moment. The pump pressure presents when transporting caramel to the line have a correlation with the viscosity and may therefore be used. If there are deviations in the viscosity, there will also be deviations in the pump pressure. As described in Chapter 2: Methodology, the presented PBCs should have been used during production to log the upcoming data, and to teach the operators how to use these. This was not possible due to an unexpected empty raw material. Therefore, only the calculated control limits and the corresponding logged data is presented in the PBCs.

The limits are calculated by, and the detection rules follows, the description in section 3.1.8 Statistical Process Control (SPC). In the next parts of this subchapter will PBCs for water content, pump pressure and temperature be shown. These are used as these measures is assumed to be variating uncontrolled, and it is assumed that these may influence the quality of the product produced. In addition, these measures are possible for the operators to measure with today's equipment.

Water content

The water content is something that prior to project Opal already was measured by the operators. The value should be aimed to be 87 %, but the specification limits are 86 % to 88 %. The measures of the water content were taken from two different days, about once every hour. The PBC is presented in Figure 24 and is a XmR chart as there is only one measure every period.

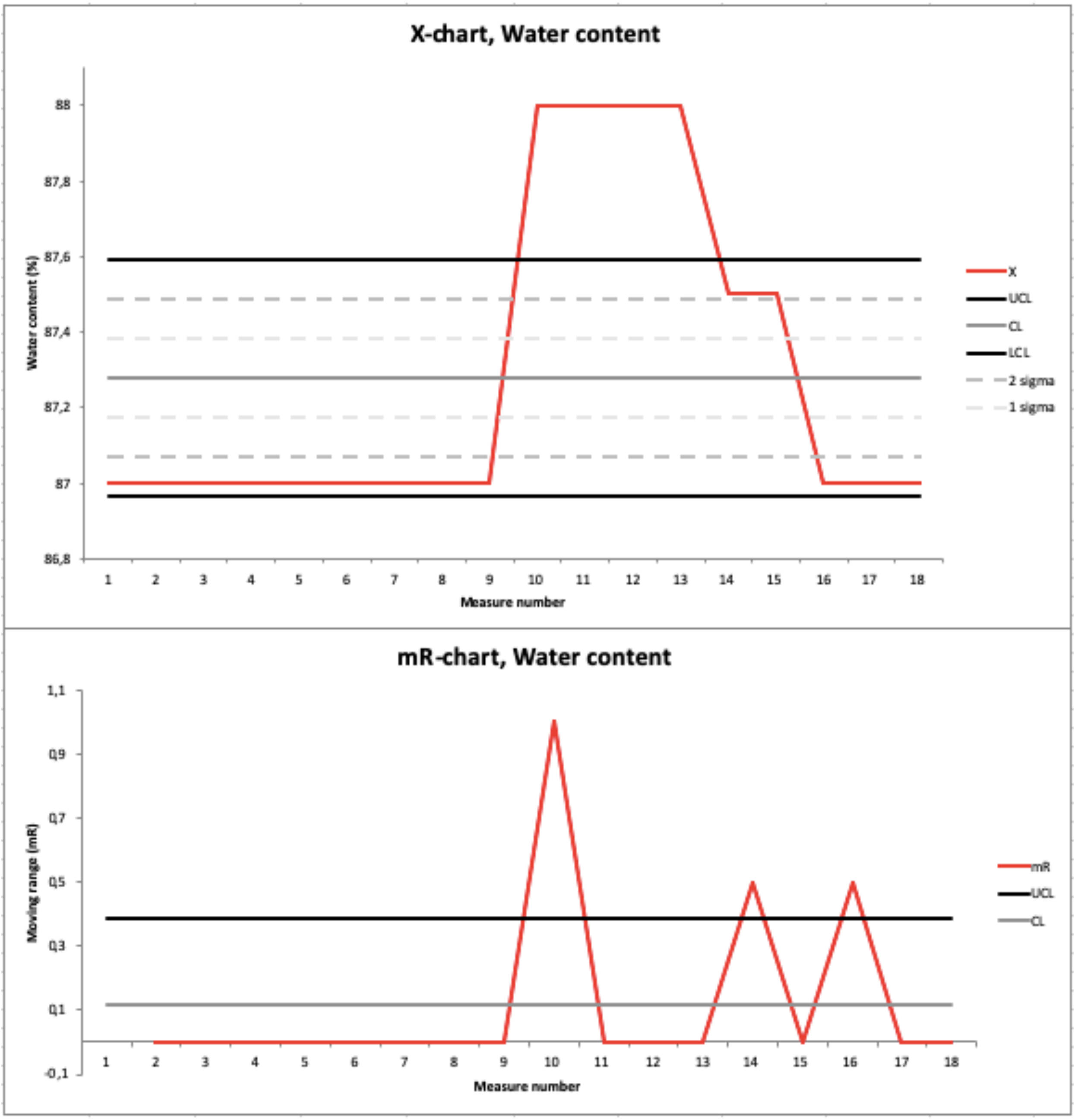

Figure 24: XmR chart of water content

The 9 first measures are from 5th of March from 10am. As seen, the data is very stable, with all measures on 87 %. The 10th measure is from the beginning of the new day, and as seen, there exist a deviation that are outside the control limit, especially seen in the mR chart. This shows that the water content may deviate a lot at the startup of production, compared to a relatively stable production during the day, as shown in the first 9 measures. The cooking temperature was adjusted a bit to get the water content to about 87 % again, and as seen in measure 16, this was reached.

The two last deviations in the mR chart is because of the unnatural change of water content because of the change in cooking temperature. The control limits are high compared to the specification limits, which is a consequence from the fact that the water content is very unstable in the beginning of the production. The operators have routines to adjust the cooking temperature to match the water content, so it seems like the factory has good control on their water content. Using SPC here may therefore be unnecessary.

Pump pressure

To get an indication on how the viscosity changes, the pump pressure was logged. This is not something the operators already do as a routine. The pump pressure is shown on the screens the operators use, but it varies a lot during the pumping of the caramel. The operators were therefore asked to log the approximately stable pump pressure, which was difficult to get precise. The corresponding PBC is shown in Figure 25 and is a XmR chart, as there is only one measure every period.

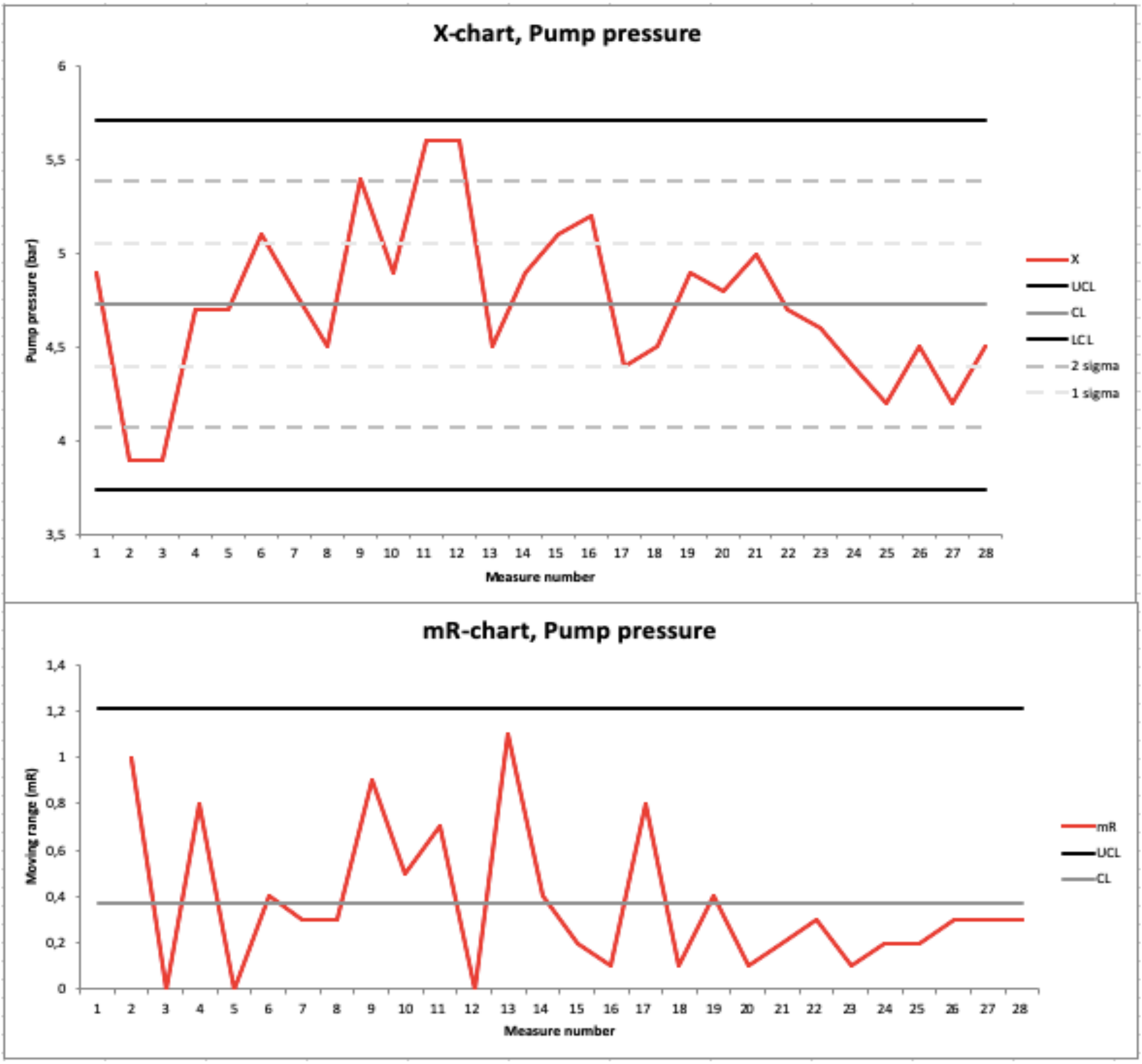

Figure 25: XmR chart of pump pressure

The data was logged over two days, with measures from every emptying of container, which occur about two times every hour. The first 13 measures were from 3th of April, and the rest from the 4th. As seen, there are no clear indications that some measures are outside the upper and lower control limits, or in other words breaking detection rule 1. On the other hand, there are clear erratic behavior of the data, especially the first day, with measures all the way from 3,9 bars to 5,6 bars. Detection rule two are present two times the first day. This erratic behavior is also very visible at the mR-chart, even if detection rule 2 to 4 is not useable here. The clear erratic behavior should be controlled and investigated more than today. The use of SPC with PBC could be useful. Making the operators be observant on the pump pressure would also be useful to prevent the mixing tool to be destroyed. The need of a high pump pressure indicates a product that are hard to get out of the container, which again leads to more damage to the equipment.

Temperature

The temperature of the caramel on the New Energy production is already assumed to be important. If the caramel and truffle has very different temperatures, it is assumed that the truffle will not stick to the caramel so well after the cooling process, which makes trouble in the cutting at the middle of the line. This leads to a lot of wasted product. The operators on line already measures the temperature regularly to keep an eye on this. Data from the line right after the cooling roller and data from right before the truffle has been measured. The PBCs are respectively presented in Figure 26 and Figure 27. The charts are X bar – R charts, with a subgroup size of three as both sides and the middle of the wafer is measured every hour. R is therefore the biggest difference between each point on the wafer. The first six measures are from the first day, 3^{th} of April, the rest of the measures are from the 4^{th}.

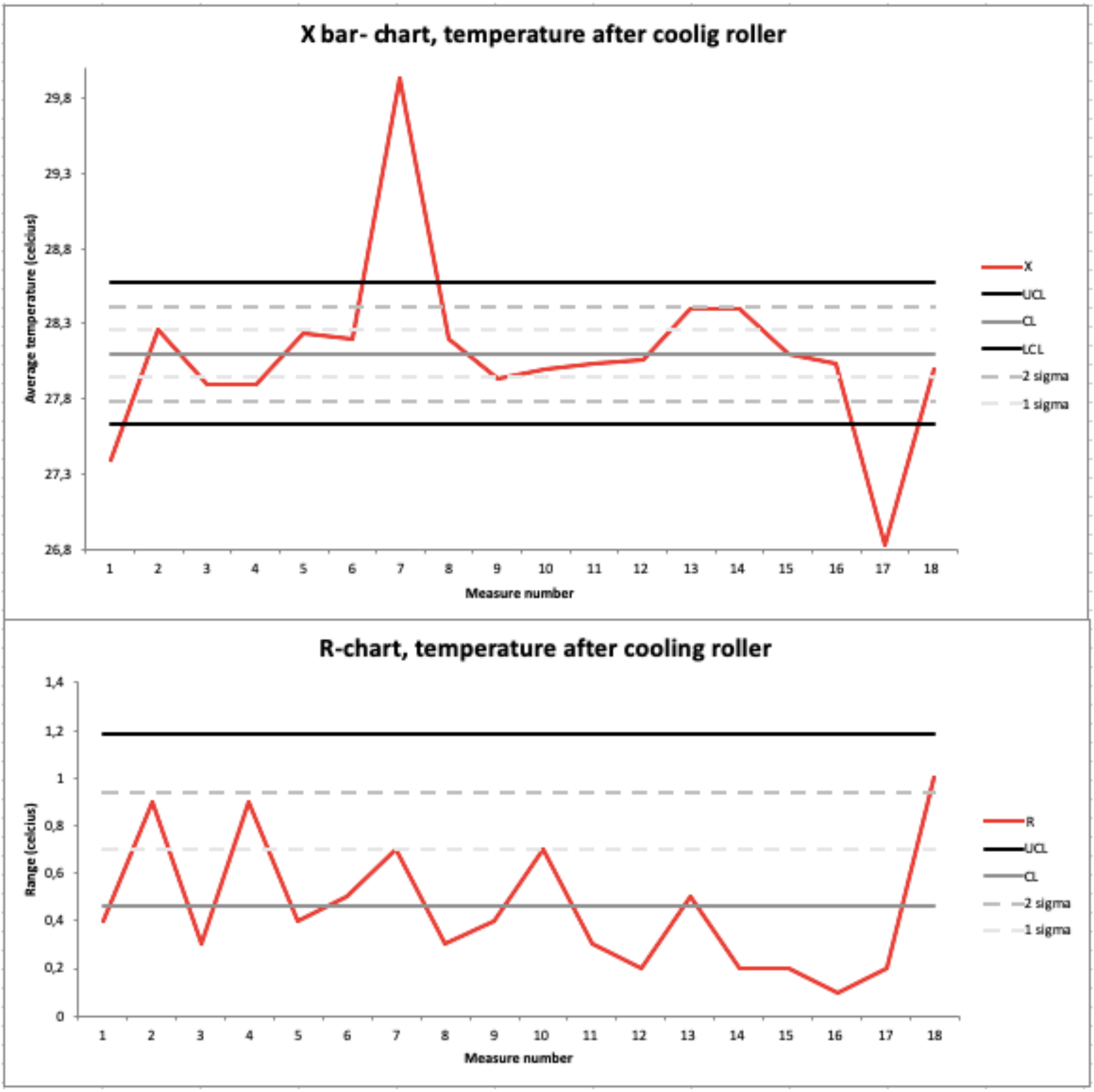

Figure 26: X bar - R chart of temperature after cooling roller

From Figure 26 is seen that there are very clear deviations in the X bar chart. Measure 7 and 17 have the biggest deviations, and suits detection rule 1. Measure 7 is the startup measure on the second day and is probably the reason for the deviation. No other detection rules are present in this chart. The R chart does not have any measurement that match the detection rules. The highest deviation between the different measuring points on the wafer is one degree celsius and is present at the last measure.

The X bar- R chart for the temperature before truffle is presented in Figure 27.

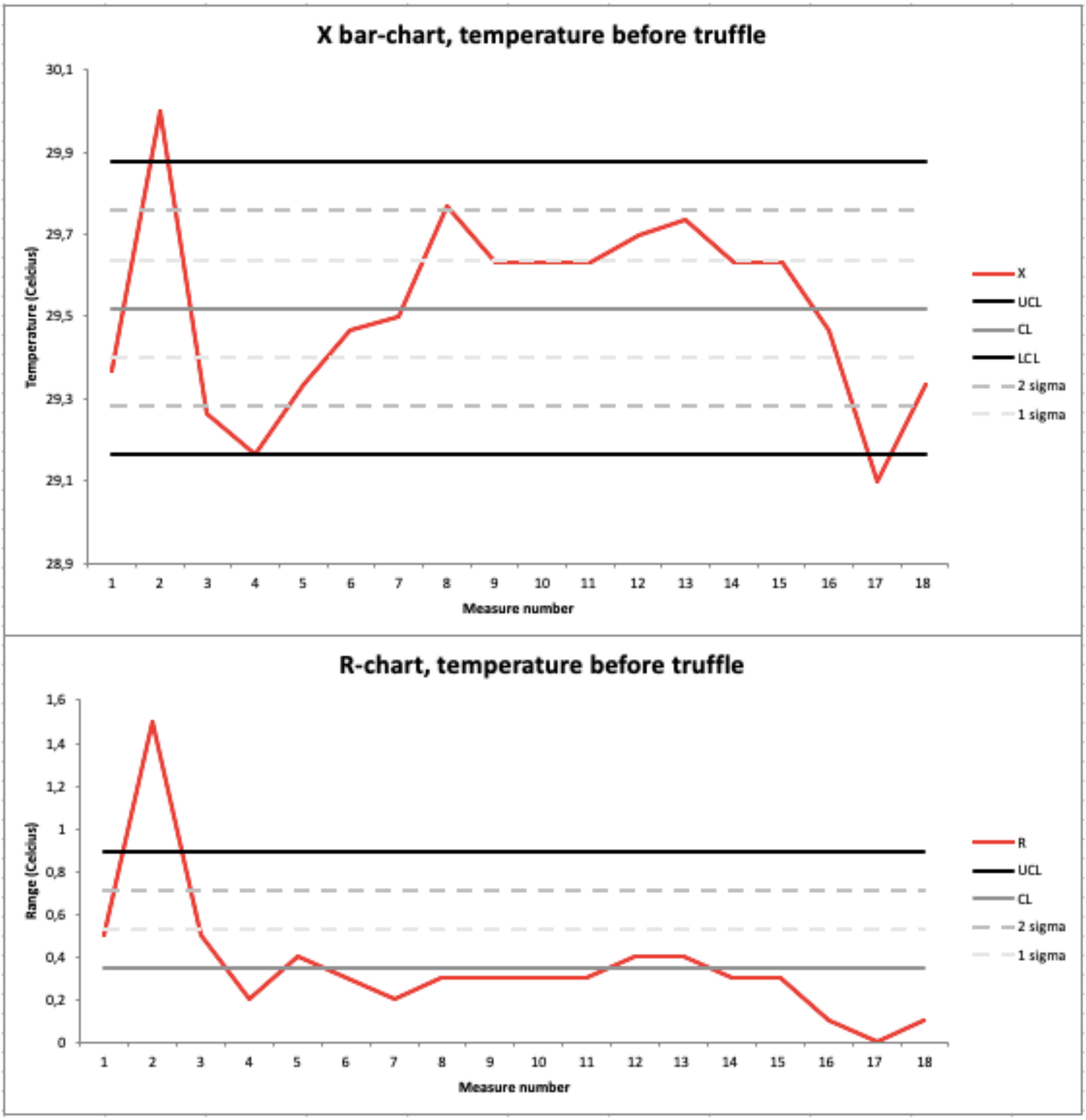

Figure 27: X bar - R chart of temperature before truffle

Figure 27 shows some clear deviations too. The X bar chart have two cases of detection rule 1, at measure 2 and 17. Detection rule 2 is present once at measure 3 to 4. Detection rule 4 is also present from measure 8 to 15. This shows clear indication of unnatural variance several times through the measurement period. The R chart also has a clear deviation in measure 2. Detection rule 1 is again present, and the difference in the width of the wafer is 1,5 degrees celsius. The same measure has deviation in the X bar chart.

It is recommended that Nidar implement these two temperature PBCs to gain more control over the variation of the temperature in the production.

5.2.3 Other Actions

PFMEA and SPC are suggested by the project team to be the two main ways to stabilize the production. In addition to these two methods there are several different smaller actions that may be introduced to gain a more stable production. Several of these actions are already mentioned in the previous sections of this chapter but will be summarized and explained further in this section. Some actions, for example reusing good product, will not be mentioned here, as this action will not help get a more stable production, which this section is about. The different stabilizing actions are explained in Table 11.

Table 11: Additional stabilizing actions

Action	Explanation
Training of operators	Many of the operators acts differentiated in relation to the same situation on the line. Investigating the best practice and train every operator to do their tasks in this way would decrease the room for variation in the production, which again will lead to a more stable production.
Revise the startup lists	The startup lists are not optimal regarding what to do when and by whom. The different startup parameters were discussed to be wrong. This leads the operators to use their intuition to decide the startup parameters, such as cooking temperature. If the startup every day is based on different intuitions, the variation from day to day will be great. The PBCs in section 5.2.2 SPC shows that there usually is some variation of importance on startup. Investigating the best startup parameters, and make every operator use these would be leading to less variation and a more stable production.
Clear rules for adjusting the parameters	This action is closely linked to revising the startup lists. Having clear startup parameters, setting clear rules for when to adjust these parameters would be useful. Today the operators follow their intuition in some degree when adjusting the parameters, which lead to variation.
Heating up cooking tank prior to startup	One of the big deviations is the first cook of caramel or binder. This is because of the container being cold, and harder to control. Heating up water in the container as the first cook would stabilize the temperature of the heater and would make less variation from the startup cook to the cooks later in the day.
Ensuring less variation in raw materials	There is some variation in the raw materials. This is especially an issue of the fondant as the viscosity and texture depends on the age of the fondant, which varies from day to day. If possible, the fondant should always be new and fresh. This is not really possible if fondant should not be wasted. Fondant is mostly made by water and sugar and is relatively cheap, so this action should be investigated further before implementing the action. If it is not effective to have new fondant every day, the properties of different age fondants should be investigated. The results of the investigation could be put into a matrix where different aged fondants give different corresponding values for flow, cooking temperature and other relevant parameters.

As seen from the table, there are several smaller actions that, in addition to PFMEA and SPC, may reduce the variation of the production processes. Some of these actions may help to some degree, but if they are easy and cheap to implement, it will be useful to do the actions anyway.

5.5 Discussions on Project Execution

Project Opal may seem very specific to the Conbar line, but as discussed earlier, there are some findings that could be useful to other lines, factories or even companies. In this subsection some of the more special aspects regarding the project execution of project Opal will be discussed to present how this project may deviate from other optimizing production projects.

5.5.1 Involvement of Operators

Having the operators involved at as much, and in as many parts of the project, as possible was very important for the project team during the whole project execution. This is much due to the ICCM methodology that focuses on this. When observing the line, the operators was informed about what was observed, and what information that were gathered. After the project execution has finished, and the report is done, the operators will be presented the findings from the project, and these will be discussed with them to get the best possible actions to improve the production. Not all of the actions presented in this thesis has been discussed with the operators, so before implementing, they will possible be revised by the operators in cooperation with the line manager.

The PFMEA workshop where held in a way where the operators were largely involved. All the operators on the line were invited, and everyone that had the opportunity came. They were continuously asked for opinions and had a lot of input. They seemed appreciate being listened too, and there were a lot of positive feedback from the operators after the workshops. It has been recommended to the factory to have more of these kinds of workshops, both on different processes of different products, but also on other issues at the line. PFMEA may also be useful on other lines at the factory. Many of the operators have been working at the factory for several decades and has very high knowledge and experience about the production.

When presenting the project findings to the steering committee, project owner and other factory worker, the project team wanted the line managers to present the findings. This is a way of involving the factory and the team on line. It may also make it easier to the factory works listen more to the findings. They know the line manager more than the project team that just was on the factory for a few weeks.

5.5.2 Use of Leading Indicators in SPC

Leading indicators are measures taken in the beginning of the line to try to say something about the quality of the product at the end of the line. This may for example be measuring the height of the wafer in the beginning of the line to get knowledge about the weight of the finished product. If this is done, the possibility to adjust the wafer height to a more correct measure, is possible, before detecting the under or overweight at the end of the line. This gives less products of bad quality.

The ICCM methodology is to a large extent about using the leading indicators instead of lagging indicators. This will reduce the amount of waste, including overweight, in the production. As seen from the SPC suggestions in section 5.2.2 SPC the lagging indicators will not even be suggested in this thesis. Measuring the weight of the finished bar at the end of the line will of course give information about the quality of the products sold, but if a deviation in the weight is found here, there may be several meters of the line filled with products that may possible be wasted. Using leading indicators, such as the height of the bar in the beginning of the line, do not only give the possibility to adjust to the right value much faster, but it also gives the opportunity to for example use more chocolate covering to get the right weight of the product, so that the already deviating product may be used anyway.

5.5.3 Using SPC on Non-geometric Factors

Usually SPC is commonly used at geometric measures such as weight or height. As just described, measuring the weight at the end of the line is a lagging indicator, and therefore not of interest in this thesis. Measuring the height in the beginning would be useful, but there is no precise method for this on the line today. A laser measurer measuring the height of the wafer and using SPC on the data would probably be very useful to reduce the overweight and reduce the risk of having to waste underweight products.

The measures that SPC is suggested on in this thesis are not the typical geometric measures. It is measures like temperature, pressure and water content. There is nothing wrong with using SPC on these measures, it is just not as usual as the more typical geometric measures as length or weight.

5.6 Prioritizing the Recommended Actions

A summary of the main recommended actions is presented in Table 12. Also, the estimated costs and benefits are presented. These are rough estimates made the same way as the Cost – Benefit diagrams presented in section 5.3 Waste Analysis.

Table 12: Estimated Cost and Benefit from all the actions recommended

Area	Action	Estimated Cost (0 – 10)	Estimated Benefit (0 – 10)	Comments
OEE	**1. Improve startup and shutdown SOP**	3	6	No direct cost of action, but some work going through the routines in detail
Overweight	**2. Standardized routines and better training of operators**	2	3	Investigate the best procedures and make this SOP. Training of the operators so that everyone does things the same way
	3. Set the weight specifications more adequate	1	3	The variation in the data is presented in this thesis, so setting more adequate weight specifications would be a very fast and free of cost job
	4. Set clear action routines for weight increase/reduction	1	2	Setting clear procedures for what to do when, regarding overweight, will help the operators to reduce the overweight
	5. Overweight as an KPI	0	1	Including overweight as a Key Performance Indicator is a very fast and easy action, but is assumed to not give a very big benefit
Waste	**6. All waste actions New Energy**	7	8	The average of all the waste actions for New Energy scaled up to match these estimated cost and benefits
	7. All waste actions Småsulten bars	4	6	The average of all the waste actions for Småsulten bars scaled up to match these estimated cost and benefits
SPC	**8. Implement SPC to reduce variation**	2	4	Not a very time-consuming implementation but will most certainly reduce the variation.

As seen, there are no action regarding the PFMEA. The Analysis is already done, so the job of the factory regarding the PFMEA is to follow up the analysis, which is assumed already done.

In addition, they are suggested to do this kind of analysis on other products and processes as well, but as that may not be directly relevant to the RQs in this thesis, it is not present here.

The corresponding Cost – Benefit diagram is shown in Figure 28.

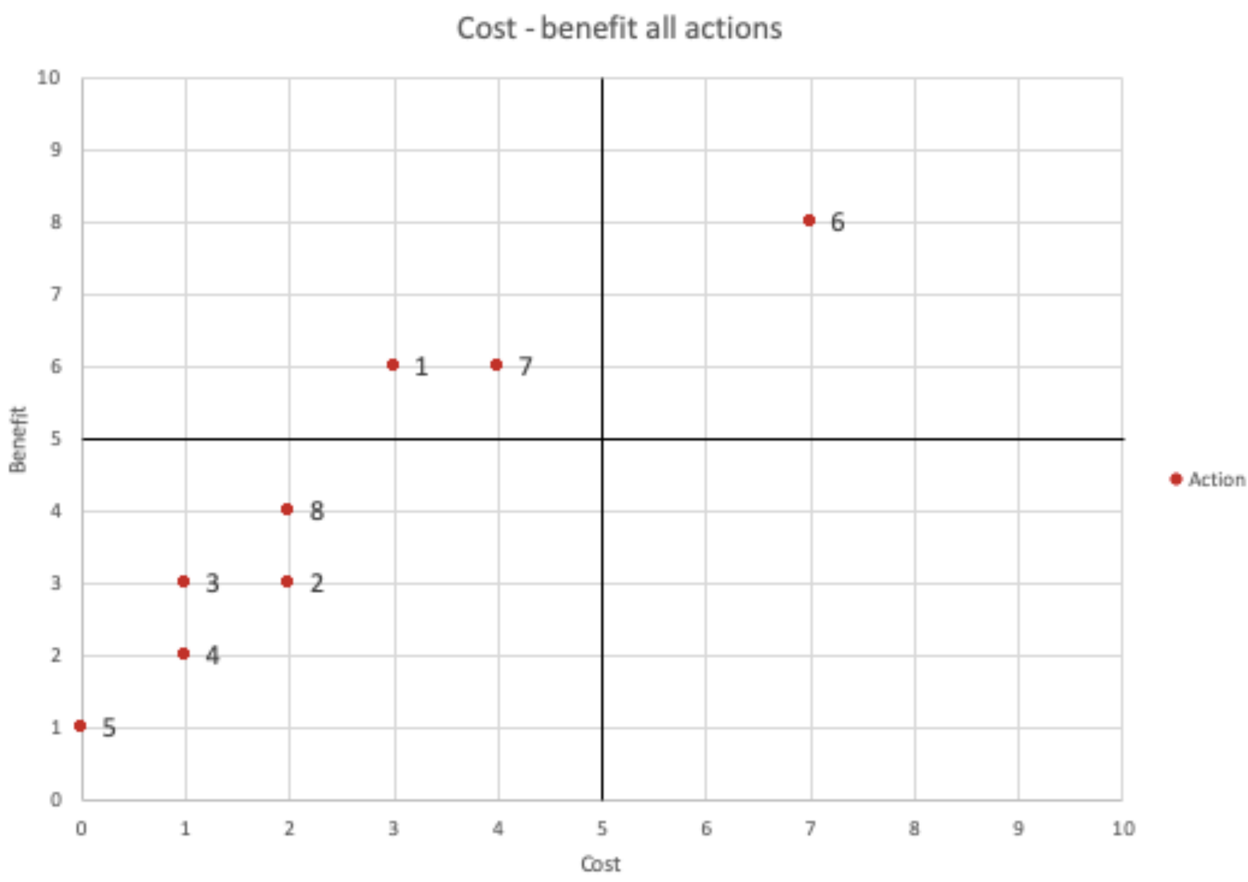

Figure 28: Cost - Benefit diagram for all the recommended actions

As seen, most of the actions is around the diagonal line from (0,0) to (10,10). Most of the actions is either in the "Low cost – low benefit" or "High cost – high benefit" quadrants. Action 1 and 7 is on the other hand in the "low cost – high benefit" quadrant and is therefore suggested to focus on. Further, the actions longest away from the diagonal line between (0,0) and (10,10) are the most recommended ones. This gives as an example action 4 and 5 the same prioritizing. To sort between the actions with the same distance to the diagonal line, some decisions has been made by the author. As an example, it is suggested that action 5, that has zero cost, will be prioritized over action 4 because there is no loss in implementing overweight as a KPI in production.

The suggested prioritized list is therefore:

1. Improved startup and shutdown SOP (action 1)
2. All waste actions Småsulten bars (action 7)
3. Implement SPC to reduce variation (action 8)
4. Set the weight specifications more adequate (action 3)
5. Overweight as a KPI (action 5)
6. All waste actions New Energy (action 6)
7. Standardized routines and better training of operators (action 2)
8. Set clear action rules for weight increase/reduction (action 4)

This cost – benefit diagram, and the corresponding prioritized list is based on some rough estimates done by the author. The factory should look more detailed into the suggested actions and revise the cost – benefit diagram. The actions regarding waste has a lot of smaller actions underneath the overall action, some more important than others. Some of these actions on their own would be useful.

It is advised that the top part of the list should be looked on. The factory must take into account what they have the opportunity to invest time and money on. Maybe it is reasonable for them to start with the "low cost – low benefit" actions rather than the "high cost – high benefit" ones if the time or economic is tight at the moment. All of these actions, in addition to some smaller ones presented in this chapter, is assumed to help save the factory a significant volume and FTEs yearly

This will be further concluded, summarized and discussed in the following chapter.

Chapter 6: Conclusion

This final chapter is concluding the findings of this thesis. A summary of the main findings regarding the RQs, linked to the problem statement, are presented. A summary of RQ1b, RQ2c and RQ3c, which is about the total estimated savings, are presented to summarize the total estimated savings of project Opal. Further the already implemented actions at the Conbar line is presented and discussed. Lastly some future research regarding this thesis is presented. Some of these suggestions is something Orkla ASA or Nidar may consider look into. These may also be of relevance to other production companies.

6.1 Main Findings

This subchapter presents a summary of all the main suggested improvements and the corresponding RQs. In addition, a summary of the total estimated savings from the suggested improvements, is presented.

6.1.1 Answer to RQs and Problem Statement

In this thesis a lot of observations, recommended actions, and corresponding savings have been presented. Now all of this information is presented together to get an overall understanding of what the conclusion to the RQs, problem statement and the whole thesis are. To be able to answer the problem statement, and make an overall conclusion, the RQs are again presented with a summary of the answers. This is found in Table 13.

Table 13: Summary of the RQs and corresponding answers

Area	RQs	Summary of answer to RQs
RQ1: Increase OEE	RQ1a: How may Nidar improve their OEE at the Conbar line regarding startup and shutdown routines at the New Energy and Småsulten products	Nidar may improve their OEE regarding startup and shut down by these actions: - Introduce clear procedures to the operators about what to do when technical difficulties occur on line. - Improving SOP for startup and shutdown - Stabilizing the process (PFMEA and SPC) - Look at the actual shutdown routines; do they have to be as comprehensive and time consuming as they are today?
	RQ1b: How much is it possible to save from these actions?	It is possible to save this yearly on the improvements: - Halving the startup time, New Energy: 0,190 FTE - Halving the startup time, Småsulten: 0,248 FTE - Reduce shutdown time with 30 minutes, New Energy: 0,079 FTE - Reduce manpower by one person on evening shift for shutdown of Småsulten: 0,183 FTE
RQ2: Overweight reduction	RQ2a: How much overweight does the Conbar line at Nidar have in total?	The total yearly overweight on the Conbar line is about 30,5 tons
	RQ2b: How may Nidar reduce their overweight at all the products produced at the Conbar line?	Nidar may reduce overweight by: - Stabilizing the process (PFMEA and SPC) - Making better weight specifications on the products - Having action plans for when and how to act if the weight is outside the accepted limits - Set overweight as an KPI
	RQ2c: How high amount of overweight volumes are possible to save from these actions?	It is stated that it is possible to save 50% to 95% of the overweight on the products, depending on the product. This gives a total saving of about 26 tons yearly.
RQ3: Waste reduction	RQ3a: How much waste does the New Energy and Småsulten products at Nidar have in total, and what is causing the waste?	The approximately yearly waste, including overweight, is: - New Energy: 70 tons - Småsulten: 40 tons The location of the waste on line can be seen in Figure 16 and Figure 17.
	RQ3b: How may Nidar reduce their waste of the New Energy and Småsulten products?	A long list of suggested actions can be found for New Energy and Småsulten respectively in Table 9 and Table 10.
	RQ3c: How high amount of waste volumes are possible to save from these actions?	The volumes possible to save from waste are: - New energy including overweight: 36 tons - New Energy excluding overweight: 27 tons - Småsulten including overweight: 21 tons - Småsulten excluding overweight: 17 tons

This is the overall summary of the RQs. More details on each of the RQs are discussed in previous chapters. The answer to the RQs show how OEE may be increased, and overweight and waste decreased by using SPC and PFMEA from the ICCM toolbox, among other actions. Table 13 presents the answer to the problem statement, which is:

> *"How may the Conbar line at Nidar increase their OEE and at the same time decrease the waste and overweight of their products using the tools included in the Identify, Control, Capable and Maintain (ICCM) methodology like SPC and PFMEA?"*

A long list of recommended actions has been presented, some actions more comprehensive than others. Therefore, the author has made a cost – benefit diagram to show which actions to focus most on. These may be found for the specific waste actions for New Energy and Småsulten bars respectively in Figure 18 and Figure 19. The general summary of all actions is found in Figure 28. It is not certain that all of these improvements and savings will be met. On the other hand, the findings indicate that there are actions with potential for savings that Nidar is recommended to consider. In addition, most of the findings in this thesis may be used on other products, lines and factories as well. The findings implicate that there are some great improvement possibilities for Nidar, and probably Orkla ASA as well.

3.1.2 Summary of Savings from Suggested Improvements

The total FTE and weight savings from the project work are summarized and presented in Table 14.

Table 14: Summary of main improvements and corresponding savings

Area	Main improvements	Estimated savings (FTE)	Estimated savings (tons)
OEE	Reduced startup time for New Energy and Småsulten bars by 50%	0,438	
	Reduced shutdown time for New Energy by 30 minutes	0,079	
	Reduced manpower with one operator the whole evening shift (Småsulten bars)	0,183	
Overweight	Decrease in overweight, all products		26
Waste	Reduced waste actions New Energy (not including overweight)		27
	Reduced waste on Småsulten bars (not including overweight)		17
Total		**0,700 FTE**	**70 tons**

As seen, the total earnings from the suggested improvements in this thesis are about 0,700 FTE and 70 tons of product. This is a summary of RQ1b, RQ2c and RQ3c.

The savings regarding OEE and waste is just for the two products New Energy and Småsulten bars. Doing these analyses on other products on the Conbar line would give even more savings. Even using the suggested improvements directly on the other products would probably make some savings.

6.2 What has already been Implemented at Nidar?

14th of May 2019 the author was in contact with the factory to get information on how much of the improvement actions that has been implemented after the project execution. Due to some time-consuming reorganizations internally in Nidar, not as many of the actions as expected had been implemented. Nidar stated that none of the actions presented has been disregarded, which is good, as it means that the actions are realistic and will be worked on to some degree.

Some of the waste actions regarding Småsulten have already been implemented and seems to be working. Some of the actions have to be modified further, but the fact that these actions already works are very promising. These actions have made it possible to increase the velocity of the line, from 13 to 15 beats per minute. In addition, the reduced manpower on the evening shift is tried, and seems to be working, or will at least be working with some modifications. Some of the operators find this action difficult accept, which is understandable. This must be further worked on, so that the operators are satisfied at the same time as operating a more efficient line. When the other actions will be implemented, this reduction of manpower should be easier to operate with.

Lastly the line manager has seen a tendency to reduced waste generally on the line until now this year. He believes that this comes from the increased focus on waste reduction that has been during the project execution. This indicates that focusing on certain problems may in a way help reduce the problem, with no further actions than the focus.

The recommendation is that the factory works further to implement as many actions as possible and continuously evaluate the savings. This seems promising to the factory.

6.3 Further Research

It is again important to state that this project focused mainly on two products, on one line, on one factory in one company. Doing some of the same analyzes, or even just directly implement some of the recommended actions to other products, lines or even factories, would be of interest. It is therefore suggested that Nidar uses this information, first of all on the two products investigated on the Conbar line, but also takes the initiative to use the new knowledge on other products, and other lines.

In addition, the PFMEA workshops was very useful for the project team, line managers and the operators. This is something that Nidar should take with them and do the analysis on several different processes they are struggling with. A lot of new information was shared, which was useful for everyone. The operators sit on some information the managers do not know of, and the opposite way.

The SPC diagrams should be implemented at the factory and be followed up to see how the operators use them. The actual benefit from using them should be investigated, to see if they actually do help stabilize the process. If the PBCs is helping, several different measures should be considered using SPC on.

Lastly, other actions could have been presented, and investigated further. Maybe in-line weights, laser measures or automatic viscosity measurer would be useful? Maybe the line could be changed to make the process more stable, or make it easier to reuse the waste? This could be done by Nidar visiting other confectionary production factories, probably Orkla ASA owned, and get ideas from how they do certain things. In that way Nidar will have the opportunity to get input on how to make the production more effective and efficient and increase the savings even more.

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Appendix

Appendix 1: Excerpt from the Weight Directive

(The Council of the European Communities, 1976)

2.4. The tolerable negative error in the contents of a prepackage is fixed in accordance with the table below, in which products are divided into two classes ('A' and 'B'), as set out in 2.5 and 2.6 below, according to their physical characteristics and/or the packaging processes which they undergo and the values of the nominal quantities.

Nominal quantity Qn, in grammes or millilitres	Tolerable negative errors			
	Class 'A'		Class 'B'	
	as a % of Qn	g or ml	as a % of Qn	g or ml
above 5 and less than 25	—	—	9	—
from 25 to 50	4·5	—	9	—
from 50 to 100	—	2·25	—	4·5
from 100 to 200	2·25	—	4·5	—
from 200 to 300	—	4·5	—	9
from 300 to 500	1·5	—	3	—
from 500 to 1 000	—	7·5	—	15
from 1 000 to 10 000	0·75	—	1·5	—

When using the table, the values of the tolerable negative errors shown as percentages in the table, calculated in units of weight or volume, shall be rounded up to the nearest one tenth of a gramme or millilitre.

2.5. The following products shall be considered as belonging to Class 'A':

(a) products which are solid or difficult to pour at the selling stage but which can be made sufficiently fluid in the course of packaging, and which do not contain any apparent solid or gaseous elements, and can be packaged in a single operation,

(b) products in powder form,

(c) products composed of pieces, fragments or grains, the unit weight of which does not exceed one third of the tolerable negative error corresponding to the nominal weight of the contents of the prepackage in the Class 'A' column of the table in 2.4,

(d) paste products which are easily spread,

in so far as these products, once they are weighed or packaged, are not subject to further processing or are only subject to processing which does not alter the actual quantity of the contents.

2.6. All products which do not fall within the class described in 2.5 shall belong to Class 'B'. The following shall also be considered as belonging to Class 'B':

(a) liquid products,

(b) prepackaged products of a nominal weight or volume less than 25 g or 25 ml,

(c) products with rheological properties (e.g. fluidity or viscosity) or density when flowing which cannot be kept sufficiently constant by appropriate technical means.

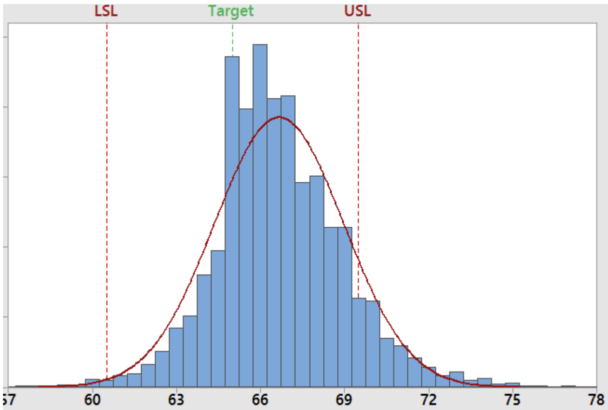
Appendix 2: Scaling Factors for PBCs

(Wheeler and Chambers, 2010)

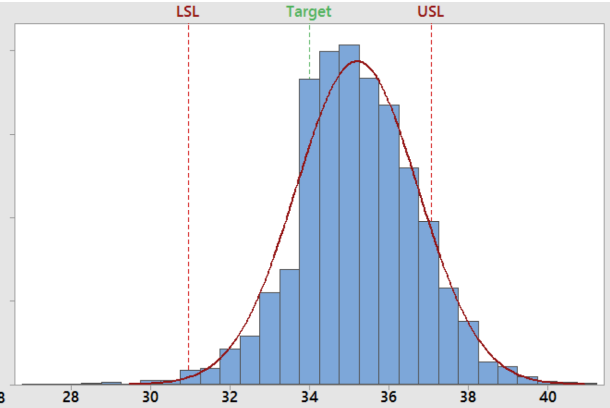
n	A_2	D_3	D_4
2	1,880	-	3,268
3	1,023	-	2,574
4	0,729	-	2,282
5	0,577	-	2,114
6	0,483	-	2,004
7	0,419	0,076	1,924
8	0,373	0,136	1,864
9	0,337	0,184	1,816
10	0,308	0,223	1,777

n = subgroup size

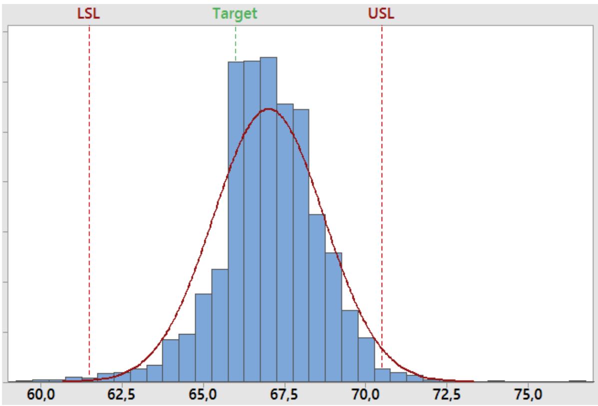
Appendix 3: Minitab Histograms of Overweight on Other Products on the Conbar Line



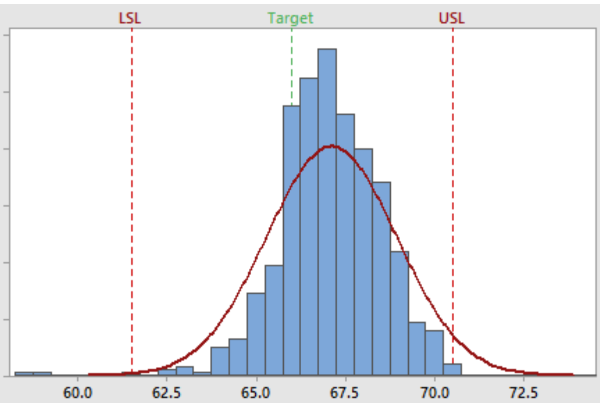
Gullbrød



Smash bar



Troika



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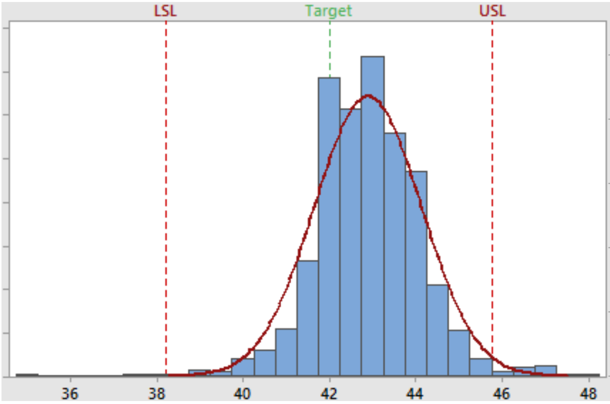

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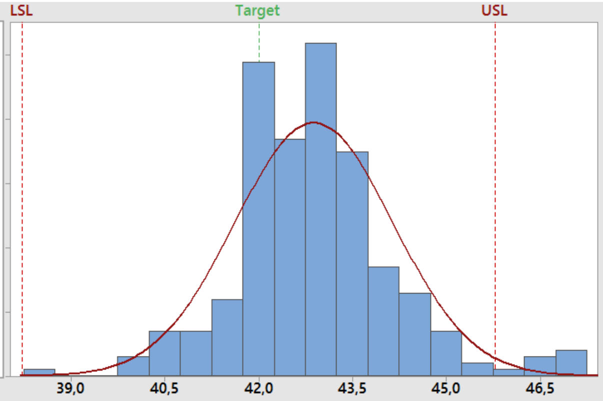
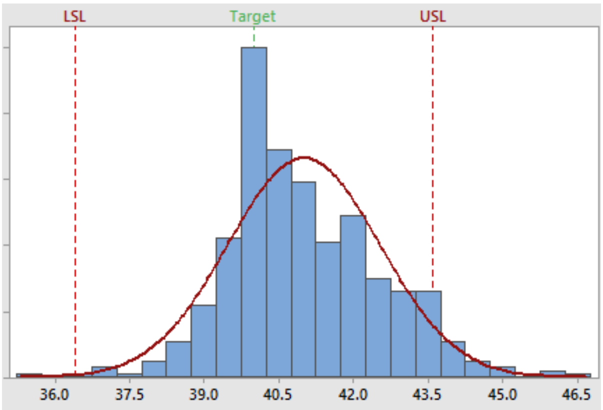


Mokkatrøffel



Vill bar

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