Improving the allocation of cream for FrieslandCampina

Master thesis at FrieslandCampina

By

S.A. (Sjoerd) Welling

January 2021

Examination committee

P.C. Schuur – University of Twente

W.J.A. van Heeswijk – University of Twente

Léon Pelgrim - FrieslandCampina

Educational Institution

University of Twente

Department of Industrial Engineering and Business Information Systems

Educational Program

Master Industrial Engineering and Management

Specialization: Production and Logistics Management

Orientation: Supply chain and Transportation Management

Preface

With this thesis, I finish my master Industrial Engineering and Management and thereby I also finish my life as a student. Before doing so, I would like to thank a few people who supported me during the period of doing this graduation research.

First of all, I want to thank FrieslandCampina for giving me the opportunity to write my thesis at their company. My special thanks go to Léon Pelgrim for being my supervisor. You were always willing to help me and I learned a lot from you. I would also like to thank my colleagues at FrieslandCampina for being very welcoming and helpful while doing my research at your departments. Despite the challenging conditions due to the Corona-virus, you continued to help me through the process of writing my thesis.

I also want to thank Peter Schuur for being my first supervisor at the University of Twente. Peter supported me by keeping the right focus during this research. I appreciate your enthusiasm and stories during our meetings. Furthermore, I would like to thank Wouter van Heeswijk for being my second supervisor and for providing feedback in the final phase of writing my thesis, which has been very useful.

Moreover, I would like to thank my family, my fellow students, my friends and my roommates for supporting me during my whole study-time. I am thankful for the great time and I am excited to start with the first steps of my professional career.

I hope you enjoy reading this thesis.

Sjoerd Welling

Enschede, 18-1-2021

Management Summary

In this thesis we analyse the cream stream of the Dutch dairy multinational FrieslandCampina (Hereafter, FC). First, we explain the problem and give the motivation of this research. Subsequently, we analyse the data and elaborate on the causes of the main problem. Then, we come up with solutions on how to improve the allocation of cream and provide recommendations for the company.

Problem description

Cream is a by-product of raw milk and within FC this by-product is released on several different production locations. The cream is a residual for most of the factories, but the three butter and butteroil factories, located in Noordwijk, Den Bosch and Lochem, use this cream as an input to produce butter(oil). At this moment, the process of allocating cream is not functioning well. The amount of cream that is supplied at the production locations differs a lot from what was planned by the department Milk Logistics, located at the head office in Amersfoort. This is a problem since the planning process is time consuming, the deviation affects the efficiency of the plans and the right products cannot be made. Due to all these problems, the planners experience a lot of pressure, which leads to frustrations between planners on different departments. The problem is known for years, but since 2019 the problem is more serious than before. Not only the deviation in cream supply became bigger, but since the sales department changed the strategy from partly demand-driven selling to completely demand-driven selling the consequences are bigger as well. The main research question of this research is:

How can FrieslandCampina organize the cream supply chain in order to improve the performance of the three butter(oil) factories?

The goal of this research is to analyse the impact of the problem, get to know the causes and provide recommendations that aim to improve the allocation process of cream within FC.

Analysis of the current situation

When analysing the data, we observe that most problems are caused on a daily basis instead of on a weekly basis. On a weekly basis, Milk Logistics predict the amount of cream that flows into the company quite accurately. However, when we investigate the planning on a daily basis, we note that the deviation is substantial, as presented in Table 0.1.

Location	Average absolute deviation of cream per day in tonnes	Average absolute deviation of cream per day in percentage
Den Bosch	66.77	28.75%
Lochem	85.14	20.46%
Noordwijk	50.93	13.45%

Table 0.1: Average absolute deviation of supplied cream between what was planned by Milk Logistics and what was supplied on day level in tonnes

For the location Den Bosch the average absolute deviation between what was planned and what was supplied is on average nearly 30%, which means that on average 30% more or less cream streams into the factory than expected. When looking at the actual differences in tonnes of cream, we see that in Lochem the deviation is on average 85 tonnes a day, which takes nearly three hours of production. During the research it turns out that there are four root causes that cause the deviation in cream supply between what was planned and what was realised. First, there is a lot of uncertainty in the supply of cream. Next, there are a lot of unclarities in the data, mainly caused by the software and how the different production locations use the software. Next, the planning on a daily level is inaccurate. This is because the planners on Milk Logistics do not spend a lot of time on making the planning on a daily level accurate and the seasonality is not included. Finally, the focus on the company is lacking, the employees mainly focus on the performance of their own departments.

Results

In order to improve the allocating process of cream, we come up with a model that allocates and valorises the available cream. This model is related to the valorisation model that has been used in the whey supply chain for years. Before we introduce the model, the input values of the model have to be improved, by solving the unclarities and by improving the forecasts on day level. The cream valorisation model is a mixed integer linear programming model, and the goal is to maximise the profit given all input variables and constraints. It considers the demand per product category, the cream supply, the margin per order, the transport cost and the storage and machine capacity of the different locations. At the moment, the location Noordwijk gets priority over Den Bosch and Lochem. In the model, we change the strategy of prioritising the cream per location into prioritising per order when allocating the cream.

The cream valorisation model is useful for multiple purposes. It maximises margin gained from sales of FC by allocating the cream in such a way that orders with the highest margin can be produced. The model helps Milk Logistics to allocate the cream since it provides as output how much cream from a certain location must be transported to another location. The model specifies how many products of each product category should be produced on each production location, so it helps the production planners to come up with an more efficient production planning. Also, when there are changes in the supply of cream, the model can be used to calculate how to handle those changes. When the model is implemented, it is necessary to do further research on the costs of production and transport. This helps the company in making a trade-off between what is leading, low transportation costs and a less reliable supply or a reliable cream supply and higher transportation costs. This subject we leave for further research.

Implementation

To implement the solutions, we come up with a roadmap, as shown in Figure 0.1. When implementing all phases of this roadmap, the company should be able to improve the cream allocation process.

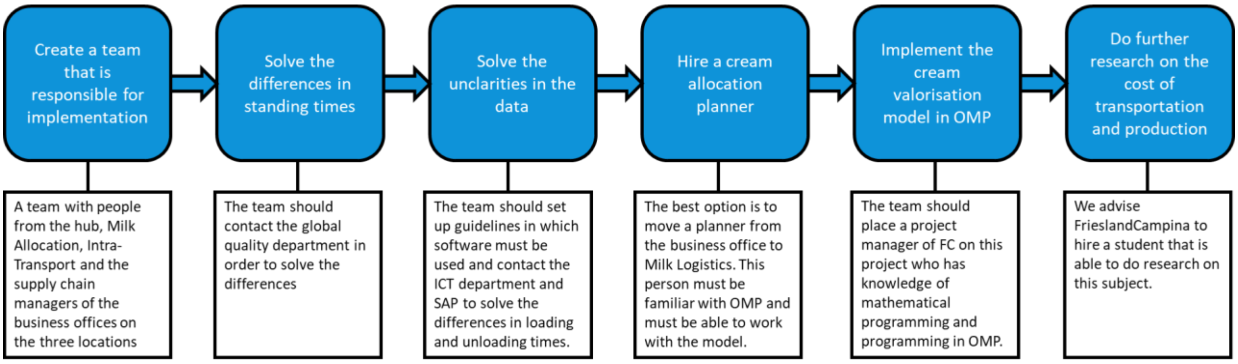

Figure 0.1: Roadmap for implementing the solutions

Table of Contents

Preface i
Management Summary ii
Table of Contents iv
List of Figures vi
List of Tables viii
List of terms and abbreviations ix
1. Introduction 10
1.1 Introduction to FrieslandCampina 10
1.2 Research Motivation 11
1.3 Problem description 12
1.4 Research questions 14
1.5 Research methodology 15
1.6 Scope 16
1.7 Deliverables 16
2. Current Situation 17
2.1 Production process 17
2.2 Allocation process 22
2.3 Ordering process 28
2.4 KPIs 29
2.5 Conclusions on the current situation 31
3. Analysing the performance of the allocation of cream 32
3.1 Causes 32
3.2 Deviation 37
3.3 Consequences 43
3.4 Conclusions on the data analysis 48
4. Literature Review 50
4.1 What kind of allocating strategies are there in general? 50
4.2 What aspects are important in the dairy supply chain? 54
4.3 What allocating strategies are suitable for the dairy supply chain? 56
4.4 Conclusions on literature 58
5. Solution design 59
5.1 Whey process 59
5.2 Which problems are we going to solve? 61
5.3 Uncertainty 63

5.4 Conclusions on solution design 64
6. Solutions 65
6.1 Solving the unclarities 65
6.2 Improving the forecasts on a daily level 66
6.3 Cream valorisation model 69
6.4 Trade-off between production and transport 79
6.5 Conclusions on the solutions 80
7. Making the model work 81
7.1 Solving the unclarities 81
7.2 Improving the planning on day level 81
7.3 Cream Valorisation Model 81
7.4 Trade-off between production and transport 85
7.5 Roadmap for implementation 86
8. Discussion and limitations 87
9. Conclusion and recommendation 89
9.1 Conclusions 89
9.2 Practical recommendations 90
9.3 Further research 91
References 92
Appendix 95
A. Multiple other scenarios to validate the model 95
B. Input variables of the cream valorisation model 98
C. Programming code AIMMS 103
D. Output variables of the cream valorisation model 107

List of Figures

Figure 0.1: Roadmap for implementing the solutions iii

Figure 1.1: Organisational structure within FrieslandCampina, the highlighted circle is the OpCo where this research takes place 10

Figure 1.2: Order fulfilment process 12

Figure 2.1: Pre-processing of raw milk 18

Figure 2.2: Dairy flows (Banaszewska et al., 2013). 19

Figure 2.3: Butter production process 21

Figure 2.4: Butteroil production process 21

Figure 2.5: Organization structure Milk Logistics (located on the head office) 23

Figure 2.6: Process of making the week plan 24

Figure 2.7: Cream locations (Google Maps, 2020), where = cream supply location and = cream processing location 25

Figure 2.8: Milkplan used at the business office (units in tonnes (1000 kg)) 27

Figure 2.9: Overview of the plans within the allocation process of cream and which department is responsible for the planning. 28

Figure 3.1: Composition of the milk throughout the year (Banaszewska, 2013, original source FrieslandCampina) 33

Figure 3.2: Example of the difference in loading and unloading times, the marked boxes present the trucks that are moved to the next day (FrieslandCampina Lochem, 2020) 35

Figure 3.3: Absolute deviation in total cream supply between the AP and the actuals per week, calculated by: 100% - (absolute value of (tonnes of cream planned in the AP – tonnes of cream supplied)) / (tonnes of cream planned in the AP) 38

Figure 3.4: Absolute deviation in cream supply per location between the AP and the actuals per week, calculated by: 100% - (absolute value of (tonnes of cream planned in the AP – tonnes of cream supplied)) / (tonnes of cream planned in the AP) 39

Figure 3.5: Absolute deviation in total cream supply between the WP and the actuals per week, calculated by: 100% - (absolute value of (tonnes of cream planned in the WP – tonnes of cream supplied)) / (tonnes of cream planned in the WP) 40

Figure 3.6: Absolute deviation in cream per location supply between the WP and the actuals per week, calculated by: 100% - (absolute value of (tonnes of cream planned in the WP – tonnes of cream supplied)) / (tonnes of cream planned in the WP) 40

Figure 3.7: Average deviation between what was planned by Milk Allocation and what was supplied on day level, where blue is the absolute deviation and orange is the real deviation 41

Figure 3.8: Average deviation between what was planned by Milk Allocation and what was supplied per location per month (on a daily basis) 42

Figure 3.9: Average deviation between what was planned by Milk Allocation and what was supplied per location per day (on a daily basis) 43

Figure 3.10: Percentage of the times a category causes deviation on a product order 45

Figure 3.11: Absolute difference (ordered by customer – produced by a production location) caused by category (units in tonnes of end product) 46

Figure 3.12: Difference (ordered by customer – produced by production location) in what was ordered and what was produced per product type (butter) (units in tonnes of end product) 47

Figure 3.13: Difference (ordered by customer – produced by production location) in what was ordered and what was produced per product type (butteroil) (units in tonnes of end product) 47

Figure 3.14: Causes and consequences of the main problem of this research 49

Figure 4.1: Classical optimization models, adapted from Talbi (2009) 52

Figure 4.2: Classical optimization methods, adapted from Talbi (2009) 52

Figure 4.3: Relation between the planning levels and the optimization methods, retrieved from Talbi (2009) 54

Figure 4.4: Seven key challenges in the dairy supply chain (Mor, Bhardwaj and Singh, 2018d) 55

Figure 4.5: Distribution of the studies according to the mathematical programming, retrieved from Nematollahi & Tajbakhsh (2020 57

Figure 5.1: Whey valorisation model, adapted from Banaszewska et al., 2014, where IDVM = Integral Dairy Valorisation Model 60

Figure 5.2: Products where the milk in the EU is used for (Eurostat, 2018) 62

Figure 6.1: Real deviation between what was planned by Milk Allocation and what was supplied, where blue is the average deviation without seasonality and orange the average deviation with seasonality. 68

Figure 6.2: Example of the resource capacity of two orders, order A and order B 73

Figure 6.3: Input parameters of the simplified version of the model 76

Figure 6.4: Output of the simplified model in the current situation, where the cream is prioritised per location 77

Figure 6.5: Output of the simplified model in the proposed situation, where the cream is prioritised per order 78

Figure 7.1: Part of the output data of the cream valorisation model (values in tonnes of cream) 84

Figure 7.2: Volume of sold end products, compared with the demand 85

List of Tables

Table 0.1: Average absolute deviation of supplied cream between what was planned by Milk Logistics and what was supplied on day level in tonnes ii

Table 1.1: Research Methodology per chapter 16

Table 2.1: Categories of causes of deviation in order supply 30

Table 3.1: Overview of the root causes and causes of the problem 32

Table 3.2: Average absolute deviation of supplied cream between what was planned by Milk Allocation and what was supplied on day level in tonnes 42

Table 6.1: Day seasonality indices 67

Table 6.2: Month seasonality indices 67

Table 6.3: Indices and sets used in the cream valorisation model 70

Table 6.4: Parameters used in the cream valorisation model 71

Table 6.5: Variables used in the cream valorisation model 72

Table 7.1: Product categories used to test the model 82

List of terms and abbreviations

Allocation Plan = 13-week planning (made by MVA together with Milk Allocation) on how much a production location will get from each milk stream

BMP = Buttermilk powder

BP = By-product

Butterhub = Hub specific for butter and butteroil

DC = Distribution Centre

Day plan = Plan made by Milk Allocation on how much cream a production location will get the next day

EVAP = Evaporated milk

HP = Half-product

Hub = Department responsible for the supply and demand network planning

IFCMP = Instant full cream milk powder

IF/GUM = Infant food and growing-up milk powder

Logistic day = A complete day used in production and is from 06:00 till 05:59 the next day

MILP = Mixed Integer Linear Programming

MVA = Milk Valorisation and Allocation, department in Amersfoort

Pre-factory = Part of the factory where the raw milk and cream will be pasteurized and stored

Production planning = Planning made by the business office on machine line level

RM = RMO-Milk = Raw milk = Milk directly from the farmer

RMO = Raw milk reception (in Dutch: Rijdende Melk Ontvangst)

SCM = Sweetened condensed milk

SMP = Skim milk powder

StdMilks = Standardized milks

Transport planning = Planning for the transport for intercompany trip made by Intra-Transport in Amersfoort

WAB = New law in the Netherlands for temporarily workers (in Dutch: Wet Arbeidsmarkt in Balans)

Week plan = One-week plan (issued by Milk Allocation) on how much ingredients a production location will get next week

WMP = Whole milk powder

1. Introduction

The chapter introduces this thesis as part of the master's degree in Industrial Engineering and Management, executed at the dairy multinational FrieslandCampina on production location Lochem and focussing on the allocation of the dairy by-product cream. We begin with a small introduction to the company in Section 1.1 and the department where this research takes place. Next, in Section 1.2 we provide the motivation for this research and explain the problem in Section 1.3. Next, in Section 1.4 we clarify the problem approach and set up the research questions and sub-questions. Lastly, we explain the research methodology in Section 1.5, define the scope in Section 1.6 and list the deliverables in Section 1.7.

1.1 Introduction to FrieslandCampina

FrieslandCampina is a Dutch dairy cooperation and is one of the ten biggest dairy companies of the world. The company is owned by a cooperative of 17,400 farmers from the Netherlands, Germany and Belgium. The head office is in Amersfoort and the company has facilities in 36 countries. On a yearly basis, the organisation has a revenue of 11.3 billion euros and worldwide, the company has 23,816 employees (FrieslandCampina, 2019).

The company is divided in four different business groups, as shown in Figure 1.1. This research is executed within the business group Dairy Essentials. This business group is business partner-driven and produces non-branded products such as cheese, butter and milk powder. The business group is responsible for 65% of the inflowing milk and is specialized in producing large volumes. As shown in Figure 1.1, one business group consists of multiple Operating Companies (OpCos). This research is done within the OpCo: 'Butter and Milkpowder B2B'.

Figure 1.1: Organisational structure within FrieslandCampina, the highlighted circle is the OpCo where this research takes place

1.1.1 Butter and Milkpowder B2B

The OpCo Butter and Milkpowder B2B consists of six production locations, five in the Netherlands and one in Belgium: Noordwijk, Den Bosch, Lochem, Leeuwarden, Gerkesklooster and Aalter (Belgium). It sells butter, butteroil, cream, blends and various types of milk powders, mainly to its business partners in the food industry, such as chocolate factories or bakeries. Most of the customers are located in Europe, Asia or Northern Africa. The OpCo contributes 1.7 billion euros of revenue to the business, which means that this OpCo is one of the biggest OpCos of FrieslandCampina.

In this research we focus on the allocation of cream. There are three production locations that process cream, namely Lochem, Noordwijk (in the province Groningen) and Den Bosch. Therefore, we consider these three production factories in this research. Next to that, the planning process of allocating cream, which is done in Amersfoort, is considered as well. The research was introduced by people from the business office in Lochem. The business office is responsible for work preparation, the production planning, and the logistics of the factory.

The production location Lochem is responsible for 200 FTEs and processes 1 billion kilograms of raw materials a year, which is about 10% of all FrieslandCampina milk, making Lochem one of the bigger production locations. The production takes place continuously, like most of the production locations. On the location Lochem, there are three different factories, namely butter / butteroil, milk powder and milk prism (milk that is treated differently). The milk prism factory in Lochem is part of the OpCo DOMO, which is an OpCo of the business group Ingredients and therefore this factory is not considered in this research. Also, the milk powder factory will not be considered since the milk powder factory do not process any cream. In Den Bosch there is a butter factory and in Noordwijk there is a butteroil factory.

1.2 Research Motivation

Within the cooperation of FrieslandCampina (FC), on a lot of different locations the raw milk is skimmed, which means that the milk will be separated from the fat. In this process skimmed milk and cream is released. The cream is for a lot of FC factories considered as residual, but in other factories the cream is an input to produce other dairy products, i.e. butter and butteroil. Within the OpCo Butter and Milkpowder there are three production locations that process the cream, namely Den Bosch, Noordwijk and Lochem. The amount of cream that each location gets, is allocated by the department 'Milk Logistics' in Amersfoort.

The process of allocating cream is not functioning well. The amount of cream that is supplied at the butter and butteroil factories differs a lot from what was planned. Sometimes the amount of cream is much more than planned, while in other cases the amount of cream is not enough. Within the production process the factories suffer from this deviation, for example the business office must adjust their machine schedule often, the production operators cannot prepare the production in advance and the production locations have difficulties with reaching the customer supply reliability goals.

The problem is well known for years, but since 2019 the problem is bigger than before. Not only the deviation became bigger, but since the company changed the way of working in the sales a year ago, the consequences of the problem are bigger as well. In the past the company sold approximately 80% of the orders before it was produced, now the company strives to sell all products in advantage, which means that the flexibility in which product should be produced is gone. It is not possible to store the cream for more than two or three days due to the perishable nature of cream. Therefore, the strategy of demand driven producing causes a lot of pressure on the planning departments. Five years ago, the company created a project team with internal employees to solve this problem. The deviation became less for some time, but these solutions were not structural, so the company fell back in their old habits.

The goal of the research is to analyse the impact of the problem on the production locations, get to know the causes and to improve the situation.

1.3 Problem description

FC is a big company, and therefore there are a lot of parties involved in the planning process. In order to understand the planning process, we need to know the order fulfilment process, as shown in Figure 1.2.

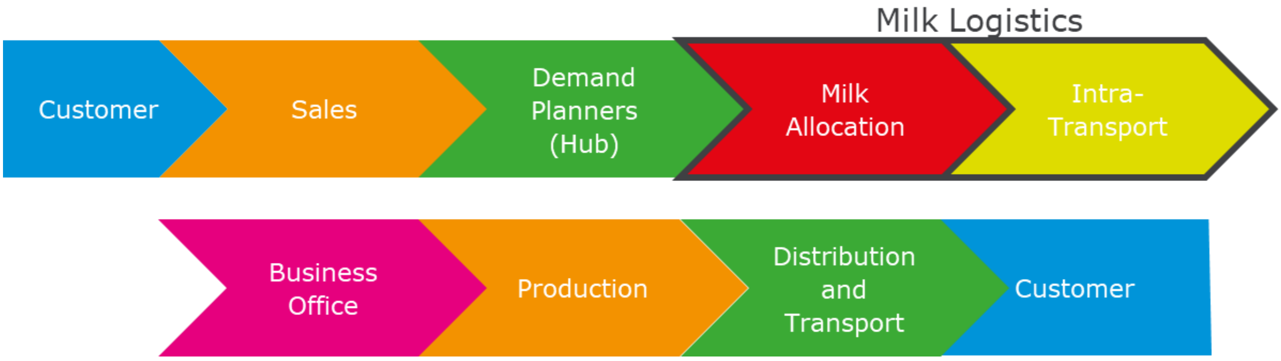

Figure 1.2: Order fulfilment process

Most of the involved departments (Sales, Demand Planners, Milk Logistics and the planning for Distribution and Transport) are located at the head office in Amersfoort. The Business Office is located at the production locations, where the production finds place.

The order fulfilment process goes as follows: First, a customer places an order via the sales department of FC. Within the OpCo Butter and Milkpowder, all customers are business partners, for example the chocolate manufacturer 'Mars Inc.'. The sales department communicates to the demand planners (the hub) the amount of end products that they can sell. The hub prioritizes the orders and next they send the details to Milk Allocation. This department connects the available cream to the demand and allocates the amount of cream each production location gets on a daily and weekly basis. Next, Intra-Transport makes a transportation schedule. This is a schedule for all internal transportations, so transport from a production location where cream is a residual to a production location where cream can be processed. This schedule gives when a truck will be loaded at a production location and when the truck arrives at the other production location. When this transportation schedule is done, the schedule will be sent to the business office. At the business office, the production planners make a production planning. This planning gives when, which product must be produced on which machine line. The production planners make the production planning on a weekly basis, but they must review this planning a couple of times a day, for example due to failures on a machine line, changes in supply or changes in customer orders. When the end-products are produced, the products are transported to a distribution centre (DC) before being transported to the customer. The production planners plan the transport between the production location and the DC and Milk Logistics plans the transport between the DC and the customer.

What makes the planning process complex, is that all streams are connected to each other. The amount of cream that flows into the company depends on the amount of raw milk and the composition of the milk. The cream is connected to which products are made from the raw milk as well. All dairy products have their own ingredients and production process. In most production processes, next to the end-product, by-products are released. These by-products may be a residual for one production location, but useful for other factories. Examples of by-products are whey, cream, permeate and serum. FrieslandCampina strives to process all milk from their cooperate dairy members and its by-products within their own factories and therefore all dairy-streams must be considered in the allocation process. For streams such as whey and serum, the problem within the planning process is not that big as in the cream allocation.

One of the problems in the allocation process, is that the cream is on the end of the supply chain. Cream is not as valuable as whey and therefore it is considered as a less important by-product. However, there are some important partners that need cream, such as the Mona brand, a brand within the Business Group Consumer Dairy. Because the margins for these partners are higher than the margins from the OpCo 'Butter and Milkpowder B2B', the cream will first be allocated to the important partners. The cream that is not needed for those partners, will be allocated to one of the three butter(oil) factories. The products that are produced in Noordwijk have more priority than products produced in Lochem and Den Bosch. Therefore, when there is deviation regarding to cream in the supply chain, especially Lochem and Den Bosch will suffer from it due to multiple reasons, which are elaborated below.

All these problems lead to one main problem for this research.

> Problem definition:
> *There is a lot of deviation in the amount of cream that is planned and what is delivered to the butter(oil) factories in Lochem, Den Bosch and Noordwijk and the OpCo 'Butter and Milkpowder B2B' suffers from it.*

The defined main problem is a problem because of four main reasons:

- The business office on the production locations must have a lot of FTEs, because it is time consuming to change the production planning frequently. When the amount of cream deviates, not only the planning for the butter(oil) must be adapted, but the planning for other factories, such as milk powder factories, changes as well. This is because changes in the butter(oil) production cause deviation in the number of residuals like serum and buttermilk, which means that the planning from e.g. a milk powder factory is also dependent on the amount of butter(oil) that is produced. Also, the employee schedule changes when the machine planning is changing. When they need more machine capacity, extra (temporary) employees must be hired. It is difficult to hire available employees on short-term, especially with the new legislation in the Netherlands which holds that workers must know if they have to work four days in advance (WAB). When the temporary workers are cancelled within four days in advance, the company must still pay the workers. When the temporary workers are hired within four days in advance, the workers are not obliged to come.

- Since the production planning changes regularly due to changes in the cream supply, the production planning is sub-optimal. The operators in production cannot prepare the production process in advance and the cleaning and maintenance cannot be scheduled on the optimal moments.
- The standard products, such as bulk products, have a lower profit margin. When more cream streams in than was planned, the products that require a lower maximum machine capacity (the specialties) will maybe be cancelled. However, these specialties have in general more profit margin than standard products, so less profit margin is gained. In this case it is not profitable to produce the specialties anyway and destroy the excess amount of cream, since the extra profit cannot cover the cost of wastage. When there is a supply shortage of cream, this can lead to downtime in the factories. In downtime the production locations cannot utilise their employees efficiently and customer orders cannot be produced.
- The business partners (the customers) suffer from the cream deviation through a lower supply reliability of the production locations. When the amount of available cream deviates, the specialties may be cancelled or may be supplied in other amounts or at different moments. This is undesirable because when the supply deviates, the business partners must also change their machine planning.

1.4 Research questions

With the description of the main problem, we can set up the main research question:

Main research question:
How can FrieslandCampina organize the cream supply chain in order to improve the performance of the three butter(oil) factories?

To answer this main research question, we first have to answer the research questions. Each research question represents a chapter in the thesis.

Current Situation – Chapter 2

1. What does the current situation of the cream supply chain look like?
    a. What does the production process of butter and butteroil look like?
    b. What does the allocating process of cream look like?
    c. What does the ordering process of cream products look like?
    d. What Key Performing Indicators (KPIs) are relevant for this research?

Analysis of the performance of the allocation of cream – Chapter 3

2. How big is the deviation between what was planned by Milk Allocation and what was delivered in cream supply and what causes this deviation?
    a. What causes the deviation in cream supply?
    b. How big is the deviation in cream supply?
    c. What are the consequences of the deviation in the supply of cream?

Literature review – Chapter 4

3. What are, according to the literature, possible allocating strategies in the dairy industry?
    a. What kind of allocating strategies are there in general?
    b. What aspects are important in the dairy supply chain?

    c. What allocating strategies are suitable for the dairy supply chain?

Solution design – Chapter 5 + 6

4. Which solutions are possible in order to improve the allocation of cream?
    a. What does the allocating process of whey look like?
    b. How can the input of the model be improved?
    c. What does the proposed cream valorisation model look like?
    d. How should the model be used?

Solution Tests – Chapter 7

5. How can the solutions be implemented?
    a. How should FC implement the improved input variables?
    b. How should FC implement the proposed cream valorisation model?

1.5 Research methodology

In order to answer the research questions, we perform the following actions per research question:

- What does the current situation of the cream supply chain look like? – Chapter 2

This is an important question, because for executing this research, we must have enough knowledge about the current situation of the cream supply chain. For example, we must know how the ordering process is done, how the planning is done and how the production process looks like. In this stage, we do observations, interviews with the planners and allocators on the head office and review the available documents.

- How big is the deviation between what was planned by Milk Allocation and what was delivered in cream supply and what causes this deviation? – Chapter 3

Before we are going to search for solutions for the problem, we first want to know the causes and consequences of the problem. In order to get more insight in the problem, we do a data analysis and try to find patterns in the data that are useful for this research. When looking for causes and consequences of the deviation in cream supply, we again interview the different stakeholders.

- What are, according to the literature, suitable allocating strategies in the dairy industry? – Chapter 4

Since the dairy industry is worldwide a big industry, we can find some useful information in literature. We find out what kind of planning strategies there are in general and look for allocating strategies that are suitable for the dairy supply chain. To answer the research question, we review and analyse relevant papers.

- Which solutions are possible to improve the allocation of cream?– Chapter 5 + 6

We combine the knowledge that is provided during the study on the university with the knowledge of the literature to come up with ideas about how to solve this problem. Together with the managers and problem holders, we look for solutions that are acceptable for all involved parties.

- How should the solutions be implemented at FrieslandCampina? – Chapter 7

In order to make clear what actions must be undertaken to implement the solutions, we provide an implementation plan. We also give more insight in the proposed solutions and make the solutions more concrete.

Table 1.1 gives an overview on the research methodology.

Table 1.1: Research Methodology per chapter

Chapter	Research Question	Subject	Research Methodology
Ch. 2	RQ 1	Current situation	- Interviews - Documentation review - Observations
Ch. 3	RQ 2	Analysis of current situation	- Data analysis - Interviews
Ch. 4	RQ 3	Literature review	- Literature search
Ch. 5 + 6	RQ 4	Solution design	- Case study
Ch. 7	RQ 5	Solution tests	- Case study - Interviews

1.6 Scope

In order to make it possible to finish this research within the given time, we cannot include the complete supply chain of FC and therefore we define a scope:

- Only the supply of basic cream is considered. Next to basic cream, the company processes other types of cream as well, such as Biological cream, Meadow cream, Planet Proof cream and Premium cream. This cream is not processed within the butter and butteroil factories and therefore we do not consider these streams.
- The allocation of raw milk or other by-products is not considered.
- Only cream intended for the OpCo 'Butter and Milkpowder B2B' is analysed. This means that the allocation of cream intended for external business partners is out of scope.
- We only consider the allocation process of cream, which means that we analyse the process from the moment that it is released at a cream supplying location until the moment that it is processed in a butter or butteroil factory. Improvements in stages in the supply chain before or after this allocation process are not considered.
- We focus on allocation strategies solution strategies that can be implemented by the company without huge investments. Therefore, we focus on mathematical programming, since from this subject there is a lot of knowledge within the company and the software to optimise mathematical programming models is available.

1.7 Deliverables

The main deliverable of this research is this report with a description and analysis of the problem and with the proposed solutions. For the solutions, we deliver a mixed integer linear programming model that can partly solve the problem. We also give advice on how to solve some causes of the problem, that must be performed before implementing the model. Furthermore, we give suggestions on which subjects further research is required and come up with an implementation plan for FC on how to improve the cream supply chain.

2. Current Situation

In this chapter we give more information about the processes within FrieslandCampina that are relevant for this research. In Section 2.1, we start with an explanation of the skimming process and describe how all dairy products are connected to each other. We also explain the process of butter and butteroil; the products where cream is the input. Next, in Section 2.2 we make clear how the ordering process is going and in Section 2.3 we explain the allocating process. Next, we explain what KPIs are important for FC and for this research in Section 2.4. At last, we conclude this chapter in Section 2.5.

2.1 Production process

FC milk is produced at more than 12000 different dairy farms in the Netherlands, Belgium and Germany. In order to collect all raw milk from the dairy farmers, FC has various milk trucks (Raw Milk collection trucks (in Dutch: Rijdende Melk Ontvangst), RMOs). The RMO collects the raw milk from multiple farmers in one route and delivers the milk to one of the production locations. The production locations are spread over the Netherlands, Belgium and Germany, so that a dairy farm always has a production location in its neighbourhood. The dairy farmers can be visited by the RMO at all times. When a RMO is arriving at a production location, the milk will be unloaded, and next it flows into the silos where the raw milk is stored until it will be processed.

2.1.1 Skimming process

To split the milk streams, the milk must be pre-processed. The raw milk is heated and subsequently separated by a separator into cream and skimmed milk (in Dutch: Magere melk). Butter and butteroil are made of cream, while most of the skimmed milk is used for the milk powder factory, as shown in Figure 2.1. The separation is also called skimming (in Dutch: ontromen). After separating, the milk and cream will be pasteurised. Pasteurised means that the milk or by-product is heated to a specific temperature for a period of time to make it safe for consumption and to extend the shelf life.

Next, the cream flows into the butter (oil) factory and the skimmed milk flows into the milk powder factory. There is also a possibility that FC wants to produce whole milk powder from the raw milk. Whole milk powder (in Dutch: volle melkpoeder) contains more fat, and therefore the raw milk will not be separated. Instead, the raw milk flows immediately to the milk powder factory after heating and pasteurising.

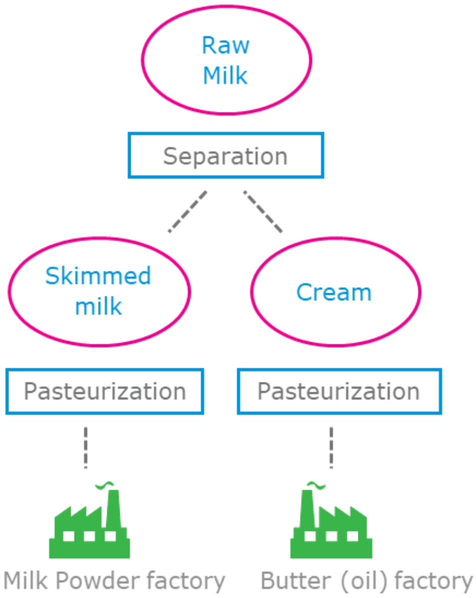

Figure 2.1: Pre-processing of raw milk

This skimming process finds place in a lot of different FC factories. In total, there are approximately 20 factories in the Netherlands, Belgium and Germany where raw milk is separated into skimmed milk and cream. In most of the factories, the cream cannot be processed and therefore it will be transported to another production location.

2.1.2 Dairy product flows

As said in Section 1.3, from raw milk various dairy products can be made. In this section we give some further explanation about the different dairy products.

Raw milk has three main components, namely fat, protein and lactose and next to that, it contains some vitamins, minerals and enzymes. The components determine the percentage of dry matter in the milk, the rest is water. The composition of raw milk varies during the year, due to the living conditions of a dairy cow, the diet and the weather. For example, in the summer when the cows can graze in the meadows, the fat percentage in the raw milk is lower. During the winter, the cows eat concentrates, which will lead to more proteins and fat in the milk. On average the milk consists of 13.2% dry matter: 4.41% fat, 4.51% lactose and 3.47% protein (FrieslandCampina, 2019).

All different dairy products have a specific composition of ingredients and all products have a different production process. Next to the various dairy end products, in the process some by-products and half-products are released. An overview of all dairy flows is given in Figure 2.2.

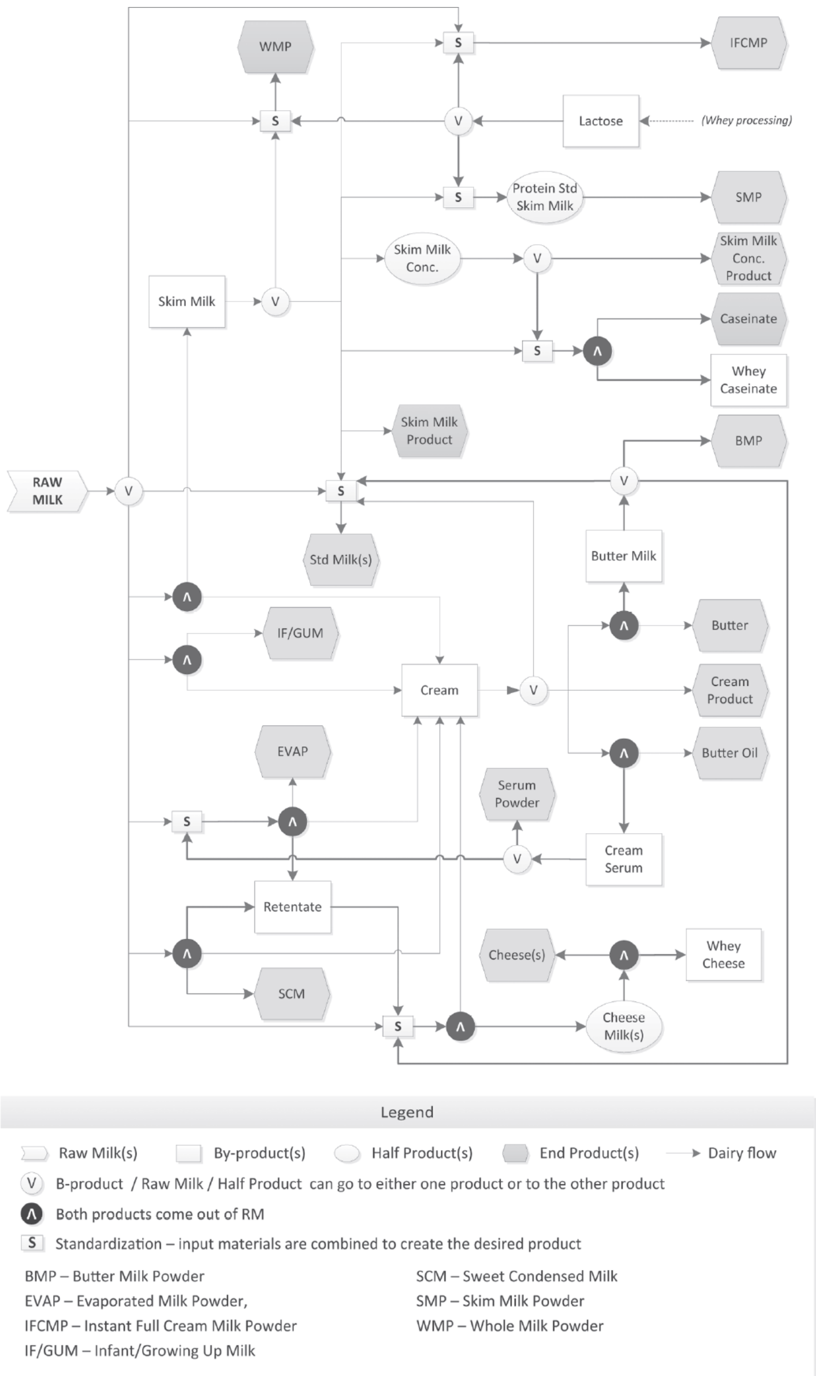

Figure 2.2: Dairy flows (Banaszewska et al., 2013).

The following by-products are relevant for this research:

- Cream: A liquid that has a fat percentage of 35% – 40%. Released in the skimming process of milk, which is done in Lochem, Den Bosch and on 18 other cream supplying locations, such as milk powder and cheese factories. Cream can be used to make butter or butteroil and is an ingredient of desserts and creamy alcohol liquors.
- Skimmed milk: Milk with a fat percentage of maximal 0.3%. The skimmed milk is released from the skimming process in the pre-factories. Powder factories make skimmed milk powder of it.

- Serum: Released from the production of butteroil. The milk powder factory makes serum powder of it, which is an ingredient for various food products.
- Buttermilk: A fermented dairy drink. Released from the production of butter. The buttermilk can be used for consumption, but most of the buttermilk will be powdered in the powder factory.

For the butter and butteroil factories, we are interested in the following end products:

- Butter, 82% fat, used for bakeries for products such as croissants.
- Butteroil, 99.8% fat, used for products such as chocolate.
- Buttermilk powder, used as ingredient for various products such as ice cream.
- Serum powder, used as ingredient for various food products.
- Skimmed milk powder, exported to use for bakeries, infant nutrition or chocolate.

In order to get a good understanding of the allocating and planning process, it is necessary to obtain some knowledge about the production process of butter and butteroil and the kind of constraints planners have to consider.

2.1.3 Butter making process

Butter is a water-in-oil emulsion and consists of 82% fat. To reach this percentage, fat and liquids must be separated. The butter making process involves a lot of stages. In the FC factories, the butter making process is continuous, which means that the butter can be created from cream automatically. Raw milk contains around 4% of fat, this means that 20 kilograms (kg) of raw milk or 2.05 kg of cream that contains 40% fat is needed to make 1 kg of butter. The production process of making butter is as follows:

First, the cream flows from the pre-factory or from a truck that is coming from other production locations into a big silo, a buffer tank. The cream is already pasteurized before it is coming into the butter factory. In the silo the cream is heated in a controlled manner.

Next, the cream must be aged in an aging storage tank. How long it takes to age the butter, depends on the kind of butter the factory produces, but mostly it takes 12 – 15 hours. This process gives the fat a crystalline structure which is needed for the next step. From the aging tank, the cream is pumped into a churn. It flows first in a churning (in Dutch: karnen) cylinder, where the cream is turning around fast. Because of the speed, it is possible to break the fat globules what causes the fat to coagulate into butter grains. The remaining liquid, called buttermilk (in Dutch: karnemelk), is drained off. The buttermilk is ready for consumption, but within FC most of the buttermilk from the butter making process is used to produce buttermilk powder.

After the churning, the butter is a sticky mass. By working the butter, the remaining fluid is dispersed as finely as possible. During the kneading, starter culture, permeate, distillate and/or salt can be added to make specialties. Now the butter is ready for packaging. In Lochem the butter is packaged in 10 kg or 25 kg boxes. In Den Bosch, the butter is made for industrial and consumer markets, for the consumer market butter products are packaged in wraps of 250 grams, while for the industrial market the products are packaged in 25 kg boxes. An overview of the process can be found in Figure 2.3. Within FC there are different type of products for butter, namely bulk soured butter, soured prestige butter, soured winter butter, sweetened butter, hard butter and extra hard butter.

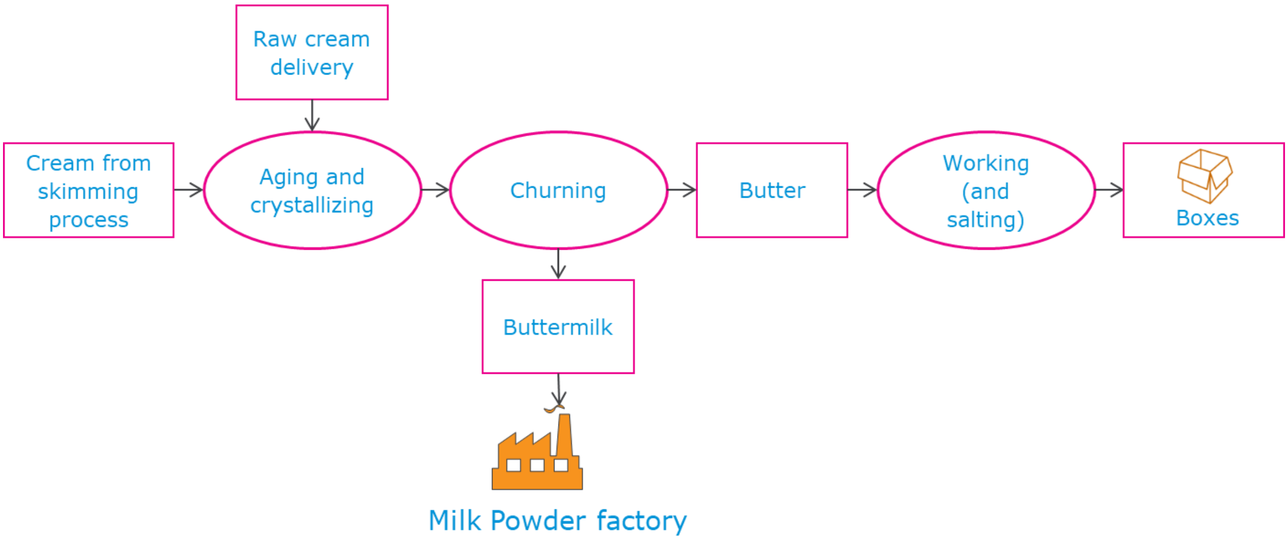

Figure 2.3: Butter production process

2.1.4 Butteroil process

Butteroil, also called Anhydrous Milk Fat (AMF), can be produced on two different methods, namely from butter or from cream. At FC, the butteroil is only produced from cream, so the method where AMF is created from butter is not considered in the research. The cream that is used for the production of butteroil has the same composition as the cream that is used for the production process of butter, so it is already pasteurised. For the production of one kg AMF, 24.95 kg of raw milk or 2.495 kg of cream is needed.

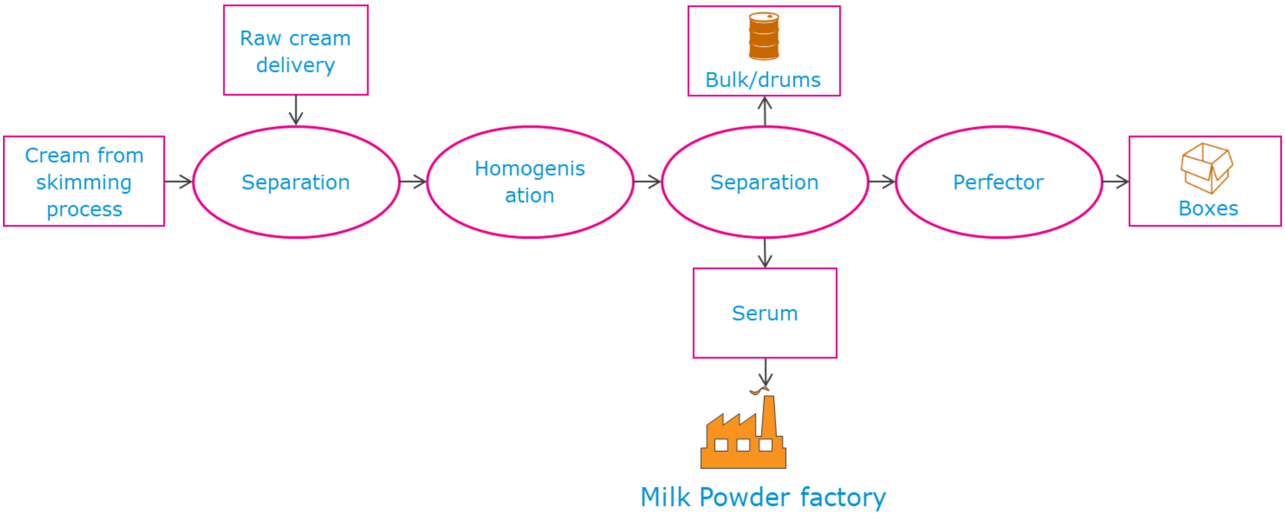

Figure 2.4: Butteroil production process

To produce butteroil, first the cream must be heated to 60°C and next it flows into the first separator, as shown in Figure 2.4. Here the cream is concentrated to a fat percentage of 75%. To concentrate the cream further it is necessary to break down the fat globules. This process is called homogenisation. During the next step, all liquid and protein are separated from the fat. The manufactured butteroil now contains 99.8% fat.

Next, the butteroil will again be heated, but now to 95-98°C. Also, the butteroil is separated again. In this separator the residual stream is called serum. This is a valuable product because of the specific characteristics of the membrane of the fat globules in the serum. Like the buttermilk, the serum will be transported to a milk powder factory to make serum powder of it.

The butteroil can be sold as bulk/drums or in boxes. When it is sold as bulk/drums, the tanker truck or drums can directly be filled from the separator. When it is sold in boxes, the butteroil must first be cooled by a perfector, because the butteroil is a liquid when it is separated. In the perfector, the butteroil becomes solid and therefore it can be packaged in boxes.

2.2 Allocation process

In the allocation process three parties are involved, namely Milk Valorisation and Allocation (MVA), Milk Logistics and the Business. MVA and Milk Logistics are centred in Amersfoort and a Business Office is located on each production location.

2.2.1 MVA

MVA is responsible for the forecasting and planning on longer term. Within this department there are sub-departments for the strategic, tactical and operational planning.

Strategic planning

The strategic planning is a forecast for the next 10 years. These planners look to trends in the dairy industry. The first aspect that the planners analyse, is the amount of milk the company gets on monthly basis for the next 10 years. In this sub-department they answer questions such as: How many farmers are associated to FC in 10 years? How much milk do the dairy cows in the future give? How many dairy cows do the FC farmers have in the future? Most of these expectations are based on government regulations and information from the sector.

Second, the strategic planners look to the trends in the market, the demand side. Here they look to the demand of dairy products in the future worldwide. For example, in the past 15 years, the demand for baby nutrition has grown a lot, especially in Asia.

With these two aspects of forecasting, the strategic planners give the company advice on which production locations must be expanded, in which new factories should be invested and should the company take over a competitor. This planning will be updated once a year.

Tactical planning

The tactical planners forecast over the next 18 months. The planning contains long term forecasts on how much milk and cream can be expected. Based on this, answers on the following questions will be provided: Are there production lines that must be changed? Is there enough capacity to handle all incoming streams? Next to that, there will be determined whether there is enough milk or cream to fulfil the demand. When there is not enough milk or cream, extra can be bought on the dairy market, which is a market where extra milk or dairy by-products as cream can be bought from external dairy companies. When there will be too much milk or cream, this can be sold to other dairy manufacturers. Because it is far in advance, the prices for buying and selling are favourable. This means that if there are adjustments in the forecasts on this planning level, this is not a problem for production. The tactical planning will be updated every month.

Operational planning

The operational planning, also called the allocation plan, is a 13-week planning and is more detailed than the tactical planning. In the allocation plan, the production locations are included, which means that this planning determines the expected amount of milk or cream a location will get on a weekly basis. The amounts are based on the valorisation model. This is a model that calculates how much profit margin can be made from different dairy products. The model maximizes the profit based on the demand and available ingredients and give priority on the products with the most profit per litre raw milk. The planning is more detailed because aspects such as maintenance or other known downtime are included as well.

The operational planning includes how many ingredients a production location should get, but not how and from where. This is part of the job for Milk Allocation and Intra Transport.

2.2.2 Milk Logistics

Milk Logistics is responsible for the allocation, short term planning and the transport of all dairy streams within FC. Milk Logistics is part of the department Cooperative Affairs, which is not part of one of the Business Groups, but a supportive department for all of the OpCos. Other parts of Cooperative Affairs are for example Finance and HR.

The process structure within Milk Logistics looks as follows:

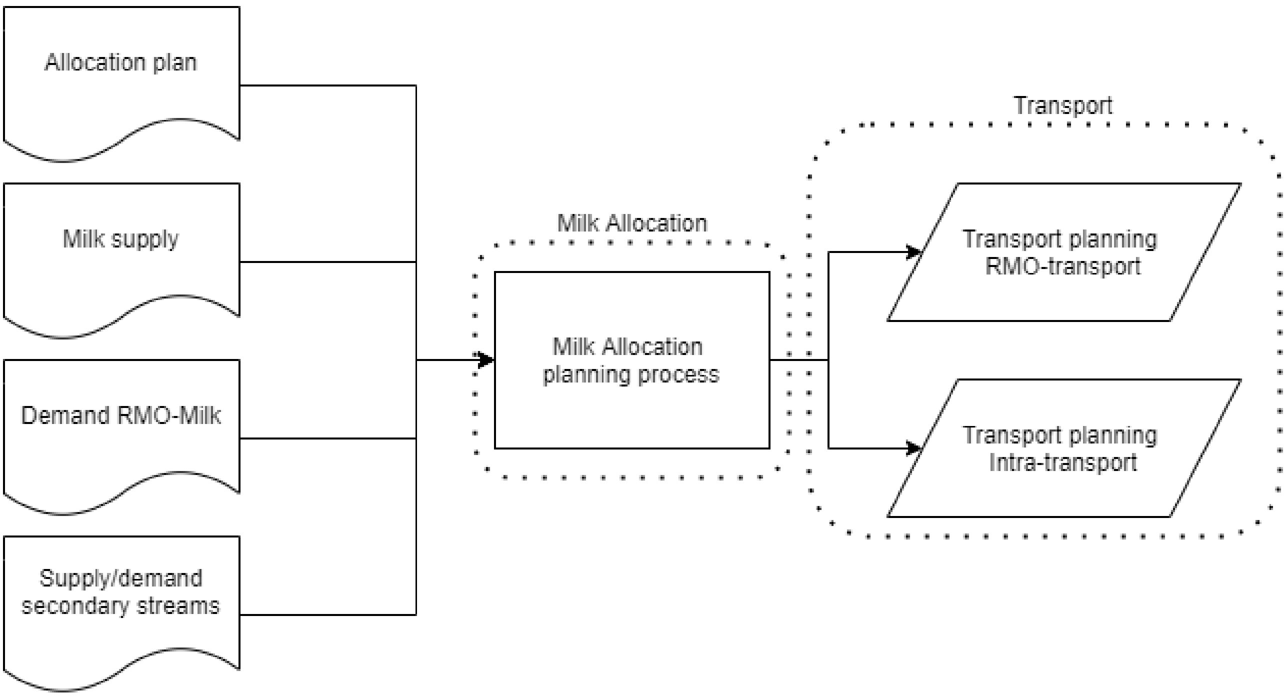

Figure 2.5: Organization structure Milk Logistics (located on the head office)

As shown in Figure 2.5, Milk Logistics consists of two sub-departments, namely Milk Allocation and Transport. The information that is needed for the planning comes from the MVA department, the hubs and from the department that manages the supply from the farmers.

2.2.2.1 Milk Allocation

From the allocation plan (the operational planning), Milk Allocation makes a week plan for the production locations. This week plan is the most recent updated version of the allocation plan for next week and gives information on how much of the ingredients there is going to flow into a factory. Figure 2.6 describes the process of making the week plan.

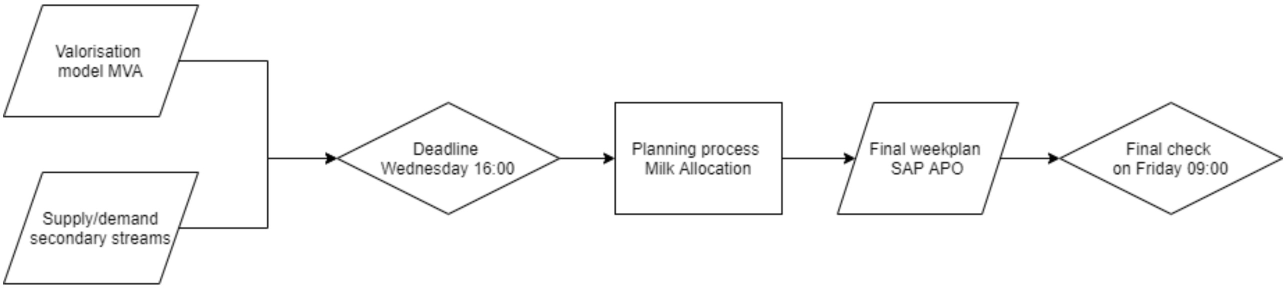

Figure 2.6: Process of making the week plan

The week plan for the secondary streams, such as cream, is based on the valorisation model and the supply from and demand of the secondary streams. On Wednesday, the week plan will be available for the business office of the production locations for week after. After it is published, the production locations can give feedback before it will be final. The final version will be entered in the software system SAP APO.

The week plan is based on the amount that flows into the production location on a weekly basis. Next, Milk Allocation makes a day plan. The day plan is made for the next day and is based on the final week plan. Next to the week plan, the production locations must submit before 11:00 all adjustments in the production planning. The cream supply locations send details on how much cream is released and when this cream will be available for loading. The (basic) cream is supplied from approximately 20 factories, as described in Section 2.1.1. Figure 2.7 presents all production locations involved in the cream supply chain.

Figure 2.7: Cream locations (Google Maps, 2020), where = cream supply location and = cream processing location

In the figure we see that the production locations are spread over Germany, Belgium and the Netherlands. The red stars are the butter(oil) factories (the processing factories), and the blue points are the cream supplying locations. In the ideal situation from a transport perspective, the factories supply the cream to the nearest of the three cream processing locations. But in reality, there are a lot of constraints that have to be considered. First, the planners have to consider the demand per product. Next, the buffer capacity of the production location must be considered. Next, cleaning and maintenance must be included. Some factories have supply restriction. For example, in Lochem the pre-factory will be cleaned between 03:00 and 06:00 and so no trucks can unload their cream. At last, the priority of the products must be included. When there is not enough cream available to fulfil the demand, Milk Allocation must plan the locations with a higher priority. In this case, generally Noordwijk receives enough cream and Den Bosch and Lochem receive less than they need. When there is too much cream available, the situation is the same. In this case, Noordwijk receives the right amount, while Den Bosch and Lochem receive more cream.

Because the production in most factories is 24/7, Milk Logistics uses logistic dates for the planning. A logistic week starts at Monday 06:00 and ends on Monday 05:59 the next week. A logistic day is from 06:00 till 05:59 the next day. So, for example, when a truck arrives on Wednesday, the truck can arrive between Wednesday 06:00 and Thursday 05:59.

2.2.2.2 Transport

Within Milk Logistics, next to the department Milk Allocation, there is the department Transport. Transport consists of two sub-departments namely, RMO-Transport and Intra-Transport. RMO-Transport is responsible for the transport planning of the collection of raw milk at all cooperate dairy farmers. This only considers raw milk and no secondary stream such as cream and therefore it will not be included in this research. Next to the RMO-Transport, there is another sub-department called Intra-Transport. This sub-department is responsible for all transport between different production locations. Intra-Transport makes the transport planning based on the information of the day plan from Milk Allocation and connects this planning with the trucks and drivers that are available. In this planning process, there are a lot of restrictions that must be considered. For example, drivers have to take enough rest between shifts and the drivers must be switched at the right locations. Next to that, the trucks must be available at the right place and the number of kilometres of empty loadings must be minimized. With all these restrictions, the transport planning is complex. This leads to differences between the day plan from Milk Allocation and the transport planning from Intra-Transport. When the transport planning is done, the planning must be filled in in the SAP module P92. Mostly the planning is finished in SAP at 17:00 for the next day.

2.2.3 Business Office

Each production location has its own planners that connect the incoming (milk)streams to machine line, buffer tanks and orders. The initial input of the production planning is the week plan created by Milk Allocation in Amersfoort. From this plan, the production lines will be scheduled in a plan called the production planning. Because the day plan changes frequently, the production planning must be reviewed several times a day. Milk Logistics uses two modules of the ERP system to manage the changes, namely SAP APO and SAP P92.

SAP APO is a system that contains a plan on how much ingredients a production location should get on a daily basis. This is the day plan from Milk Allocation. The intention is that the day plan is finished on 11:00 for the next day and on Friday the day plan is for Saturday, Sunday and Monday. However, in most cases the day plan is finished later than 11:00. The amounts of ingredients in SAP APO are based on how much a production location should get. However, Intra-Transport (also located on the head office) can change the day plan due to driver unavailability, inefficient routing or unloading restrictions. To check how much cream the production location actual will get, the business office can check the SAP P92 module. Because Intra-Transport finishes the transport planning at the end of the afternoon, the business office cannot use this planning for their own production planning. They work usually from 7:30 till 16:00. So, they know the final amount of supplied cream at the start of the operational day. When creating the production planning, there are a lot of restrictions that have to be considered, namely employee availability, maintenance, batch sizes, cleaning, production times and ingredients.

For the employee availability there is an input file where the production lines fill in the working times. Most of the employees are regular employees, but extra temporary employees can be hired in advance. As stated in Section 1.3, when temporary employees must be hired, it is only possible at least four days in advance.

The maintenance is scheduled far in advance and is planned by the engineering division. When there is maintenance, all machines must be cleaned in advance. Also, after each batch of products, the machine must be cleaned. How big the batch can be, depends on the product type. Some products have other quality requirement restriction than others. Also, after downtime, the machine must be cleaned.

The production times vary for different products. Especially for the butter products, it depends on the product. The ageing time varies due to the composition of the cream, which depends on the season in the year and the food of a cow. Next to that, there are end-products that must be softer than others and therefore it must be crystallized longer.

To manage all ingredients, the business office uses a file called 'Milkplan'. This is an Excel file where they keep the inventory up to date. The Milkplan for butter and butteroil looks as presented in Figure 2.8:

MONDAY	523	Cream from previous day		Supply	Initial Inventory	Processed	End Inventory
Initial inventory RMO	637	0	Cream total	273			
Supplied RMO-Buffer	7		Cream Butteroil	45	104	100	51
	0		Cream Butter	228	639	399	462
Total proccessed RMO	644		Cream supply	0	0	0	0
Whole milk powder PF	0		BM >> PF	200	Se >> PF	60	
Skimmed milk powder PF	644		Cream Line 11	0	0	0	0
Cream from own skimming process	70		Starting time oil	16:00	Second starting time :		
Supplied cream	203		Remarks cream ->				
	0						
Total cream	273		Line 12	0			

Figure 2.8: Milkplan used at the business office (units in tonnes (1000 kg))

In this Milkplan, the inventory of cream will be managed. Important numbers are the BM >> PF and the Se >> PF. These numbers give the amount of buttermilk and serum that flows into the powder factory. The planning of the powder factory partly depends on the amount of buttermilk and serum.

At the start of every (working) day the amount of milk that will be skimmed, the amount of supplied cream and the inventory from the previous day will be updated. The planners check if there is enough cream to produce all products. When there is supplied too much or not enough cream to produce the planned orders, the planning must be changed. This will be communicated with the hub and they will suggest alternative products that can be made.

Another complex restriction is the time that cream can stand before it will be processed, which is called the standing time. Due to safety restrictions the cream can only stand for a determined number of hours before it must be processed. Which is remarkable is that the standing times differ per production location. In Lochem, the cream can only stand for 24 hours, while in Den Bosch the cream may stand for 48 hours and in Noordwijk it may stand for 72 hours. This is because the quality department of a production location determines the safety restrictions for that factory. A longer standing time means that more quality checks must be done during the process.

The longer standing time for Noordwijk is logical, because in the production process of butteroil most bacteria will be killed. The difference in standing time for butter in Den Bosch and Lochem is remarkable since these two locations produce partly the same products. Within the company, there is no good explanation for that.

Next to these standing times, there are time restrictions for each stage in the process, to ensure that the safety of the products.

2.2.4 Conclusions on allocation process

The allocation process within FC is complex and we use a lot of different names for a planning, therefore we give an overview of all different plans in Figure 2.9.

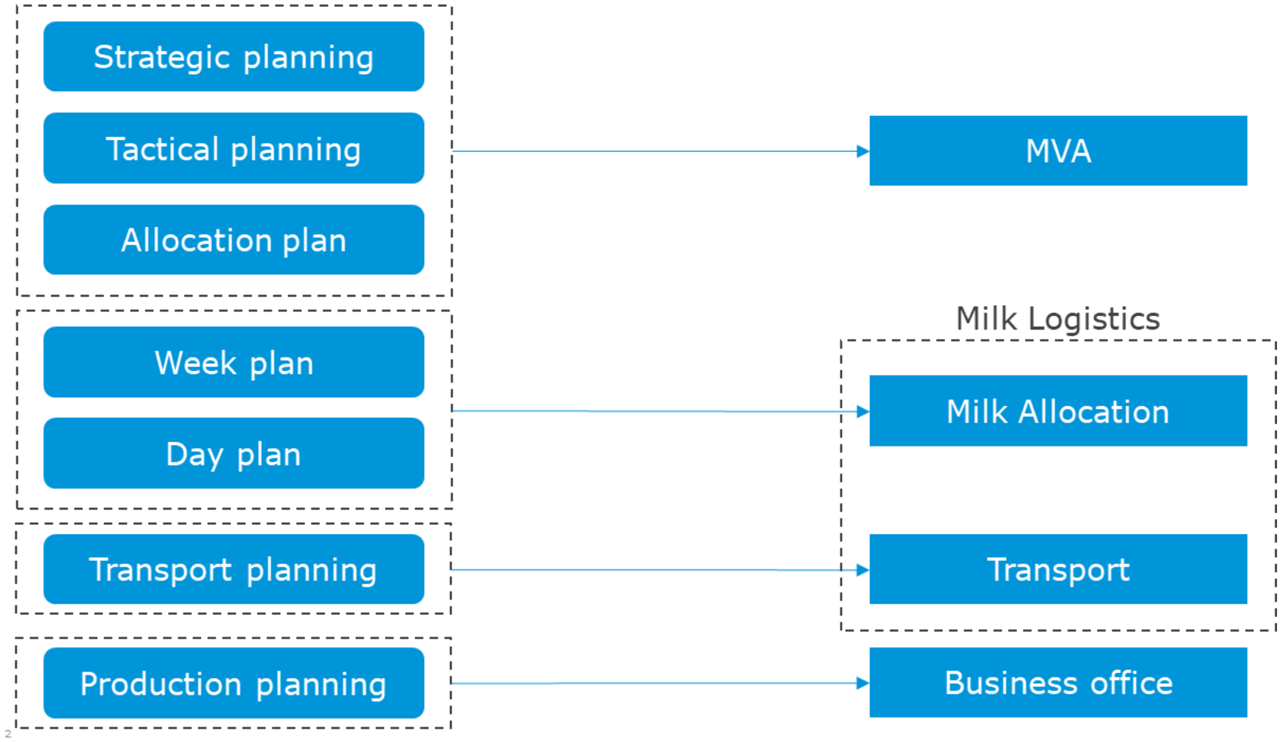

Figure 2.9: Overview of the plans within the allocation process of cream and which department is responsible for the planning.

Here we see that the strategic and tactical planning and the allocation plan is created by the MVA department. The week and day plan are created by Milk Allocation and the transport planning is issued by Transport. The week plan gives the amount of cream per location per week, while in the day plan and the transport planning the amount of cream per location is given per day. At last, the business office makes a production planning of it. Which is remarkable in the process is that the time that cream can stand before production, is different on each production location.

2.3 Ordering process

The ordering process is centrally managed by the hub. The hub is a department that manages the supply and demand of the network and this department is the link between the MVA, Milk Logistics and the business offices. Within the company there are 10 hubs, one for every product family. The hub that is responsible for the butter and butteroil is the Butterhub.

The hub communicates with MVA and Milk Allocation on how much ingredients the company has and how many orders can be sold. This is based on the tactical planning and the allocation plan, so the 18-month planning and 13-week planning. Next, the hub goes to the sales partners to communicate how much can be sold and the sales partners try to sell all products.

Most of the customers are external, but the Butterhub also sells some products internal. These internal products are sold to other Business Groups, for example to Customer Dairy where a product like Campina Botergoud can be made of it. There are no priority rules for those external and internal orders. The customer orders are translated by the hub to internal orders, which are placed at the production locations. The production locations fulfil the internal orders, so that customer orders are fulfilled as well.

The hub, together with Milk Allocation, reviews the allocation plan once a week. Information from the sales department will be communicated to the allocators. When the demand deviates from the expected demand, the valorisation model can be changed, and the operational planning can be updated.

As mentioned in Section 1.2, the way of working in the Butterhub has been changed. In the past, 80% of all products was demand driven and the rest supply driven. So, most of the products that were produced, were already sold. The rest was supply driven, which means that from the cream that was not used for the orders, standard butter products were made. These products were sold, after it was produced, for spot prices. Now, with the new strategy in sales, which was introduced in 2019, it is the goal to sell all products in advance. So, the company strives to sell all products demand-driven to increase the profit margin. This means that all production locations must exactly produce what was sold and do not have any flexibility in which products they produce. This is contradictory to the idea that Den Bosch and Lochem are buffer locations. There cannot be any buffer locations when all products are already sold. This new strategy gives a lot of pressure on the whole supply chain. When there is an adjustment in one of the factories, it will be hard to produce all orders. While sales implemented the new way of working, the company did not invest in the supply chain. The supply chain has the same team as before, so the number of employees has not been increased. The team experiences way more workload due to the extra restrictions. Next to that, Milk Logistics already had understaffing before sales implemented the new strategy, which means that much is asked from the employees of this department.

2.4 KPIs

Within FC there are a lot of different Key Performance Indicators (KPIs), but most of them are used to ensure the safety for employees or for food quality. For example, within all production locations there is a KPI for the number of days without accidents and percentage of products that were the first time right. But these KPIs are not important for this research. For this research there are two important KPIs, namely the Production Plan Conformance (PPC) and the service level.

2.4.1 PPC

To calculate the performance of a factory, FrieslandCampina uses the PPC. The PPC is a KPI that registers what percentage of an internal order is delivered. An order consists of several tonnes from one product and the order is placed by the hub. The PPC_n per order *n* is calculated by:

$$PPC_n = \left(1 - \frac{(abs\ (actual\ volume - planned\ volume))}{planned\ volume}\right) * 100\%.$$

When an order is finished, the business office registers how many tonnes of the product for that specific order is produced. When the difference between what was planned and what was realised is less than 10% the order is ‘OK’. When the difference is more than 10%, and so the PPC_n is beneath 90%, the business office must give the order a category dependent on the reason of the deviation. Table 2.1 presents all categories of causes that lead to deviation in order supply.

Table 2.1: Categories of causes of deviation in order supply

Categories		**Influence on the PPC?**
1.	*OK (the deviation is within the 10% margin)*	*Yes*
2.	*Disturbance in the factory*	*Yes*
3.	*Difference in cream supply*	*No*
4.	*Insufficient amount of package materials*	*Yes*
5.	*Too much / not enough ingredients*	*Yes*
6.	*Changes in production planning*	*Yes*
7.	*Changes at the request of the Supply Chain*	*No*
8.	*Changes at the request of the customer*	*No*
9.	*Staff planning*	*Yes*

To rate the performance of the production location, some categories are not included. There are three categories that the production location has no influence on, namely the difference in cream supply and changes at the request of the supply chain or the customer.

The total PPC of a production location is given by $PPC = \frac{(\sum_{n=1}^{N} PPC_n)}{N}$, where N is the total number of product orders and is calculated per week. The target is that the PPC, with the exclusion of the three categories mentioned above, from a production location should be at least 92.0%. Note that the category 'OK' has influence on the PPC. This means that in theory it can happen that all orders are categorised as 'OK' (which means that all orders have a PPC_n of at least 90% and so the difference in what is ordered and delivered is less than 10%), but still the target of 92.0% is not reached.

2.4.2 Service level

To manage the service level of FC to the customer, the company uses the OTIF. OTIF stands for on-time and in-full and calculates the percentage of ordered quantities that are delivered on time to the customer. The OTIF is different than the PPC, since the OTIF is the service level from FC to the customer, while the PPC is the performance of a production location in fulfilling internal orders from the hub.

The calculation is as follows, where *m* is an order of a customer and *M* is the total number of orders within an OpCo. The *M* differs from the *N* of the PPC, since *M* is the total number of customer orders, while *N* is the total number of internal orders placed by the hub at a production location.

$$OTIF = \frac{\sum_{m=1}^{M}(Initial\ order\ quantity_m - abs(initial\ order\ quantity_m - delivered\ quantity\ on\ time_m))}{\sum_{m=1}^{M} Initial\ order\ quantity_m} * 100\%$$

Note that over-delivery will be penalized as well. In this OTIF, backorders are not used and measured. In case of re-ordering missed volume, the OTIF is negatively influenced. We can clarify this OTIF with an example with one order. When the initial order quantity is 100 tonnes, while the amount that is delivered on time is only 80 tonnes, the $OTIF = \frac{100-abs(100-80)}{100} * 100\% = 80\%$. When the initial order quantity is again 100 tonnes, but the amount that is delivered is now 120 tonnes. So, the OTIF is now again 80%: $OTIF = \frac{100-abs(100-120)}{100} * 100\% = 80\%$.

The OTIF is calculated per month. The target for the butter within the OpCo Butter and Milkpowder is 97.0%. The average of 2019 was 96.9%, so the target was just not reached. In comparison with 2017 and 2018, the service level is decreasing. The average service level in 2017 was 97.7% and in 2018 was 97.9%. The service level is not directly connected to the PPC, because for some products FC holds a safety stock. But a bad PPC performance will mostly have influence on the service level, because the safety stocks are not that big. When FC cannot fulfil an order in time, the company can get a penalty from the customer.

2.5 Conclusions on the current situation

On a lot of production locations the milk is skimmed, which means that the fat is separated from the milk. In this process the by-product cream is released, which is a liquid that contains 40% fat. The cream is used to produce butter and butteroil.

Within FC there are four departments that are involved in the allocation of cream, namely, Milk Valorisation and Allocation (MVA), Milk Allocation, Intra-Transport and the business office of a production location. The MVA is responsible for the plans on a longer time period. Milk Allocation makes plans on how to allocate the cream for a shorter period of time, Intra-Transport makes a transportation plan on how this cream will be supplied to the cream processing location and the business office of a production location makes a production plan out of it. The hub is a department that controls all orders within a specific OpCo and is important in the communication between Milk Logistics and the production locations.

In this research there are two important Key Performance Indicators: the Production Plan Conformance (PPC) and the On-Time and In-Full (OTIF). The PPC gives the performance of a production location and the OTIF calculates how the operating company is performing in producing the right customer orders.

This chapter provides insight into the processes of FrieslandCampina, which is important before analysing the problem. In the next chapter we do a data analysis and describe the causes and consequences in more detail.

3. Analysing the performance of the allocation of cream

In this chapter, we analyse the performance of the allocation of cream and give an in-depth view about the deviation in cream supply. First, in Section 3.1 we explain the causes of the deviation in cream supply. Next, in Section 3.2 we measure how big the deviation actually is, by analysing data from the company. Next, in Section 3.3 we give the consequences of the deviation for the company. A conclusion on the performance of the allocation of cream is provided in Section 3.4.

3.1 Causes

To get to know the causes of the deviation, we discussed the problem with different planners within the company, such as allocation planners from Milk Logistics, demand planners from the hub and production planners from the production locations. During these discussions, it turns out that there are four root causes for the deviation and the corresponding consequences, as given in Table 3.1. In the sections below we elaborate on them.

Table 3.1: Overview of the root causes and causes of the problem

Section	Root cause	Cause
3.3.1	Uncertainty	Uncertainty in milk production
		Uncertainty in the milk composition
		Changes in valorisation model
		Disturbance in factories
3.3.2	Unclarities in the data	No clear guidelines in which software must be used
		Difference in loading and unloading times
		Changes will not be adapted for the next days
		Good communication is missing
3.3.3	Inaccurate week plan on day level	Milk Allocation makes a day plan that cannot be realised
		Seasonality is not included
		Differences for next days will not be adapted
3.3.4	Focus on company is missing	Most important is to reach own KPIs
		High pressure from the sales and the hub
		Cream delivering locations

3.1.1 Uncertainty

The most important factor from where the deviation arises is the uncertainty in the whole supply chain. There are a lot of variables that lead to uncertainty.

Milk production

First, FC is dependent on the milk production of its farmers. For the company, the risk that a single farmer produces less milk than expected is real, but on system level it is negligible since FC has nearly 12,000 cooperating farmers. When there are factors that affect a lot of farmers it becomes risky for the company. There are four main risk factors, namely the weather, animal diseases, government regulations and dissatisfied farmers that switch to another dairy company. The weather has influence on how much milk a cow gives. When there is a dry period, cows give less milk than when it is rainy. Also, when the weather is hot, the cows will give less milk. Animal diseases are an important risk factor that can cause variety in the milk production. When there is an animal epidemic, it can happen that a lot of dairy cows must be culled. An example was the foot-and-mouth disease (In Dutch: Mond en Klauwzeer, MKZ) in 2001, where in the Netherlands 300,000 cows were culled (Scholtens, 2001). Another factor that causes uncertainty in the milk production are the government regulations. In the European Union there are very strict agricultural rules, for example for the number of cows a farmer may have. When there is a change in the regulations, FC must adapt their expectations. The last risk factor for the milk production is dissatisfied farmers. When the cooperate farmers are dissatisfied with FC, the farmers can switch to a competitor. This cannot be foreseen in the forecast models since this is caused by single events where many farmers switch at once.

Composition of milk

The second factor that causes uncertainty in the supply chain is the composition of the raw milk. Figure 3.1 shows the seasonality over a year.

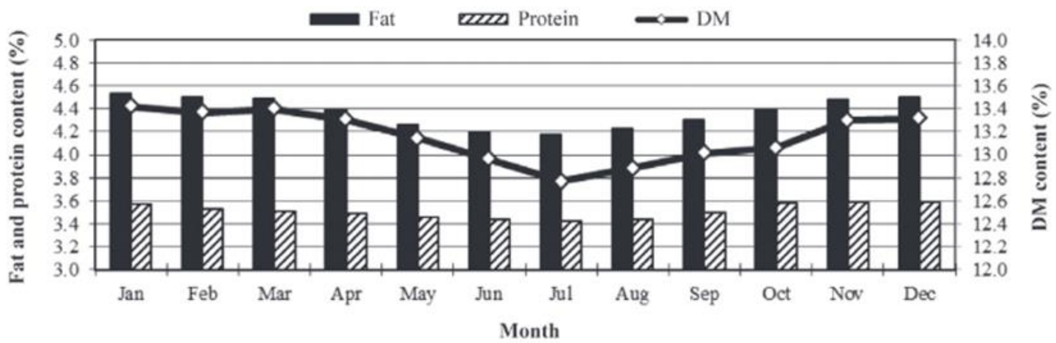

Figure 3.1: Composition of the milk throughout the year (Banaszewska, 2013, original source FrieslandCampina)

In the figure we can see that during the summer, the fat percentage of the raw milk is lower. This is because of the diet of the cows. During the summer, cows can graze in the meadows and therefore the percentage water of raw milk is higher. In the winter, when the cows are in the stables, the cows eat more concentrates which leads to more fat and protein in the milk. When the fat percentage is lower, less cream is released in the process. Government regulations can have influence on the milk composition as well. For example, in the summer of 2020, the Dutch government wanted to decrease the number of proteins in the food of the cows to reduce the nitrogen emissions. When there is less protein in the food, the raw milk will also contain less protein.

Change in valorisation model

As described in Section 2.1.2, cream is a by-product. This means that the amount of cream depends on the production of other dairy products. The forecasts on how much cream will be available include how many products are sold from other products. There can be a change in orders. In this case, the valorisation model will be solved again, and the amount of cream can be different. Cream is not as valuable as other by-products, and therefore there are more changes for cream in the valorisation.

Also, the OpCo Butter and Milkpowder B2B is less valuable as other business partners that process cream. When there are changes, the OpCo will suffer from it.

Disturbance in factories

At last, there can be disturbance in factories. Disturbance can lead to changes in the orders that can be made and therefore it can happen that the allocated amounts are different than the valorisation model. If there is disturbance in a factory, the milk flows to another factory where other products are made. In this case other by-products are released in the process.

3.1.2 Unclarities in the data

The second root cause of the deviation in the cream supply are the unclarities in the available information from Milk Logistics and the business office.

No clear guidelines in which software must be used

The first unclarity is due to the software. Within the company, there are no corporationwide instructions for the use of the available software. It is not clear which system must be used to get the right information. Different production locations use different modules and therefore there is a lot of unclarity in the communication between the different locations. For example, Den Bosch and Lochem also skim their own milk. In the module SAP P92 the cream that is released from its own skimming process is not included, while in the module SAP APO this amount of cream is included. This leads to miscommunication between the different production locations. Next to that, it is not clear if the surplus of premium cream is included or not. In Den Bosch, also so called 'Landliebe cream' flows in, while this amount of cream is not included in SAP P92, because there only basic cream is included.

Difference in loading and unloading times

Another factor that causes unclarity in the information is the difference in loading and unloading times. In SAP P92, a day is from 6 AM till 6 AM the next day. The times are given in loading times, so the time that a truck is loaded at a cream supply location. The unloading times differ because the filled truck must be transported to a butter(oil) factory. Due to restrictions, such as cleaning and driver restrictions as described in Section 2.2.2 , it can happen that the truck arrives the next day. This is not a problem when the number of trucks that is moved to the next day is every day the same, but on some days, there are a lot of trucks moved to the next day. Figure 3.2 shows an example of a case that a lot of trucks were moved to the next day.

Planning: Lossen | Planning: Laden

Artikel	Charge p.	Art.omschr	Dat lossen	Tijd los.	Σ Hvh. ton	Lev.fabr.	Charge p.l.	Dat laden	Tijd lad.	Act. ID	Contractwagen
692207		Taptemelk past.	03.03.2020	07:00	25	Keulen - FC	2039383	02.03.2020	16:06	000856467	ZVIS06
692207		Taptemelk past.	03.03.2020	08:00	25	Keulen - FC	2039384	02.03.2020	18:15	000856470	ZHSV08
692207		Taptemelk past.	03.03.2020	09:00	25	Keulen - FC	2039385	02.03.2020	17:41	000856472	ZSAES02
692207		Taptemelk past.	03.03.2020	10:00	25	Keulen - FC	2039386	02.03.2020	19:00	000856473	ZSTAM01
692207		Taptemelk past.	03.03.2020	11:00	25	Keulen - FC	2039387	02.03.2020	20:52	000856474	ZHSV07
6922...					**300**						
694108	0083648441	Room basis (8)	02.03.2020	07:45	33	Beilen - FC	0083648441 meenemen wat er zit, minimaal 10 ton	02.03.2020	02:24	000856218	ZSLOMP01
694108		Room basis (8)	02.03.2020	11:42	33	Veghel - FC	Am20030228	02.03.2020	08:00	000856499	ZHSR02
694108		Room basis (8)	02.03.2020	12:50	33	Veghel - FC	TA20030230	02.03.2020	09:00	000856502	ZSAES04
694108		Room basis (8)	02.03.2020	15:45	32	Maasdam - FrieslandCampina NL B.V.		02.03.2020	11:41	000856501	ZVIS05
694108		Room basis (8)	02.03.2020	16:02	30	Born - FC		02.03.2020	12:03	000856496	ZHSB08
694108		Room basis (8)	[illegible]	[illegible]	28	Lelystad - Farm Dairy		02.03.2020	20:55	000856515	ZWEP01
694108		Room basis (8	03.03.2020	00:53	33	Beilen - FC	0083649298	02.03.2020	22:16	000856522	ZTAK01
694108		Room basis (8	03.03.2020	06:07	32	Maasdam - FrieslandCampina NL B.V.		02.03.2020	17:00	000856510	ZHSB03
694108		Room basis (8	03.03.2020	06:20	15	Steenderen - FC		02.03.2020	19:37	000856513	ZSLOMP02
694108		Room basis (8	03.03.2020	07:00	28	Balkbrug - FC		02.03.2020	18:13	000856521	ZHSB08
694108		Room basis (8	03.03.2020	09:17	33	Rijkevoort - FC		02.03.2020	20:26	000856511	ZVIS03
694108		Room basis (8	03.03.2020	10:45	32	Rotterdam - FrieslandCampina NL B.V		02.03.2020	21:17	000856520	ZSAES04
694108		Room basis (8	03.03.2020	06:00	33	Beilen - FC	0083649299	03.03.2020	03:00	000856527	ZSLOMP01
6941...					**395**						
694212		Roomserum	02.03.2020	20:59	33	Zelhem - VIV Buisman	VBR714711	02.03.2020	18:34	000856556	ZHSB05
6942...					**33**						

Figure 3.2: Example of the difference in loading and unloading times, the marked boxes present the trucks that are moved to the next day (FrieslandCampina Lochem, 2020)

In the figure we see that from the 395 tonnes (sum of all trucks), 173 tonnes (sum of all trucks that arrive after 03.03.2020 06:00) is moved to the next day. What makes the data confusing, is that it is not clear if the moved amount is included in the day plan from SAP APO. Therefore, the business offices do not know how much cream there will be supplied the next day.

Changes will not be adapted for the next days

When there is a change in supply for the next operational day, the amount of supplied cream for the days after is not adapted. When tomorrow arrives more cream than expected, the business office does not know what happens the days after tomorrow. The operational planners do not know if the extra cream of tomorrow cancels out the during the week or if it is a surplus. Even when Milk Allocation knows that the cream for the days after the next change, it will not be adapted. This is because of three reasons. One reason is due to understaffing on the Milk Allocation department. Due to the change in the way of working of the sales department, Milk Allocation experiences extra pressure. As described in Section 2.3, the flexibility in the supply chain is gone and therefore the planning process is more complex. The second reason is that Milk Allocation has the priority over other (by-) products. Other products generate more profit margin and therefore it is more important to allocate those products accurate. Also, within the cream stream, the Butterhub is less important, because there are more important business partners, as described in Section 1.3. However, cream is one of the largest by-product streams in the dairy process. Improvements in this process can have a lot of impact on the company. Within the cream allocation, the Butterhub may be have lower profit margins, but it has large volumes. Approximately 80% of all cream flows into the Butterhub. The third reason is that for Milk Allocation it feels like it is unnecessary work to adapt all expectations. This is because in one day there can be a lot of changes, since the cream supply is depending on 20 different factories. When Milk Allocation changes the expectations for the next days, there is a possibility that those changes cancel out during the days and therefore the extra work can be redundant. The adaptions in the planning for the days after the next day are important for the business offices since the production planning contains orders for the complete week.

Good communication is missing

Good communication between different departments within the company is lacking. Information regarding changes in cream supply are not always communicated with the business offices. It happens that the amount of cream that arrives at a production location is different than what was communicated by Milk Logistics. Because the information is not always clear, the business office should check manually how much is arriving every day. They can get a mail notification when something has changed, but then it is not clear what has changed since the original planning is overwritten by the new planning. Next to that, on average the transport planning changes 15 times a day, so it is not worth to check all mail notifications. Another problem is that all information regarding the day plan and transport planning must go via the hub, which can be cumbersome.

3.1.3 Inaccurate week plan on day level

There are three causes that lead to an inaccurate week plan on day level.

Milk Allocation makes a day plan that cannot be realised

For the week plan, Milk Allocation uses the demand per factory as input. In this demand per week, Noordwijk gives up how much cream they want to have every day. The rest of the cream is divided over Den Bosch and Lochem and their demand is evenly distributed over the week. Next, Milk Allocation plans the available cream such that Noordwijk will get the right amount, while the rest is divided over Den Bosch and Lochem. But the expectations for the incoming amount of cream per day are not accurate and Milk Logistics knows this fact. But still, to give a kind of indication they make a week plan. For the business office this week plan is important since they make their original production planning from it.

Seasonality not included

One of the reasons why the week plan is not accurate, is that seasonality is not included. The seasonality is known, but it is not included in the right way in the week plan per day. Because the business office knows that it is not included, they use their own seasonality indicators, while Milk Logistics have way more insight in these expectations.

Differences for next days will not be adapted

As said above, the changes for the next days will not be adapted until the day before the operational day. This fact does not only make the data unclear, it also can cause high deviation during the week. The week plan will not be adapted after the Friday on the week before and therefore sometimes it is known that amounts has been changed, but the expectations are still the same. The changes are only included in the day plan, which is for the business office often too late to anticipate. Especially in the butter making process this is a problem due to the aging restrictions.

3.1.4 Focus on company is missing

The last root cause of the main problem is that the focus on the company is missing. There are three causes that lead to this root cause.

Most important to reach own KPIs

When there are problems in the process, the main focus for all departments is how it affects their own KPIs. The focus on what is best for the company is missing. Getting good performance on KPIs do not have to be the best for the company. Some departments may have conflicts of interests. For example, for Intra-Transport it is the goal to minimize the transport costs, but that is not necessarily best for the company. For example, when Noordwijk gets too much cream and the other two locations do not get enough, it is better to drive some trucks to the south to Lochem or Den Bosch, even though it gives extra transport costs.

Next to that, within the company the PPC of a production location is important, while this KPI can distort the picture of the supply chains performance. The PPC namely do not include the cream supply deviation. It might not be fair to include that in the PPC for the production locations, but this gives a clearer view of the supply chain. This is because the cream supply deviation also affects the overall service level and so should be included in the performance.

High pressure from the sales and the hub

Due to the new way of working in sales, the pressure on the supply chain has been increased. There is no flexibility in the planning process anymore and bad supply chain performance lead to dissatisfied customers. Nowadays, the sales department sells all expected cream in products, while there is a lot of uncertainty. When the amount of cream is lower than expected, the company has a problem. Also, because all orders are sold in advantage, the complete allocation process must be changed in case of changes in cream supply.

Another factor is that sales and the hub look to the capacity per week and do not include the deviation of cream supply over the week. For them it is hard to understand that even when there was enough cream, orders cannot be produced. This can happen when a production location has downtime in the beginning of the week because there was not enough cream while in the weekend, there was too much cream. In this case, for the production locations the only option is to produce standard products, because of the higher machine capacity.

Cream delivering locations

The cream supplying locations do not realise the effects of changing cream supply. For those cream supplying locations cream is a residual and therefore they do not pay much attention on when the cream releases. For these locations it is best if the cream is transported as soon as possible, since they do not need the cream and having full silos can cause downtime in their factory.

Next to that, cream deliver locations do not give a good insight in when the cream will be released. The amount of cream that is released is only known one day in advantage for Milk Allocation. Therefore, Milk Allocation cannot anticipate on the amount of cream that will be released.

3.2 Deviation

To check how big the deviation between what was planned and what was supplied actually is, we use different data files. First, Milk Allocation in Amersfoort keeps record on the deviation of the allocation plan with the actuals and of the week plan with the actuals. These values are on a weekly basis, so the difference between the cream that was planned per week by Milk Allocation and that actually flowed into the location per week. Next, there is a file where the business offices keep record on how much cream flows in on a daily basis. They calculate the difference of what flowed in per day and what was planned by Milk Allocation in the week plan, so what was filled in in SAP APO by Milk Allocation in Amersfoort. This is done on Friday for the next operational week.

To evaluate the data, we analyse the following data:

- Deviation Allocation Plan (AP) – actuals (week differences)
- Deviation Week Plan (WP) – actuals (week differences)
- Deviation per location on a daily basis (day difference)

Hereby the actuals are the amount of cream that was actually arriving at a production location. All data is based on the year 2019, since this is the most recent complete year.

Before we analyse the data, we have to make some remarks:

- The deviation can be caused by a lot of different reasons and is not necessarily bad. For example, some changes are on request of the production location itself. When there is disturbance in the factory, the factory cannot receive the planned amount of cream.
- There are differences in the data from the business office and Milk Allocation. This is caused by the use of different parameters. For example, when using premium cream for basic cream products when there is a surplus of premium cream, then the business office includes this amount, while Milk Allocation do not include it. For Milk Allocation it is a different parameter.
- In Den Bosch and Lochem there is also cream from its own skimming process. When more raw milk flows into the pre-factory, more cream will be released. In the data for the deviation per location on a daily basis, we do not include cream from the skimming process, since the deviation caused by the allocation of raw milk is out of scope.

3.2.1 Deviation of cream per week

First, we analyse the performance of the allocation plan. To check the performance, we compare the expected amount of cream in the allocation plan with what was actually arriving in a week. The target for the total cream is that at least 96.0% of all cream that is allocated is actually arriving at the cream processing factories. Figure 3.3 shows the deviation of the total cream supply.

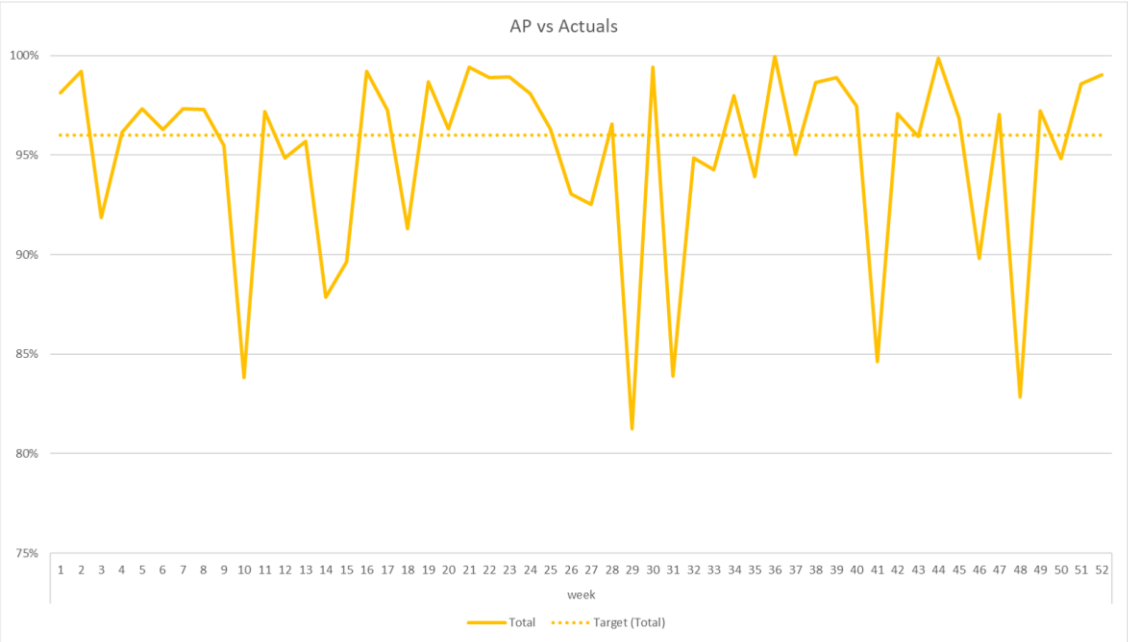

Figure 3.3: Absolute deviation in total cream supply between the AP and the actuals per week, calculated by: 100% - (absolute value of (tonnes of cream planned in the AP – tonnes of cream supplied)) / (tonnes of cream planned in the AP)

In Figure 3.3 we see that there is quite some difference in the Allocation Plan vs the actuals for the different locations, but the total is close to the target of 96.00%, namely 95.1% accuracy on average. The percentage on the vertical axis is calculated by 100% – (absolute value of (tonnes of cream planned in the AP – tonnes of cream supplied)) / (tonnes of cream planned in the AP). This means that in the allocation plan, MVA can predict the total amount of cream that flows into the three butter(oil) factories accurate, in contrast with the amount of cream per location, as shown in Figure 3.4.

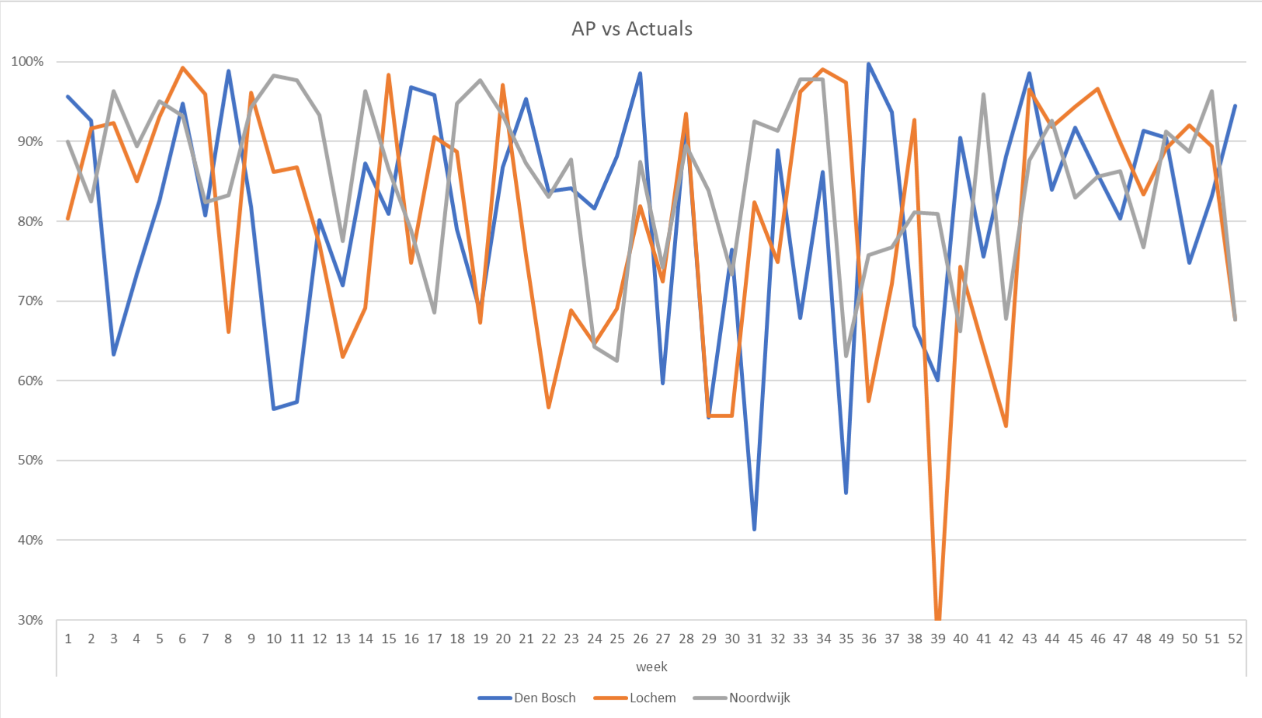

Figure 3.4: Absolute deviation in cream supply per location between the AP and the actuals per week, calculated by: 100% - (absolute value of (tonnes of cream planned in the AP – tonnes of cream supplied)) / (tonnes of cream planned in the AP)

For the locations separately there is a lot of difference, as shown in the figure. This is because when a production location gets more cream than what was planned, another location gets less than was planned, since the total amount of supplied cream is accurately forecasted.

The next data we analyse, is the difference between the amount of cream as forecasted in the week plan (issued by Milk Allocation) and the actual amount of supplied cream. In the week plan we see similar patterns as in the difference in the AP.

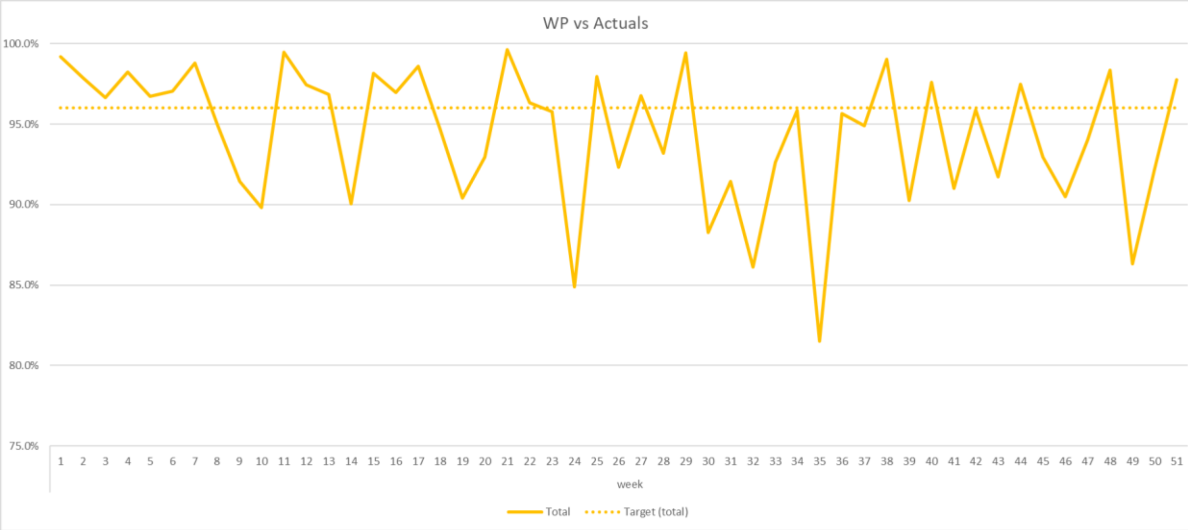

Figure 3.5: Absolute deviation in total cream supply between the WP and the actuals per week, calculated by: 100% - (absolute value of (tonnes of cream planned in the WP – tonnes of cream supplied)) / (tonnes of cream planned in the WP)

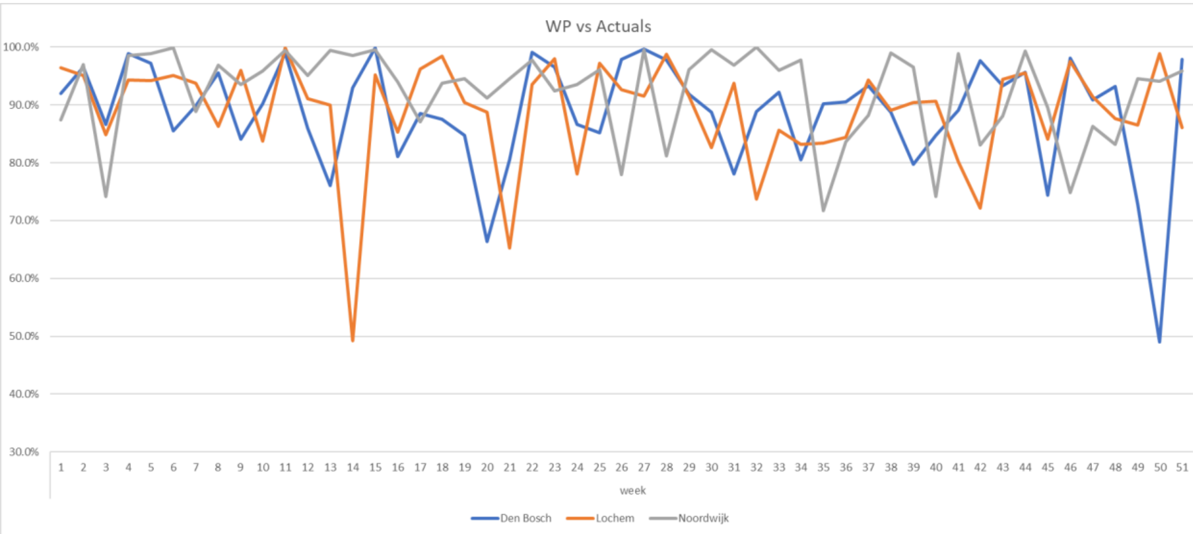

Figure 3.6: Absolute deviation in cream per location supply between the WP and the actuals per week, calculated by: 100% - (absolute value of (tonnes of cream planned in the WP – tonnes of cream supplied)) / (tonnes of cream planned in the WP)

Figure 3.5 and Figure 3.6 show the data for all three locations and the total for the OpCo Butter and Milkpowder. The percentage on the vertical axis is now calculated by 100% – (absolute value of (tonnes of cream planned in the WP – tonnes of cream supplied)) / (tonnes of cream planned in the WP). When we look to these percentages, we see that the planned amounts in the Week plan for the single locations is closer to the actuals than in the allocation plan. Furthermore, we see that for Noordwijk the difference between what was planned and what was realized is less than for Lochem and Den Bosch. This is in line with the strategy rule that Noordwijk has more priority. On average, Den Bosch has an accuracy of 88.6%, Lochem of 88.9% and Noordwijk of 92.2%.

Again, we see that the total amount is quite accurate. However, on average the total cream is forecasted more accurate in the allocation plan than in the week plan. The allocation plan has an accuracy of 95.1%, while in the week plan the accuracy is 94.4%. This means that the company can predict the total amount better in the 13-week plan than in the 1-week plan. From this section we conclude that the problems in the deviation of cream supply are not caused by the AP and WP on week level.

3.2.2 Deviation per location on a daily basis

The data from the previous section are based on the data per week, so how much cream flows into Butterhub per week. These forecasts are accurate for the expectations of the total amount, but not for the different locations. We also measure the deviation in cream supply per day. Figure 3.7 presents the deviation of supplied cream per day per location.

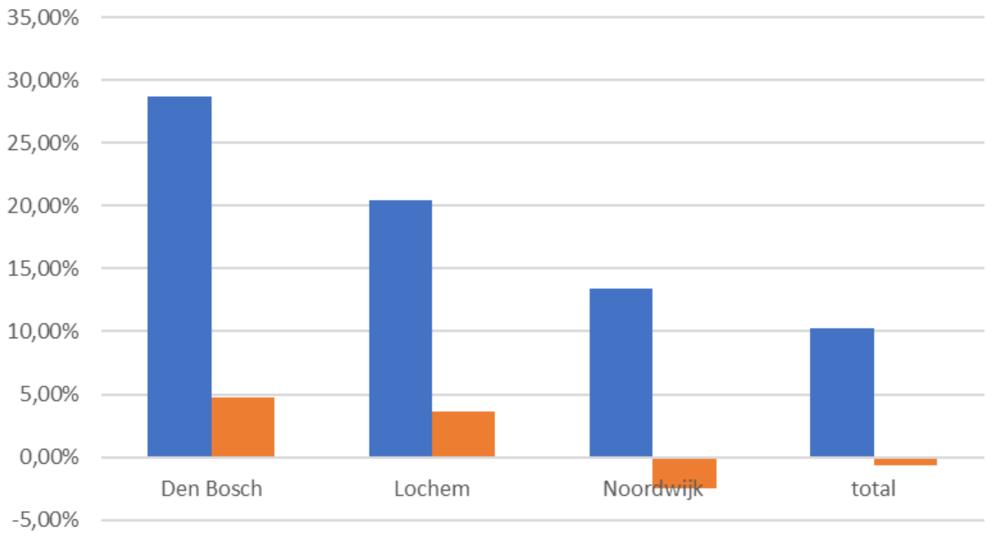

Figure 3.7: Average deviation between what was planned by Milk Allocation and what was supplied on day level, where blue is the absolute deviation and orange is the real deviation

The percentages in the figure are given in absolute deviation and real deviation. The absolute deviation is the deviation per day no matter if the location gets more or not enough cream. For the real difference it matters if it is more or less cream. We can explain that by an example. For example, when we consider a time period of two days and the amount of supplied cream is the first day 30% more than what was planned and the second day 30% less, the average absolute deviation in cream supply is 30% while the average real deviation is 0%.

In the data we find out that the deviation in cream supply on a daily basis is huge, especially in Den Bosch. There is almost 30% difference on what was planned and on what was realized on a daily basis, while per week it was only 11.4%. When we look to the real difference, we still see some difference. In Den Bosch, almost 5% more cream is arriving every day, in Lochem 3.7% more, while in Noordwijk there arrives on average 2.5% less cream per day over the whole year. If we look to the total amount, we find out that the difference is on average 10.26%, while in the week plan it is only 5.6%.

When we scale the percentages to actual differences in kilograms, we see that Lochem has the most difference. This gives that on average there is a difference of 85 tonnes cream in Lochem, 66 tonnes cream in Den Bosch and 51 tonnes cream in Noordwijk, as given in Table 3.2.

Table 3.2: Average absolute deviation of supplied cream between what was planned by Milk Allocation and what was supplied on day level in tonnes

Location	Average absolute deviation of cream per day in tonnes	Average absolute deviation of cream per day in percentage
Den Bosch	66.77	28.75%
Lochem	85.14	20.46%
Noordwijk	50.93	13.45%

To give an indication of the size of the problem, on maximum capacity the butter factory in Lochem can handle 30 tonnes of cream per hour. So, on average the deviation in Lochem is at least 3 hours of production in a butter factory a day. The deviation in Noordwijk and Den Bosch is less in tonnes of cream, but their capacity is less as well. From this we can conclude that the (daily) deviation is a huge problem for the production locations.

To give more insight in when the deviation occurs, we look to the average daily (real) difference per month per location, as shown in Figure 3.8. From May till September the released amount of cream is lower than expected, while in the other months it is higher than expected. From May till September the cows are in the meadows and so the percentage fat in milk is lower and so less cream is released. This seasonality is known within the company, but not included in the daily expected amount. Since this seasonality is not included in the planning created by Milk Allocation and the production locations want to have an accurate planning, the operational planners calculate the seasonality parameters for themselves. These parameters are calculated based on historical data that is available within the administration of the production location and included in their Milkplan.

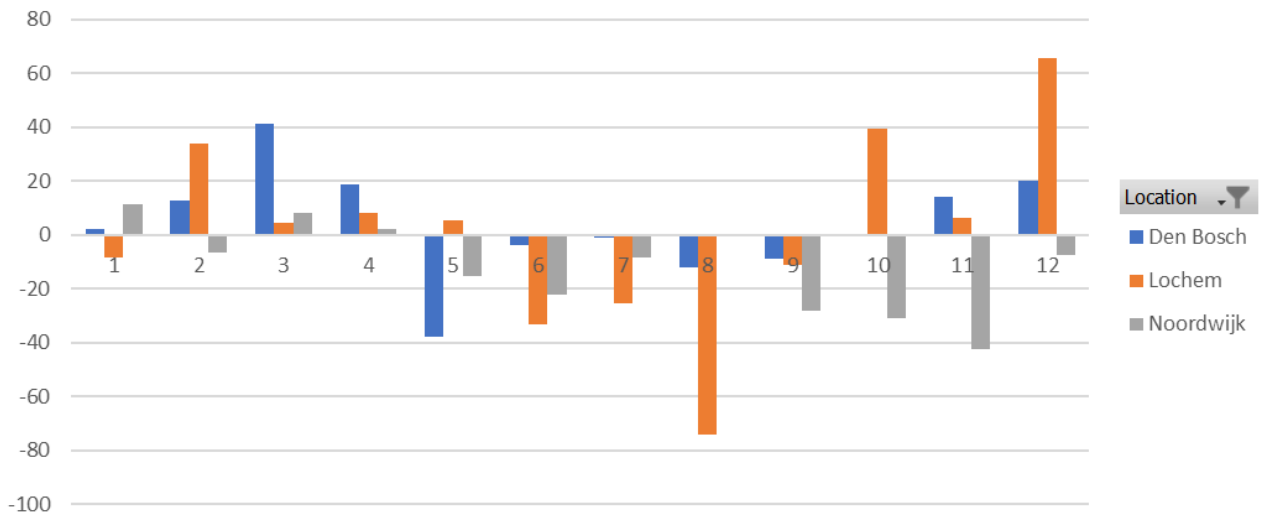

Figure 3.8: Average deviation between what was planned by Milk Allocation and what was supplied per location per month (on a daily basis)

We analyse the deviation per day as well, as shown in Figure 3.9. Here we see a remarkable insight as well. During the week, the production locations get less than expected, while in the weekend especially Den Bosch and Lochem will receive a lot more cream than was planned.

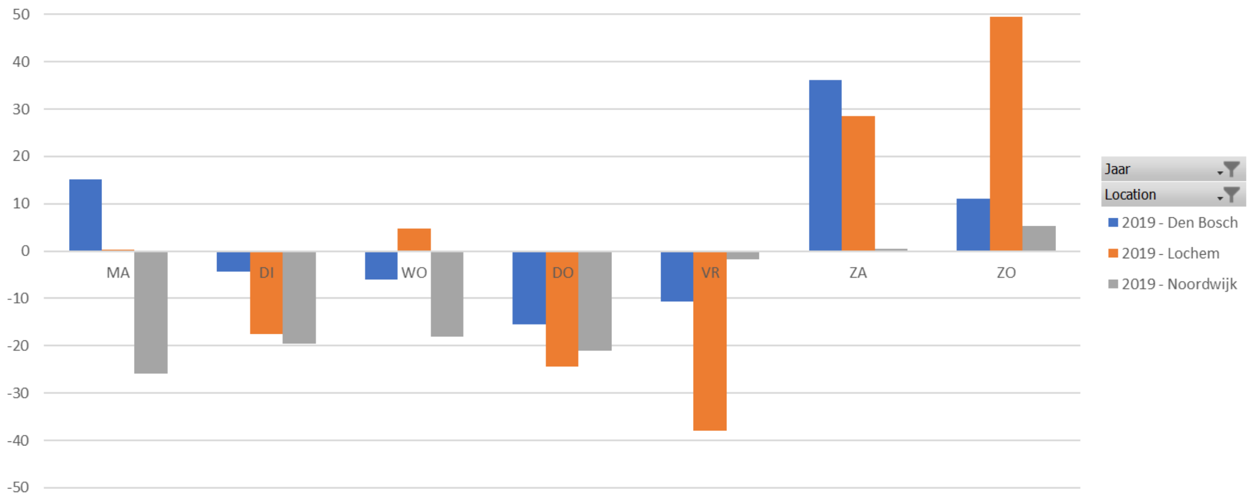

Figure 3.9: Average deviation between what was planned by Milk Allocation and what was supplied per location per day (on a daily basis)

The deviation over the week can be explained by the production hours of the other factories. The other business partners (as described in Section 1.3) are closed during the weekend and therefore there is more cream available for the Butterhub. This data is known as well, but also not included in the daily expectations.

3.2.3 Conclusions on the data analysis of the deviation in cream supply

After an analysis of the data, we can conclude some aspects:

- Milk Allocation predicts the total amount of cream for the OpCo Butter and Milkpowder quite accurately. This means that the total amount of released cream within the company and the amount of cream that is sold to the more important business partners is known.
- When we analyse the deviation on a daily level, the deviation is bigger. Where the total amount deviates on week level approximately 5%, it is on day level approximately 10%. So, FC knows the amount of cream that flows into their butter and butteroil factories but lack insight into when the cream is released.
- We see that the deviation in cream supply is a substantial problem especially in Den Bosch and Lochem. For example, in Lochem, the deviation in cream supply is equal to 3 hours of machine capacity on average a day.
- Seasonality is not included in the week plan on a daily level. In the summer, when the cows graze in the meadows and the fat percentage in the raw milk is lower, Milk Allocation plans structurally more cream than available. When we look to the deviation per day, we see that from Monday-Thursday there is planned too much cream, while in the weekend Milk Allocation plans not enough cream.

3.3 Consequences

After the data analysis and discussions with the hub, Milk Logistics and the production locations, we see the consequences of the deviation for the company. Some of them are already briefly mentioned in Section 1.3, but now we describe these consequences in more detail. The consequences can be categorized in four main problems.

3.3.1 Pressure on supply chain

The deviation in cream supply gives a lot of pressure on the whole supply chain. Due to the time-consuming planning process, a lot of time is wasted. It gives a high workload on all departments in the planning process.

Especially since the new way of working in sales, the pressure on the supply chain became bigger. Due to the demand driven mindset, all flexibility in which products must be produced is gone. There is no room for deviation anymore since all changes will affect the customer orders. It is a remarkable company decision that despite the change in sales and so a more complex planning process, no investments have been done in the supply chain. Milk logistics has understaffing and are satisfied with any good feasible transport planning. The pressure on the supply chain gives a lot of frustration between different parties as well. There are a lot of discussions between the different departments on how to plan the cream most efficient, which leads to frustrations.

3.3.2 Time consuming planning

Another main problem is that it is time consuming to make the planning for the business office, Milk Allocation and Intra-Transport. The business office must consider a lot of restrictions and all processes are connected. When there is a change in the amount of cream that a production location will get, it has effect on the Milkplan. The number of by-products changes when there are adaptions in the production planning and this has effects on the production planning for other factories, such as the milk powder factory.

Next to that, when there is a change in cream supply, especially the butter factories will suffer from it. The butter factory cannot switch quickly to other products since the aging and crystallising takes 12 - 15 hours. This means that when there is an adaption, the planning for the whole week must be changed. If it is not feasible for a production location to handle all cream given the orders, the business office contacts Milk Logistics and the hub to discuss what to do. An option is that the hub changes the orders that the factory must produce. For example, when there is too much cream, specialty orders will be changed into standard bulk product orders. Another option is to change the day plan. In this case Milk Allocation and Intra-Transport must change their planning. This second option is time consuming for Milk Allocation and Intra-Transport as well. It is hard to come up with a feasible planning because less cream for one location means more cream for another location. In this case the other production locations must change their production planning as well. Also, for Intra-Transport it takes a lot of time to make adaptions in the transport planning due to the many restrictions in the transport planning.

When changing the planning there are hidden costs, for example for the administration. When a trip of a truck is different than in SAP P92, the truck information must be changed manually in the system, what takes a lot of time. Next to that, the transportation costs are higher than before since the transport planning is less efficient.

3.3.3 Lost resource capacity

Deviation in cream supply has a huge effect on the efficiency of the production planning, since the optimal batch size of production cannot be reached. The machine will be cleaned more often since there must be a cleaning after every batch and after downtime. Also, the employees cannot be scheduled optimally. The personnel must be scheduled in advance and must be paid, even when the machine has downtime. A change in products that will be scheduled, will lead to problems with package materials as well. There must be enough package materials in inventory for all products that can be made since the production planning can be changed all the time.

Another problem with deviation in cream supply is that it will lead to lost machine capacity. When a machine has downtime at the beginning of the week because there is no cream, this capacity cannot be caught up at the end of the week. For example, when the maximum capacity in a week is 400 tonnes of cream for a machine line and it has downtime on Monday, the maximum capacity is only 343 tonnes (week capacity * six out of seven days availability). This leads to problems when the amount that is ordered in a week is for example 350 tonnes. Then in the week capacity it is feasible to produce all products, while due to the daily deviation in supply it is in reality not feasible.

3.3.4 Right products cannot be made

To get to know the effect of the deviation on the product orders, we analyse a data file that contains all information on the internal orders, gathered by the hub. This file consists how much tonnes were planned in the orders and how much tonnes were actually produced of that order, the KPI PPC_n.

Due to a lot of different reasons an order cannot be made by a production location, as described in Section 2.4.1. Figure 3.10 shows an overview on the categories that causes deviation in the amount that is ordered.

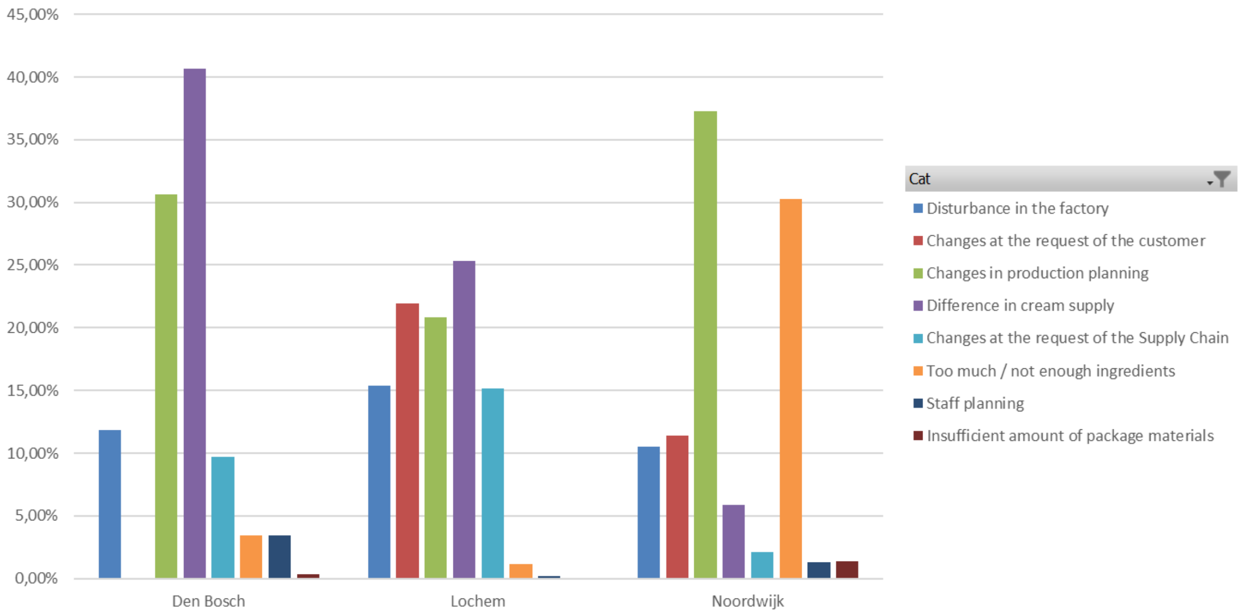

Figure 3.10: Percentage of the times a category causes deviation on a product order

The given percentages are calculated as follows:

$Percentage_i = \frac{Number\ of\ times\ an\ order\ has\ deviation\ due\ to\ category\ i}{Total\ number\ of\ times\ there\ is\ a\ deviation\ in\ an\ order} * 100\%$, where $i\,\{1,\dots,9\}$, given in Table 2.1. Note that in the data, $PPC_i > 90\%$ are not included, since the category is OK.

The figure shows that in Den Bosch and Lochem most deviation in cream supply is caused by difference in cream supply, while in Noordwijk most of the deviation is caused by changes in the production planning. To scale the given data, we also look to the absolute difference in product orders that is caused by the categories. This is calculated by $Difference_i = abs(total\ amount\ of\ tons\ planned\ that\ has\ deviation\ due\ to\ category\ i -$

$amount\ of\ tons\ realised\ that\ has\ deviation\ due\ to\ category\ i)$. Again, where $i\ \{1, \ldots, 9\}$, given in Table 2.1.

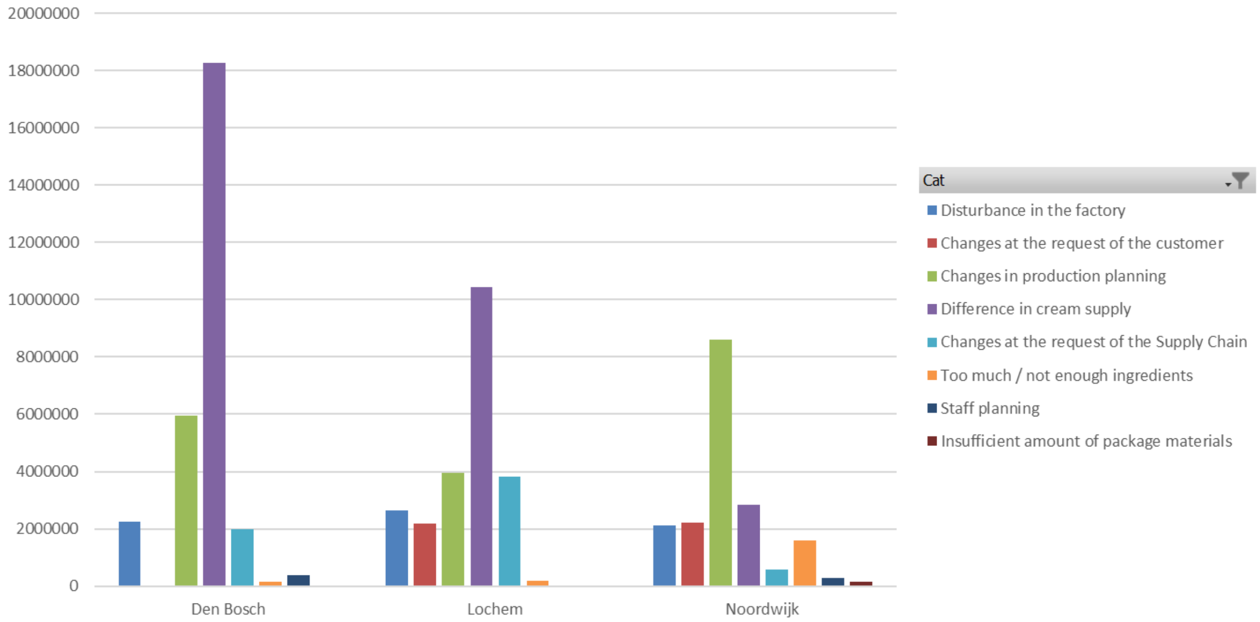

Figure 3.11: Absolute difference (ordered by customer – produced by a production location) caused by category (units in tonnes of end product)

In Figure 3.11 we see that in Den Bosch and Lochem not only the percentage of the time that a deviation is caused by the difference in cream supply is the biggest, but also when there is deviation, the deviation is huge. For Noordwijk, the amount deviation that is caused by difference in cream supply seems to be manageable. The amount of absolute difference is given in tonnes of end products, so not on the amount of cream that is needed to produce the end product, but there is a difference in amount of cream needed for a tonne of AMF and a tonne of butter. Namely, AMF has a fat percentage of 99.8%, which means that for one tonne AMF it needs 2.495 tonnes of cream, while butter has a fat percentage of 82% and therefore one tonne of butter needs 2.05 tonnes of cream.

To get more insight in the impact of this deviation, we filter the data on all orders that has been changed due to the difference in cream supply. We divide the products in butter and AMF to give a better perspective, since the amount of cream that is needed differs for butter and AMF. Figure 3.12 and Figure 3.13 show the difference in product orders.

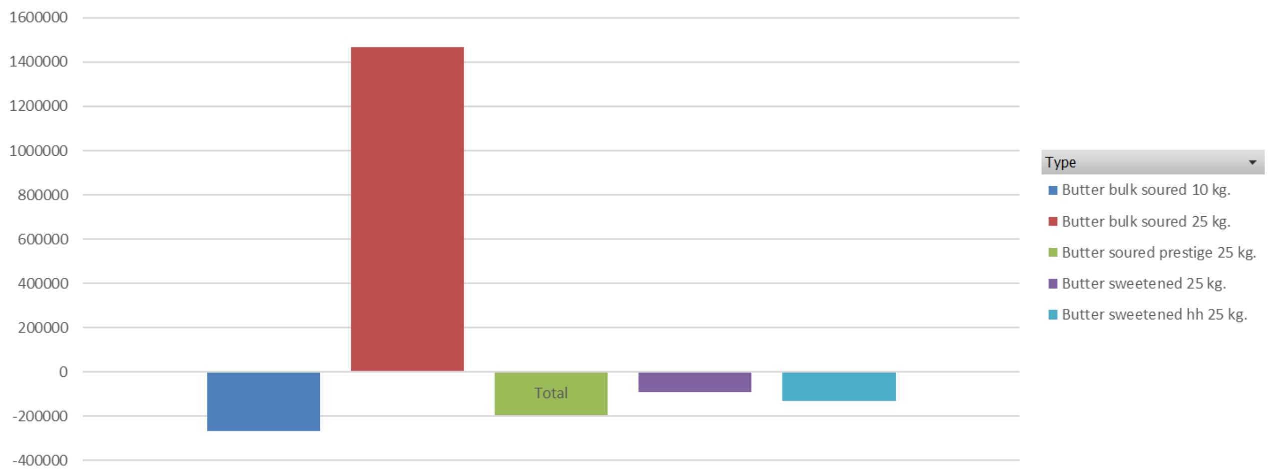

Figure 3.12: Difference (ordered by customer – produced by production location) in what was ordered and what was produced per product type (butter) (units in tonnes of end product)

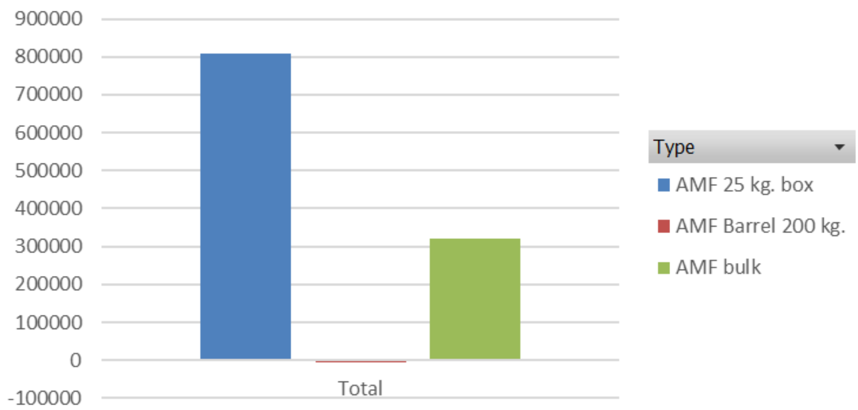

Figure 3.13: Difference (ordered by customer – produced by production location) in what was ordered and what was produced per product type (butteroil) (units in tonnes of end product)

For butter, we see that the standard butter (bulk soured 25 kg), has been produced more than what was planned, while the other products (the specialties) has been produced less than ordered. This is because of the maximum capacity of the machine lines. The maximum capacity for those specialties is lower and therefore when more cream arrives than was expected, the specialties will be cancelled, and standard butter will be produced instead. To give an indication, in Lochem the maximum capacity for a standard product such as bulk soured butter 25 kg is 26.27 tonnes of cream, while the maximum capacity for a specialty such as soured prestige butter 25 kg is only 19.53 tonnes. So, the maximum capacity is 34% higher for bulk standard products. Next to that, the batch size for soured prestige butter is only half of the of maximum batch size from the bulk soured butter, so producing specialties will lead to more cleaning time as well.

For AMF, we see that in general there is more produced than ordered, with the exception of 200 kg barrels. This is because for AMF, the cream does not have to be crystallized and aged and therefore there can be switched faster to other products in production. So, when there is more cream available than planned, the production location makes in general more standard butter or AMF and less specialties to process the cream faster, to avoid overflowing cream silos.

Cancelling specialties will affect the service level to the customers and will have negative influence on the profit margin. The specialties have higher profit margins and therefore will lead to more profit per tonne cream. Also, over production of standard products will affect the service level since the service level is calculated by the absolute difference.

3.4 Conclusions on the data analysis

In this chapter we analysed the available data on the deviations in cream supply and the effects of it. There are four root causes that cause the deviations in the amount of supplied cream. First, there is a lot of uncertainty in the demand and the supply of cream in the whole supply chain. The second root cause is that there a lot of unclarities in the data. The production planners do not know what is included in the data and what is not. Third, also when the data is clear, the forecasts on a daily level are not accurate. Fourth, the last cause of the problem is that all different departments work on the planning separately, without a focus on the whole company.

In the data, we found two important patterns, namely that the problems are caused in the planning on day level and that seasonality is not included in the day plan. We see that the amount of cream that is expected during a complete week is accurate, on average there is only 4% absolute deviation, while on day level the total amount deviates on average 10%. The deviation of cream supply on the different locations is even bigger. In Lochem the deviation is on average 3 hours of maximum machine capacity a day, which is a lot.

From the analysed data, we see the consequences from the problem as stated in Chapter 1. For example, in Den Bosch there is a difference of approximately 30% in the amount of cream that was allocated and what was actually was arriving at the production location per day. The deviation leads to a lot of tensions between different departments of the company. Next to that, the planners on the production locations spend a lot of time on the production planning to keep control on the deviations in the amount of cream that is supplied. Also, production capacity is lost, and the resources cannot be used in an efficient manner. Not only the production locations suffer from these deviations in supply, also the customers suffer from it when the right orders cannot be made, which makes FC less reliable.

Figure 3.14 gives an overview of all causes and consequences of the main problem.

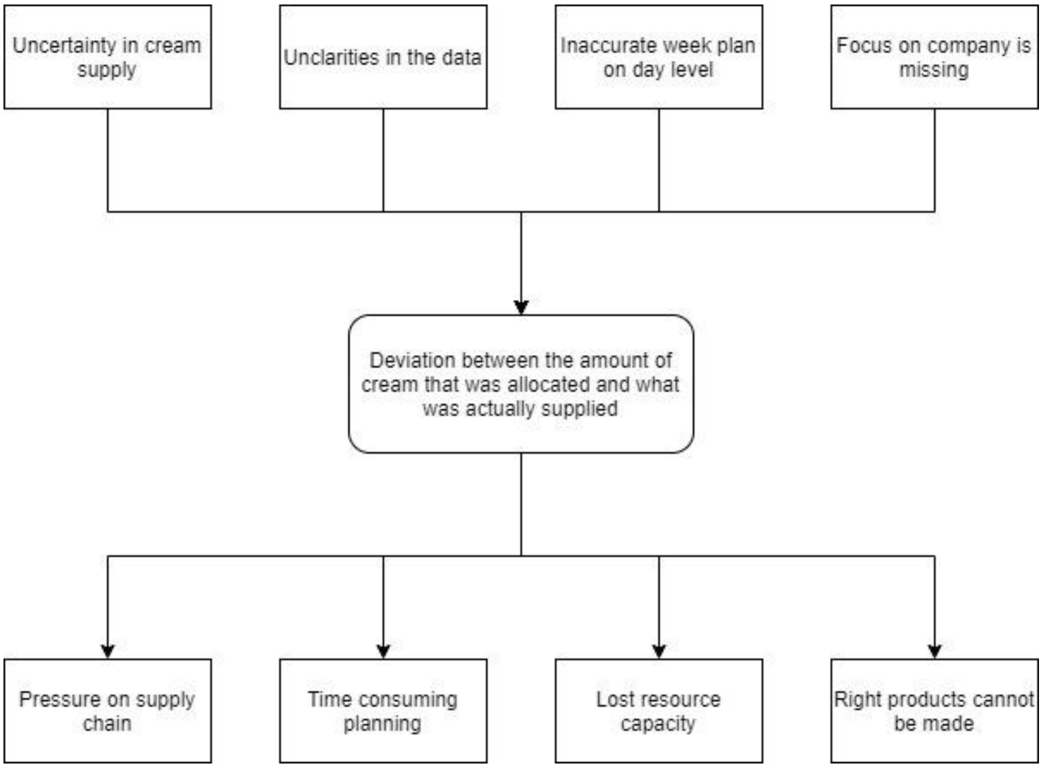

Figure 3.14: Causes and consequences of the main problem of this research

Now we know the problem in detail and the causes and the consequences of the problem, we can search for solutions. In finding solutions, we focus us on the planning on day level, since the problems are caused on this planning level. In the next chapter, we perform a literature review on what is already known in literature about this kind of problems. The main goal of this literature review is to get insight in allocating strategies and the dairy industry in general and find possible ways to implement allocation strategies in the dairy industry.

4. Literature Review

In this chapter, we perform a literature review about research question 3: What are, according to literature, possible allocating strategies in the dairy supply chain? In order to give an answer on this question, we divide this chapter in three sections. In Section 4.1 we answer the sub-research question: What kind of allocating strategies are there in general? In Section 4.2 we answer the question: What characteristics and challenges are important in the dairy supply chain? Finally, in Section 4.3 we look to what allocation strategies are suitable for the dairy supply chain.

4.1 What kind of allocating strategies are there in general?

Supply Chain Management (SCM) is the process of planning, implementing and controlling the operations of the supply chain in an efficient way (Melo, Nickel & Saldanha-da-Gama, 2008). It considers the storage and all movements of products from raw material to end products for consumers. SCM is one of the most popular subjects within operational research and management science (Misni & Lee, 2017). The success of a company depends on the efficiency of the supply chain network. The development of SCM is for companies not only driven by internal drivers, but also due to external factors such as increasing globalisation, improvements in information availability and environmental concerns (Gunasekaran, Patel & McGaughey, 2004).

Strategical, tactical and operational planning

SCM literature classifies three planning levels, namely strategic, tactical and operational planning (Melo et al., 2008; Misni & Lee, 2017; Schmidt & Wilhelm, 2000; Crainic & Laporte, 1997, Chopra & Meindl, 2013).

Strategic is the long-term planning of a firm. Decision making in strategic planning involves the highest level of management and large capital investments are required (Crainic & Laporte, 1997). Strategic decision making is important for designing the logistic network (Schmidt & Wilhelm, 2000). Decisions in infrastructure, general business environment and closeness to market and suppliers are typical strategic-level decisions. On this planning level it is important that there is a strategic fit between the supply chain strategy and the competitive strategy (Chopra & Meindl, 2013).

Tactical decisions are medium term decisions. The tactical level deals with decisions with a time-horizon of 6 to 24 months and is the connection between strategic and operational decisions (Schmidt & Wilhelm, 2000). The decisions are mostly related to inventory management, production planning, procurement and lot sizes (Misni & Lee, 2017). The data from different parts of the company are aggregated for this level of decisions (Crainic & Laporte, 1997). The data is sensitive for broad variations in the data, but day-to-day data is not included. Tactical level decisions consider both production and transportation issues, but those decisions are often made separately, especially in a multi-plant environment (Schmidt & Wilhelm, 2000). The policies regarding production and transportation decisions are mostly made at strategic level but must be refined at tactical level, since variables have less uncertainty.

The operational decision planning includes day-to-day decisions (Misni & Lee, 2017). This level of planning is mostly located at the plants and plan production in such a way that in-time delivery of final products to customers is assured (Schmidt & Wilhelm, 2000). At operational level, the constraints imposed by strategic and tactical levels must be considered. Planning in an operational environment is highly dynamic where the time factor plays a crucial role (Crainic & Laporte, 1997). Operational decisions are being made in a short time, so within minutes, hours or days (Chopra & Meindl, 2013). This means that there is less uncertainty about demand information. Typical operational decisions are routing vehicles and scheduling staff, maintenance and machine lines.

These three planning levels are comparable to the planning levels within FrieslandCampina. The strategical and tactical level of planning are done by the department Milk Valorisation and Allocation (MVA), where within FC the strategical decisions are made within a time horizon of 10 years and the tactical decisions have a time horizon of 18 months. The operational level within FC contains multiple layers and is done by three different departments, namely MVA, Milk Logistics and the business offices at each production location. The MVA makes a 13-week plan, which is part of the operational planning level because the 13-week plan contains strategies on how to ensure in-time delivery and the 13-week plan have great influence on the day-to-day decisions. Milk Logistics makes the allocation plan on week and day level and the production planners at the business office make a production plan on week and day level. This research focuses on operational decision planning, since the problem is caused on this planning level, as described in Section 3.2. This means that characteristics such as time and in-time delivery are important for this research.

Optimization models

Due to the complexity and importance of a supply chain, (mathematical) optimization models are highly suitable to use when analysing the supply chain (Schmidt & Wilhelm, 2000). The goal of an optimization problem is to find an (global) optimal solution. Most of the successful models are based on mathematical programming and constraint programming (Talbi, 2009). As shown in Figure 4.1, mathematical programming models can be divided in 3 different classes, namely continuous, integer and mixed (which is a combination of integer and continuous variables), based on the input variables of the problem.

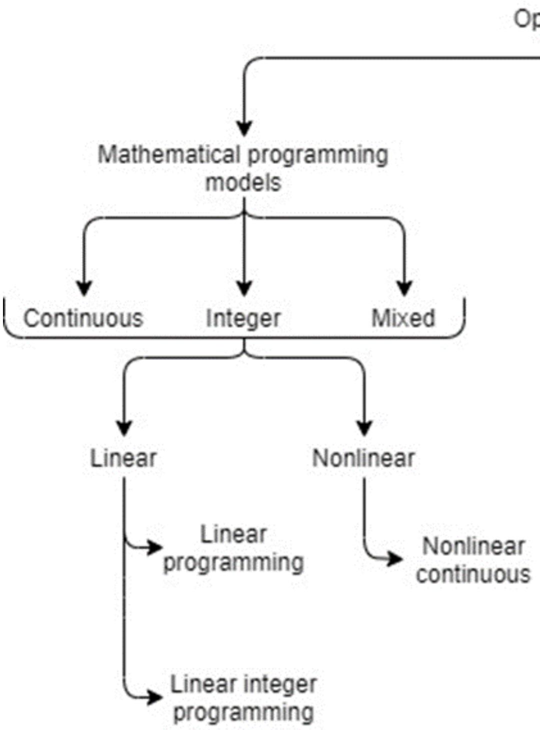

Figure 4.1: Classical optimization models, adapted from Talbi (2009)

Next to splitting the mathematical programming models by looking at the input variables, the mathematical programming models can also be divided in linear and nonlinear programming, where linear programming is the most commonly used model (Talbi, 2009).

The goal of a linear programming is always to minimize or maximize an objective function. Linear programming can be seen as a solving method itself since the linear program can be solved by a software package (Winston, 2003). However, Talbi (2009) considers linear programming not as a solving method itself and says that there are different other optimization methods, as shown in Figure 4.2 and elaborated below.

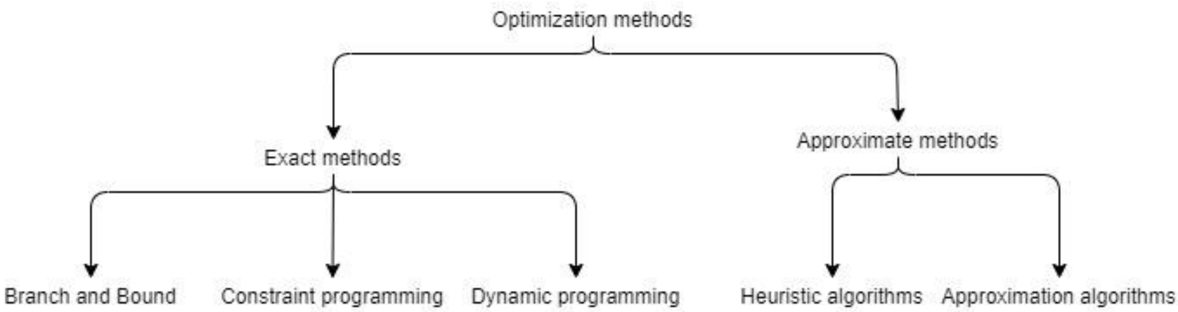

Figure 4.2: Classical optimization methods, adapted from Talbi (2009)

To solve a linear programming model, first must be determined how complex a model is. The model can be solved by an exact method or an approximate method. The main difference between these models is that with exact methods the optimal solution can be guaranteed (Talbi, 2009). Approximate methods can find 'good' solutions within reasonable time, but optimality cannot be guaranteed. Which solution approach is best for the problem not only depends on the size of the problem, but on the structure as well (Talbi, 2009).

Exact Algorithms

There are three classical exact algorithms: dynamic programming, branch and bound and constraint programming.

Dynamic programming is a technique that obtains solutions by working backward from the end of the problem to the beginning. It breaks up a large problem into smaller problems (Winston, 2003). The technique can be used to solve a lot of different optimisation problems.

Branch and Bound is a solving technique that is useful for pure integer programming problems (Winston, 2003). With Branch and Bound we branch the problem in subproblems, where a subproblem is a possible partial solution. The subproblems can be displayed in a tree. The nodes at the end of the tree are potential solutions.

When solving a problem with the use of constraint programming, the problem will be modelled by the means of a set of variables linked by a set of constraint (Talbi, 2009). Constraint programming is a language that is built around the principles of tree search and logical implications. The variables only can take values within a finite domain of integers.

Approximate methods

Next to these exact approaches, there are some approximate methods that can be used to solve the problem. Approximate methods are mostly used when a problem is too complex to solve it exactly or if it is important to find a 'good' solution within reasonable time. The approximate methods can be divided in two different subclasses of algorithms, namely approximation algorithms and heuristic algorithms (Talbi, 2009).

An approximation algorithm can provide a good solution quality within provable run-time bounds, but with such algorithm it is unlikely to get the optimal solution. In approximation algorithms the solution is with guarantee a good solution (Talbi, 2009).

Heuristic algorithms on the other hand do not have a proof of the solution quality. There are three different kind of heuristics, constructive, improvement and destructive (Rader, 2010). Hereby the constructive heuristic starts with an empty solution and adds a partial solution to it until a complete solution is constructed. Next, an improvement heuristic can improve the solution for example by switching partial solution. Destructive heuristic does not start with a partial solution but starts with a complete solution. Next, at each iteration elements of the current solution will be deleted and repaired by trying different options. The heuristic stops when there are no feasible neighbour solutions left.

Quality of solutions versus search time

In solving mathematical programs, it is always important to find the balance between the running time and the quality of the solution.

At the top level, the strategic level, the running time is not that important, because the problems are generally solved once (Talbi, 2009). It is important that the quality of the solution is very good. These problems are also called design problems. If possible, exact algorithms must be used to solve the design problems. When modelling at the strategic level, decision-makers do not have enough information to specify all parameters and therefore there is a lot of uncertainty in the process (Schmidt & Wilhelm, 2000). Another issue is that parameters can change over time. This means that all parameters and variables must be time dependent, which makes it an exceptional challenge to compute (Schmidt & Wilhelm, 2000).

At operational level, the time factor is important since there is limited time available. Therefore, fast approximation algorithms are recommended when solving these problems (Talbi, 2009). The quality of the solution is less critical. The short-term operational problems can also be called control problems. Figure 4.3 shows the relation between the planning levels, the quality of the solution and search time.

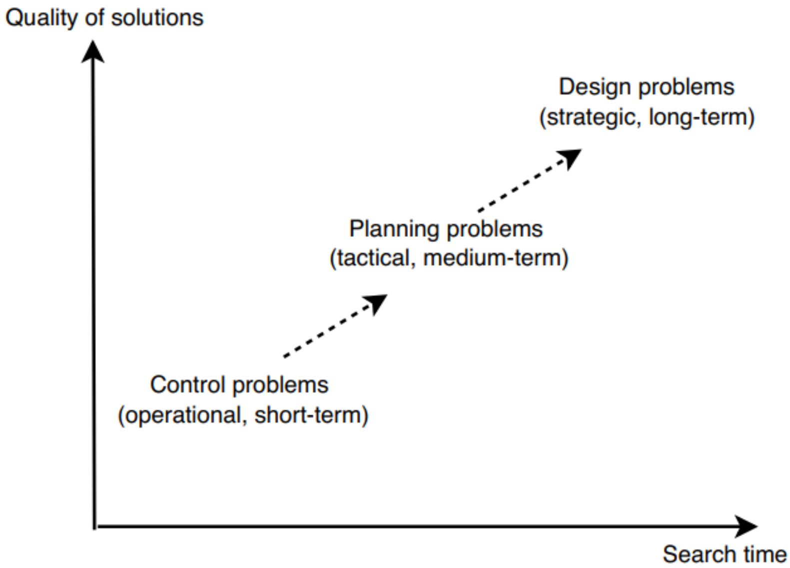

Figure 4.3: Relation between the planning levels and the optimization methods, retrieved from Talbi (2009)

In-between the control and design problems, there are planning problems, problems on tactical level. These problems require good quality solutions, while the running time is important as well (Talbi, 2009).

4.2 What aspects are important in the dairy supply chain?

During the years, dairy products have an increasing importance, since the dairy industry has found its position all over the world, and therefore the market demand has been lifted (Ebrahimi, Khoshalhan & Ghaderzadeh, 2018). The dairy market is hypercompetitive with on average profit margins of only 1%-2% of sales (Ayag, 2012). Due to the high competitiveness on the dairy market, dairy companies must optimize their profits from its production and sales to survival (Guan and Philpott, 2009). The dairy supply chain will be more and more important, since the production of milk and other dairy products are increasing daily, since the dairy industry in developing countries as Iran and India is growing (Ayag, 2012).

What makes the dairy supply chain complex is that dairy companies facilitate a huge variety of products, such as yoghurt, butter and cheese (Jouzdani et al., 2018). Even within a specific product group the products can variate by adding fat contents, different flavours or having different package sizes (Doganis & Sarimveis, 2007).

The main difference of the dairy supply chain with other supply chains is that the dairy supply chain involves perishable products, which influences the whole chain, from getting the milk at dairy farms till the delivering end products (Ebrahimi et al., 2018). Also, the dairy network is a composite network where all streams are connected. Farmers, input suppliers, cooperatives, warehouses, transporters, importers, wholesalers, retailers and consumers are all linked to the 'farm to fork' chain (Bhardwaj et al., 2016).

According to the literature review of Mor, Bhardwaj and Singh (2018d), there are seven key challenges within the dairy supply chain, as shown in Figure 4.4:

Sr. No.	Challenges
1	Effectiveness of information systems
2	Perishable nature of dairy products
3	Traceability of quality related issues
4	High risk of milk adulteration/contamination
5	Effectiveness of cold chain
6	High demand fluctuations
7	Logistics, transportation and road infrastructure

Figure 4.4: Seven key challenges in the dairy supply chain (Mor, Bhardwaj and Singh, 2018d)

Effectiveness of information systems

Singh and Javadekar (2011) proved that the non-usage of IT can lead to a lot of wastage in the perishable food industry, where the dairy industry is part of. Also, Bowonder, Raghu and Kotla (2005) found that the properly use of ICT can help to improve the productivity of the industry. Effective supply chain management need a good flow of information across the network (Srivastava, 2006). Therefore, the workers in the dairy industry "need to develop high responsiveness in supply chain directing on the coordination and effective information system" (Mor et al., 2018d, p21), which makes it a key challenge.

Perishable nature of dairy products

What is an important difference of the dairy supply chain with others, is its perishable nature, which has influence on the whole supply chain (Ebrahimi et al., 2018). Due to the perishable nature, the products need special treatment, cooling mechanism, handling and quick actions from raw milk till end product (Mor et al., 2018d). All these extra restrictions can lead to high wastages and it can potentially reduce the product value (Mishra & Shekhar, 2011). The shelf-life constraints also have impact on the logistics of the chain. The limited shelf life puts extra requirements on the speed and reliability of logistics and therefore it needs special transportation trucks and special warehouses to store the products (Van der Vorst et al., 2007).

Traceability of quality related issues

Traceability means that the company is able to track the downstream path of the product in the supply chain. Due to the perishable nature of the dairy products, traceability always has been important in the industry (Mor, Bhardwaj & Singh, 2018a). Therefore, the logistics of the company need to have configurations that facilitate tracking and tracing (Van der Vorst et al., 2007). Traceability is not only important for the quality and safety risks but can also promote the development of effective dairy supply chain management (Pant, Prakash & Farooquie, 2015).

High risk of milk adulteration/contamination

Another challenge in the dairy supply chain is the high risk of milk adulteration and contamination. An example of milk adulteration is the milk incidents of 2008 and 2011 in China where more than 300,000 people became ill of drinking milk that contained poisoned ingredients (NOS, 2011). When there is not enough traceability, adulteration of the milk, for example by adding water to the milk to increase the volume by the farmers, cannot be tracked (Mor et al., 2018a).

Effectiveness of cold chain

A cold chain is essential for products that are highly sensitive to temperature and other environmental conditions (Chaudhuri et al., 2018). When lacking on regulation, the food products can lead to wastages and unsafe products, which can cause effects on human health, product prices and food availability. Since 20% of all dairy products globally are wasted (Gustavsson et al., 2011), the cold chain will continuously be a challenge in the dairy supply chain.

High demand fluctuation

The fluctuations of the dairy market will constant be a challenge for the industry (Guary et al., 2010). Dairy companies who can react to the fluctuation in demand can achieve higher profit margins on their milk (Van der Pool, 2007). Before 2015, the European market gained stability due to the milk quotas. However, the European Union removed the milk quota in 2015, which influenced the price volatility, which was already expected by Guary et al. (2010).

Logistics, transportation and road infrastructure

A typical dairy supply chain consists of three different kinds of transport, namely transportation of raw milk, inter-transportation of semi-finished products that are transported to other plants and transportation of finished products (Wouda et al., 2002). What makes the supply chain very complex is that there are a lot of farmers, different products, distribution centres and shops involved.

According to various other articles, there is another factor that has been a challenge in the dairy supply chain, namely seasonality. Seasonality affects qualitative (milk composition) and quantitative features of the raw milk (Ebrahimi et al., 2018). According to the authors, seasonality is the most effective factor that influences the valorisation of the dairy supply chain. Also, Van Der Vorst et al. (2007) mention the seasonality in production and composition of raw milk as one of the main characteristics of the supply chain network. Banaszewska et al. (2013) has proven that including seasonality in the dairy supply chain model can improve the profitability and make the model more useful.

4.3 What allocating strategies are suitable for the dairy supply chain?

To see which allocating strategies are common in literature, we analyse the article of Nematollahi and Tajbakhsh (2020). The article is a literature review and analyses articles in the agri-cultural supply chain, where the dairy supply chain is part of. The authors found 247 articles in the last 30 years that were useful for the review. Figure 4.5 gives an overview of the mathematical programming models that were applied in the reviewed articles.

The distribution of the studies according to the mathematical programming.

Mathematical programming		Solution approach	
Linear programming	19	Exact method	16
		Approximation method	3
Non-linear programming	8	Exact method	2
		Approximation method	6
Mixed-integer programming	72	Exact method	40
		Approximation method	32
Multi-objective programming	39	Exact method	27
		Approximation method	12
Dynamic programming	1	Exact method	1
		Approximation method	0
Stochastic programming	17	Exact method	5
		Approximation method	12
Robust optimization	2	Exact method	0
		Approximation method	2

Figure 4.5: Distribution of the studies according to the mathematical programming, retrieved from Nematollahi & Tajbakhsh (2020

Here we see that mixed-integer programming (MIP) is the most common method to model the supply chain (Nematollahi & Tajbakhsh, 2020). Besides the programming methods, also the solution approaches are reviewed. Most researchers use exact methods to find a solution, which means that the models obtain optimal policies. However, to implement real life problems into a MIP-model, a lot of simplifications and assumptions must be done, what makes it unlikely to obtain an optimal solution in practice.

There are various applications of mathematical programming within the dairy industry. Below we give some examples of how mathematical programming can improve the dairy supply chain.

Guan and Philpott (2011) presented a model that computes an optimal sales policy. The authors make use of uncertain milk supply. The model has been tested at Fonterra, which is a dairy company from New Zealand and is one of world's largest dairy companies. The model is the first model in the dairy supply chain using multistage stochastic programming (Guan & Philpott, 2011). The model is solved and tested by using simulation experiments as solving approach.

Nemati, Madhoshi and Ghadikolaei (2017a) came up with three MIP models for an Iranian dairy company that optimizes the performance of the Sales and Operations Planning (S&OP). The first model is a fully-integrated S&OP approach, which integrates the planning of sales, production, distribution and procurement. The second model only partially integrates the S&OP and only integrates sales and production planning, while the rest is performed discretely in each site. In the third model, the authors compare the approaches by solving the problem with the use of the exact solution method Dynamic Programming (DP).

Marandi and Zegordi (2015) developed a MIP model that integrates the production and distribution scheduling for short shelf-life food products, such as dairy products. Most of the approaches in literature focus on tactical decision level, while integrating scheduling in the operational planning is significant to achieve optimal supply chain performance (Marandi & Zegordi, 2015). To solve the model, a meta-heuristic method is used.

Sel et al. (2015) considers a problem on integrated planning and scheduling in the production of the dairy product yoghurt. The problem is formulated in a mixed integer linear programming model, which minimizes the total cost by considering a shelf-life dependent loss function given a specific demand. The model is solved by a heuristic approach and the proposed approach is also applicable for other dairy production processes, such as butter.

Finally, Banaszewska et al. (2013) presented a valorisation (linear programming) model for allocating raw milk. The allocation planning considers mid-term (tactical) decisions and includes important constraints as recipes, seasonality and demand and supply fluctuation. The authors were able to solve the model to optimality and it was tested at FrieslandCampina. After this research, the model was extended, and FC is still using this model. The model is implemented in an external software package, which calculates the optimal solution.

4.4 Conclusions on literature

In literature, a lot is written about modelling the supply chain. When managing the supply chain problem, there are three levels of planning, namely strategic, tactical and operational planning. Due to the complexity and importance of supply chain management, it is highly suitable to analyse with mathematical programming. In mathematical programming there are three categories, namely continuous, mixed and integer models, depending on the input variables. The mathematical programming models can also be divided in linear and non-linear, where linear is the most common variant. When solving mathematical programming, either exact or approximate solving methods can be used, depending on the size and complexity of the problem. The dairy supply chain has some characteristics that has to be considered, like its perishable character, seasonality and demand fluctuation.

In the dairy industry there are multiple applications of mathematical programming, but Mixed Integer Linear Programming (MILP) is the most commonly used. In literature has been proven that MILP are highly suitable to use when optimising an allocating problem. Next to that, the structure and size of our problem is comparable with the structure of the model from Banaszewska et al. (2013). Therefore, we use MILP in solving the cream allocating problem of FrieslandCampina. Furthermore, given the size of the problem, we expect that the model is solvable to optimal within reasonable computation time. Therefore, we use an exact solving method for this problem.

5. Solution design

In this chapter, we answer the research question: What are possible solutions to solve the problem? In order to do so, we first take a look on the allocation process of whey, which is another by-product stream, in Section 5.1. In Section 5.2 we give an overview of what can be expected in the next chapter and which problems we are going to solve. In Section 5.3 we explain how we can handle the problem of uncertainty. Finally, in Section 5.4 we conclude this chapter.

5.1 Whey process

At FrieslandCampina, there are a lot of different product streams, as described in Section 2.1.2. Within the company it is known that the stream of whey is better managed than the stream of cream. Therefore, in this section we take a look on the stream of whey how this supply chain is designed and managed.

Whey is the major by-product of the dairy industry (Koutinas et al., 2009) and is released in the process of producing cheese. It became more and more valuable during the last fifty years. Most of the whey used as ingredient for producing powders, for example as ingredient for growing up milk powder. The role of whey in the dairy network is quite similar to the role of cream since whey is like cream a by-product of milk and can only be obtained when other dairy products are produced. This means that all cream and whey are transported intra-company. Another important similarity is that in the whey process of FC all obtained whey must be processed within the company. So, the people that are involved in the whey supply chain cannot determine how much whey they want to process. The whey is mainly released in the process of producing cheese, so the amount of whey depends on how much cheese is made within the company.

There are also some differences between the cream supply chain and the whey supply chain. The first difference is that within the whey supply chain, most products are made-to-stock, while in the cream supply chain most products are made-to-order. Whey can be produced made-to-stock because when whey is powdered, it has a long shelf life. Therefore, within the whey supply chain it is not as important as for the cream products to make the right orders on the right time. Next to that, there is a difference in the number of factories that process the by-product. Within the cream supply chain, there are only three factories that process most of the cream, while within the whey supply chain, there are eight processing factories, which creates more flexibility in the supply chain. Another big difference of the whey supply chain in comparison with the cream supply chain, is that the whey end products also need other ingredients like lactose, which is also a dairy by-product. The cream end products, like butter and butteroil, do not need any other dairy by-products as ingredient and therefore the production of butter and butteroil do only depend on the amount of cream, which makes the process is less complex.

Within the whey supply chain of FrieslandCampina, the whey is valorised separately from the other dairy supply chain, based on Banaszewska et al. (2014). In this article (research executed at FrieslandCampina), the authors extend their valorisation model of Banaszewska et al. (2013), as described in Section 4.3. The original model did not include whey processing. In the extended model, called the Integral Dairy Valorisation Model (IDVM), the production levels of non-whey products are calculated first. Next, the production levels of the non-whey products are an input for the so-called stepwise valorisation, as described in Figure 5.1. Next, the production levels for whey products will be optimized to maximize the profit.

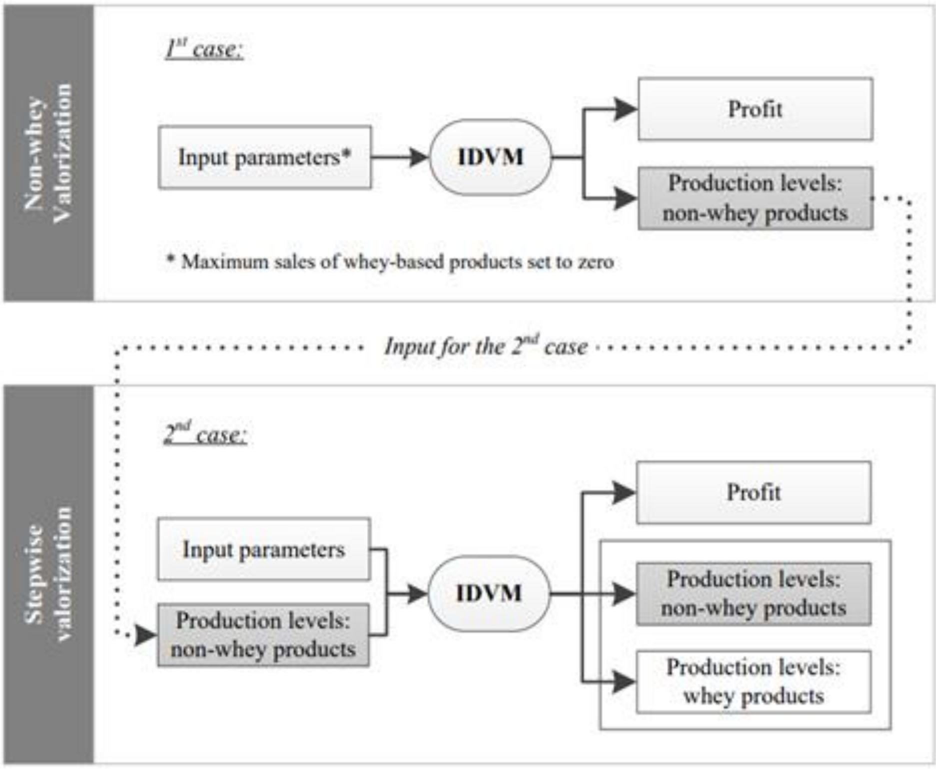

Figure 5.1: Whey valorisation model, adapted from Banaszewska et al., 2014, where IDVM = Integral Dairy Valorisation Model

Next to the stepwise valorisation, the article of Banaszewska et al. (2014) also uses an integral valorisation that includes the whey streams into the IDVM and compares it with the stepwise valorisation. The authors conclude that the effect of integral valorisation is small. Only when the demand of whey increases significantly, it is profitable to use the integral valorisation.

In practice at FC, the whey valorisation is separated from the Milk Valorisation and Allocation (MVA) department. MVA makes an allocation plan for all other streams. This allocation plan contains a strategy on how many products must be produced of a dairy product. But for the allocation of whey, there is an allocation planner that is not part of the MVA department who does the strategic, tactical and operational planning for the whey streams specifically. First, the MVA calculates the production levels of all non-whey streams and sends this information to all hubs. Next, the whey allocation planner uses this information as input for the whey valorisation model.

The whey valorisation model is a mathematical programming model which is implemented in the planning tool 'OMP'. OMP is software that calculates the optimal amount of ingredients that all production locations should receive, given a set of input parameters. The software is based on a MILP-model. For the whey valorisation model, the input parameters are the amount of available whey, the demand of all end products, cost prices, sales prices and seasonality effects.

The output of the model is so called buckets with how many end products of a specific type must be produced. The model first fills the most important bucket, next the second important bucket and so on. The least important bucket can be seen as buffer-bucket. Products that are in this bucket, are only produced when there is enough whey available within the company. The software of OMP calculates the amount of ingredients in each bucket and next it divides the amounts to the production locations. In practice, there is one production location that handles all products from the least important bucket. So, there is one buffer-location in the supply chain. Furthermore, the production locations will not be planned on 100% capacity, due to the uncertainty in the process. The locations will be planned on 95%, to deal with the fluctuations in supply.

When there are changes in the supply, Milk Allocation works with buckets as well. The most important bucket will always be supplied in full, while the least important bucket will only be filled when there is enough whey. This is different than the cream process, where the supplied cream is prioritised per location and Milk Logistics do not have information on the priority of the orders. Next to this, in the cream supply chain the cream is not valorised separately by a model. The hub determines which orders have the most importance and in the case of changes in the process, the hub mails the production locations which orders can be adapted.

Changes in the supply of whey can be foreseen, because when there are changes in the orders or the valorisation, the effects on the whey-production are calculated immediately. Next to that, some changes are forecasted in advance, for example due to trends in the market and weather forecasts. In the whey supply chain these changes are considered, while in the cream production these changes are barely considered and therefore there is a lot of fluctuation on day level, as described in Section 3.1.3.

The research by Banaszewska et al. (2014) showed that the valorisation of the by-product whey is very profitable. In their research it turns out that the total profit is 24.3% higher when considering whey valorisation into the valorisation model.

5.2 Which problems are we going to solve?

In this section, we design the setup for the solutions. We explain which problems we want to solve and explain how we are going to solve these problems. The solution section consists of four steps, where a mathematical programming model (the third step) is the most important step. The first two steps are used to improve the input for the model and the fourth step must be taken after the model is implemented.

First, there are unclarities in the data and no guidelines on how to use the available software. In Section 6.1 we provide feedback on how to prevent these unclarities. We give advice on how to improve the communication between different parts of the company. Solving the problem of unclarities helps to make the input variables of the model clearer and more reliable.

Second, one of the biggest problems within the cream supply chain, is that there is a lot of deviation between what was planned and what was delivered to each production location on day level. This problem leads to inaccurate forecasts on a daily level. In Section 6.2 we give advice on how to solve this problem. When improving the forecasts during the week, the production locations can make their production planning more efficiently and planners do not have to change the production planning several times a day. Next to that, we can use these forecasts on day level for our cream valorisation model.

Third, in Section 5.1 we saw that the allocation of whey is better managed than the cream supply chain. This is because there is more attention for this stream due to the use of the whey valorisation model. To improve the allocation of cream, we come up with a new cream valorisation model that is comparable with the whey valorisation model. This is a model that should improve the connection between the orders and the allocation of cream. In the current situation, the allocation by Milk Logistics and the orders are not connected. Milk Logistics allocates the cream by a priority rule, based on the production locations. We think that it is outdated to prioritise the products per location, because all three production locations produce important and less important products. Especially due to the new way of working in sales, it is important to improve the connection between the orders and the allocation plan. For the company it becomes increasingly important to produce the right products on the right time. This can lead to significant revenue gain, as proven in the whey supply chain. As described in Section 5.1, it can be very profitable to valorise a by-product stream separately. Even for a by-product as cream, which is maybe not as profitable as whey, it can be profitable to valorise separately since the processing volumes are high. As shown in Figure 5.2, from all milk, 41.3% (29.4% from butter + 11.9% from cream products) is intended for producing cream products in the EU. Next to that, from all cream within FC, approximately 80% flows into the Butterhub, which makes this hub an attractive part of the company to make improvements.

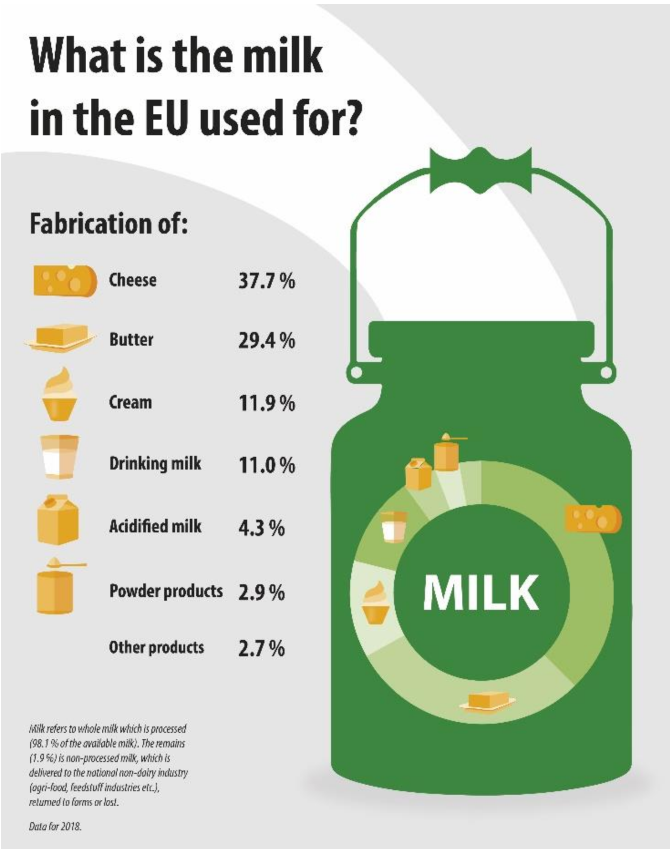

Figure 5.2: Products where the milk in the EU is used for (Eurostat, 2018)

The proposed model is not exactly the same as the whey valorisation model since the horizon of the planning is different. In the whey valorisation model, the planning horizon is 3 months. However, as described in Section 3.2.1, we see that the problems within the cream supply chain arise in the day plan. Deviation in cream supply on strategic or tactical level have less impact, since on this planning horizon cream can be bought or sold for a favourable price. On operational level the problems arise and the consequences as bigger than on a higher planning level. This is the reason why we use in the cream valorisation model a planning horizon of one week, instead of the 3-month horizon used in the whey valorisation model. The output of the model is on day level.

Fourth, we analyse how this model should be used. We discuss the trade-off between production and transport. Now the transport is sometimes leading in the allocating process of cream, while maybe the production locations suffer from these choices and make extra costs. However, the transport network within FrieslandCampina is too complex to analyse completely within this research, since there a lot of departments, policies and restrictions involved. Therefore, we do not give advice on how to improve the situation on this department, but we only start a discussion on which aspect is leading in the allocating process, production or transport and give advice on which subjects need further research.

5.3 Uncertainty

One of the biggest challenges of a dairy company is the uncertainty in the process. As described in Section 3.1.1, there is uncertainty from grass (How much milk will a cow give?; What will be the composition of this milk?; How many farmers will be associated to FC?) to glass (How much milk will be bought by the customers?) and all what is in-between. Uncertainty arises due to a lot of different factors, such as disturbance in factories, changing customer demand and a different supply than expected.

Uncertainty can be included by using scenarios or by programming the model as a stochastic linear programming model. Scenario sampling in this problem means that there must be included multiple scenarios for each supplying locations, so the supply of a supplying location can for example be low, average or high. Next, the model takes a scenario for each supplying location with a certain probability. Scenario sampling is less suitable for this problem, since when the cream is not released on one supplying location, it is released on another, since the total amount of cream can be predicted quite accurate. To include this fact in scenario sampling, we have to use conditional probabilities for each scenario, which is quite comprehensive, since 20 factories are involved in the supply. Another option is to use stochastic programming. However, stochastic programming will increase the complexity of the problem enormously. Also, from the current data we cannot determine a distribution function of the uncertainty since the amount of planned and realised cream from the supplying locations are not registered on day level. The deviation on day level that we used in Section 3.2.2 is the deviation at a cream processing location, while for calculating the uncertainty we need to know the deviation in cream at a cream supplying location. Next to that, the proposed model has a planning horizon from only one week. In this level of planning, the model requires solutions that have a short search time, as described in Section 4.1. When including uncertainty, the search time will increase a lot.

Due to the above mentioned reasons we decided to that we do not include uncertainty in this model. However, including and reducing uncertainty can be interesting subjects for further research. Despite the fact that we do not include uncertainty into the model, we can take the uncertainty into account when looking for solutions. We know that there is uncertainty, so we can allocate the streams in such a way that when something is different than expected, the company can switch to an alternative plan quickly. A method we are going to use, is not planning full capacity in advance but on 95% capacity, like in the whey supply chain. When factories are not planned for the full 100% capacity, there is flexibility to handle changes in the supply chain. However, the disadvantage from this method is that when all input values are the same as what was planned, the total capacity is lower than when planning on full capacity, so we miss capacity for sure. We use a percentage of 95% since this percentage works well for the whey supply chain, and we prevent the system from a lot of missing capacity when taking a lower percentage.

5.4 Conclusions on solution design

In this chapter, we set up a design for the next chapter, the solutions. We analysed the whey supply chain and note that a lot can be learned from the whey supply chain. In the whey supply chain, there is more control and insight on how much whey will be supplied. In the whey process there is a separate valorisation model that maximizes the revenues gained from whey products. In the whey process this is profitable. Banaszewska et al. (2014) proved that this separate valorisation model improved the profit with 24.3%.

In the next chapter we also come up with a valorisation model for the cream. Before implementing this model, we first improve the input variables. After the model is introduced, we start a discussion on how the output variables must be used. In the model, we do not include uncertainty.

6. Solutions

In this chapter we come up with solutions for the main research problem. First, in Section 6.1, we give advice on how to improve the communication between different parties and how to avoid unclarities. Next, in Section 6.2 we provide recommendations on how to improve the forecasts on a daily level. Next, in Section 6.3 we explain the proposed cream valorisation model, where we use these forecasts on a daily level as input variable. Next, in Section 6.4 we start a discussion about the trade-off between production and transport within the company. Finally, in Section 6.5 we conclude this chapter.

6.1 Solving the unclarities

As described in Section 3.1.2, there are a lot of unclarities in the data, which causes bad communication between the planners on the head office and planners on the production locations. Improving the communication is the first step when improving the situation. There are multiple aspects that must be improved.

First, in the transportation planning, the times are given in loading times at the supplying location instead of the times that a truck arrives at the processing location. For the production planners this makes it unclear how much cream can be expected on a logistic day, because it often happens that a truck is loaded on one day but arrives at a processing location the other day. In order to solve this unclarity, the software module must be able to sort the trucks on unloading times. When is not possible, the transport planners must communicate how much trucks will arrive the next day.

Next, at the moment, the production planners can choose which software they use. There are no instructions on what software is best to use. Next to that, when the production locations communicate with other production locations, there is a lot of unclarity in the amount of cream, for example if the cream from its own skimming process is included or not. Milk Logistics must be clear and consequent about which software module must be used by the production locations and therefore a manual with work instructions for the production planners might be helpful.

Next, as mentioned in Section 2.2.3, the time that cream can stand before production, is different at each production location. This is because the quality department of the production location can decide this standing time for their own factory. This is remarkable since production locations can make the same products from it. In practice, it happens that a truck with cream is transported from Lochem to Noordwijk to make the same end product with the same production process. To prevent those situations, FC must draw up the safety regulations company wide. This must be done by the global quality department of FC. If it is possible to achieve a standing time of 72 hours for all three locations (maybe with additional quality checks), this gives the butter(oil) factories a lot of extra flexibility in their production planning.

Last, in the planning process changes are not always communicated from Milk Logistics to the production locations. The production locations can get a notification when something has been changed in the planning. However, this is on average 15 times a day as described in Section 2.2.3, which makes it cumbersome to check continuously these changes. Instead, Milk Logistics must communicate these changes in time for the production locations. Also, when changes are expected for the next days, for example when there is disturbance in one of the cream supplying locations, this must be communicated. In that case, production planners can take this into account when making the production planning.

6.2 Improving the forecasts on a daily level

When analysing the data, as described in Section 3.2.1, we see that the total cream that streams into the company per week is accurately forecasted. However, when we look to the forecasts in the day plan, we see that those expectations are less accurate. This means that the company knows the total amount of cream but does not know when this cream is available. There are three main opportunities to improve the daily forecasts.

6.2.1 Include seasonality

First, it is important to include seasonality in the day plan. In the data analysis in Section 3.2.2, we see that there is a pattern in when the cream arrives. In Figure 3.9 we see that in Den Bosch and Lochem during the weekdays the amount of cream that arrives is below what was expected, while during the weekend there flows in more cream than expected. In Noordwijk those effects are not that strong, but we also see that the amount of cream during weekdays is lower than expected. Now it is the case that each production location calculates their own seasonality based on their own historical data. However, for the company it is better that Milk Allocation include those day seasonality effects. Milk Allocation has more insight in the fluctuations during the week and has more historical data available.

Next to the day effects, we have also analysed the seasonality per month. In Figure 3.8 we see that there are patterns as well. We see that the variation of fat percentage during the year due to the living conditions of the cow is not included. To make the week plan on day level, created by Milk Allocation, more accurate, seasonality should be included.

An interesting method to include the seasonality, is to use multiple seasonality indices, one for the day effects and one for the month effect. With the day effects we capture the variation over the week, for example due to closed factories in the weekend or due to patterns in the production planning of the cream supplying locations. With the month effects we capture the variation of the milk composition throughout the year.

We come up with the following seasonality factors, as shown in Table 6.1 and Table 6.2. We calculated these seasonality factors by taking historical data of the realised amount of cream on a specific day or in a specific month. We calculated these seasonality factors over all data we have about the realised amount of cream per location, so that is 2017, 2018 and 2019. An index is calculated by the total amount of cream realised on a specific day or month in relation to the average realised amount. For example, when the seasonality index is 0.900, 10% less cream is realised than average.

Table 6.1: Day seasonality indices

	Den Bosch	Lochem	Noordwijk
MA	0.900	0.874	1.030
DI	0.856	0.851	0.978
WO	0.880	0.821	0.961
DO	0.980	0.935	0.974
VR	1.072	1.153	1.013
ZA	1.209	1.273	1.017
ZO	1.102	1.093	1.026

Table 6.2: Month seasonality indices

	Den Bosch	Lochem	Noordwijk
JAN	1.277	1.356	1.354
FEB	1.367	1.361	1.299
MAR	1.084	0.988	1.060
APR	1.129	1.043	0.990
MAY	0.968	0.979	1.021
JUN	0.934	0.981	0.845
JUL	0.868	0.860	0.877
AUG	0.836	0.852	0.917
SEP	0.662	0.825	0.959
OCT	0.939	0.885	0.843
NOV	0.907	0.846	0.875
DEC	1.041	1.035	0.963

After we calculated the seasonality indices, we test the indices on the data of 2019. We take the original planned amount of cream and multiple this with the two seasonality indices. We use the same factor for both seasonality indices. We test the calculated amount of cream with the amount of cream that actually was supplied and calculate the difference. Figure 6.1 shows the results in differences between the planning with and without seasonality.

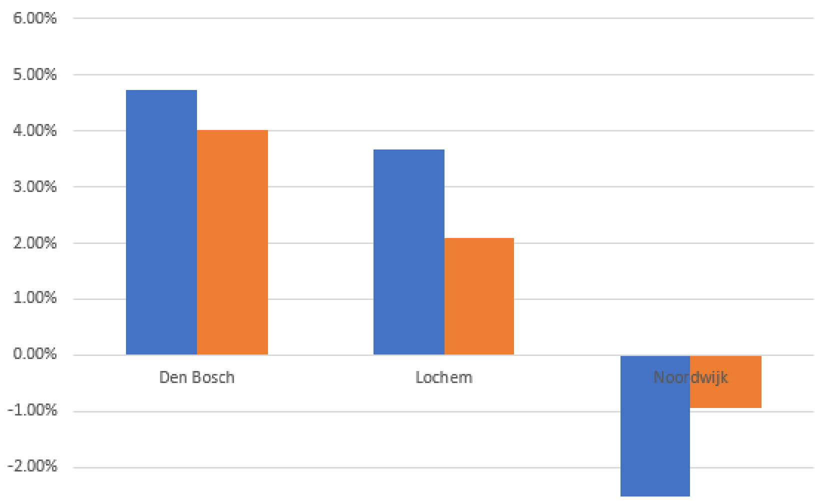

Figure 6.1: Real deviation between what was planned by Milk Allocation and what was supplied, where blue is the average deviation without seasonality and orange the average deviation with seasonality.

In the figure we see that for all three locations the real deviation in supplied cream between what was planned and what was realised is less when including seasonality. Including seasonality makes the day plan more reliable, which makes sense since the seasonality of the cream is real, as shown in Figure 3.8 and Figure 3.9.

The seasonality indices can be improved by using exponential smoothing for a seasonality model. When using exponential smoothing, the seasonality will be updated after each forecast by comparing the expected seasonality with the real data. This method makes the seasonality indices more reliable since recent data will be more important than data from far in the past and trends in the planned amount of cream can be cancelled out.

6.2.2 Scale day plan back to the total cream from the allocation plan

As described in Section 3.2, the total expected amount of cream per week is accurate. This total amount of cream during a week can be used for the day plan. Our advice is to scale the daily expectation back to the total amount per week which is available in the allocation plan or the week plan. With scaling back, we mean that if there are changes during the week, always use the total cream per week as guideline. So, when there arrives more cream than expected in the beginning of the week, it is likely that at the end of the week there flows in less cream than expected.

6.2.3 More attention to the day plan

Now the day plan is just a kind of indication for the production locations, while the day plan is important for production planners since deviation in cream supply on day level can cause significant changes in the production plan. An accurate planning on day level became more important due to the new WAB regulation (where temporary employees must be hired four days in advantage, as described in Section 1.3) and the implemented strategy of selling all products demand driven. Therefore, it is important that the day plan gets more priority. Some changes in the supply of cream can be foreseen when there is more attention for the fluctuations, as proven within the whey supply chain. Next to that, when the planning in a cream supplying production location has been changed, it does not directly lead to changes in the cream supply. The milk still must be processed and in most processes this milk will still be skimmed, which means that there is still cream released in the process. It is important that Milk Allocation calculates what effects changes in supply will have for the cream production. These changes must be adapted for the days after the next day as well. In this way, the production locations have more insight in how much cream will arrive during the week. This is important for Intra-Transport as well. More insight means that they can better anticipate on changes, making it less complex to come up with a feasible transport planning.

6.3 Cream valorisation model

After we improve the day plan, we can use the more accurate input values as input for our cream valorisation model. This model improves the connection between the available cream and the orders, and with this model it must be easier to handle the demand driven strategy of selling on the sales department. This model provides more control on producing the right products, which also improves the customer reliability.

6.3.1 Model description

The proposed cream valorisation model connects different parts of the supply chain together. First, it connects the orders to the available cream. In the current situation, Milk Logistics do not know the number of orders of all production locations. Milk Logistics only knows the demand of total cream for each production location. In case of a surplus or a shortage of cream or changes in cream supply the cream is prioritised per location. This model changes the strategy of prioritising per location in prioritising per order. It calculates which order has the highest profit margin and those orders get the highest priority. Second, the model allocates the cream from cream supplying locations to cream processing locations. The model considers the costs of transport by implementing the distances between different factories and the transportation cost of a truck. Third, the model considers the production capacity of all factories per product type per day. We choose to determine the capacity per day, since this makes it possible to include maintenance or foreseen disturbance on day level. So, for example when the production location Den Bosch has maintenance on Monday, the capacity for all products on that day is zero. Since the model determines which products are optimal to produce on each day, it helps the production planners to come up with an efficient production planning. Fourth, this model includes inventory and storage capacity of each factory. This prevents that the factory overflows and cannot process all cream. Fifth, this model calculates which demand must be fulfilled, given all constraints, to maximise the profit.

The proposed model uses a planning horizon of one week, because most problems are caused within this time horizon, as described in Section 3.4. We try to include all variables that are important for the company, such as seasonality, demand fluctuation and buffer capacity.

To make the model not too complex, we make some assumptions:

- In the model the revenues gained by by-products like buttermilk and milk serum are not considered.
- The production location Lochem is divided into two factories, a butter factory and a butteroil factory. This is because the capacity in the butter factory cannot be used to produce butteroil

and vice versa. The disadvantage of this assumption is that the inventory for the butter factory cannot be used for the butteroil factory, while in reality this is possible.

- The throughput time is that short that the standing time is negligible. This means that we assume that it never happens that the cream is standing longer than 24 hours for Lochem, 48 hours for Den Bosch or 72 hours for Noordwijk.
- There are no inventory costs. When there is cream in the silos waiting to be processed, there are no costs, since these silos are already there and are automatically cooled.
- The cleaning and converting times of the machine are included in the day capacity of a product, so these do not have to be considered when allocating the cream.

6.3.2 Mathematical formulation

For this model we define indices, parameters, variables and constraints. First, we have four sets of indices, as shown in Table 6.3.

Table 6.3: Indices and sets used in the cream valorisation model

Index and set	Description
$t \in T$	T – set of time periods, for this planning horizon those are days
$e \in E$	E – set of end products
$p \in P$	P – set of cream processing locations
$s \in S$	S – set of cream supplying locations

The sets in this model are mostly fixed. The indices can only be changed when another planning horizon is used, the end products has been changed or when a cream processing or cream supplying location is built or shut down.

Next, we use various parameters, which can be seen as input for the model. An overview of the parameters can be found in Table 6.4. Note that if the unit of the parameter is in tonnes, it can be tonnes of raw cream or tonnes of end product. This is because the end products are not ordered by number of products, but in tonnes instead.

Table 6.4: Parameters used in the cream valorisation model

Parameter	Unit	Description
$Supply(t,s)$	Tonne (t)	The amount of cream supplying location *s* can supply in time period *t*
$Demand(e)$	t	Demand of end product *e* during the full planning horizon
$Margin(e)$	€	Profit margin of end product *e*
$Capacity(t,e,p)$	t	Maximum day capacity when producing end product *e* on processing location *p* in time period *t*, given in tonnes of end products
$Distances(s,p)$	km	Distance between supplying location *s* and processing location *p*
$TransportCost$	€/t/km	Transport cost to transport one tonne of cream one kilometre
$ProductionRate(e)$	Rate	Production rate of end product *e*, so rate on how much cream one tonne of end product contains.
$MaxInv(p)$	t	Maximum inventory of cream that can be stored in the silos of processing location *p*
$InitialInv(p)$	t	Initial inventory of production location *p* at the start of a week

The (decision) variables are used to solve the model. While solving, the variables can take values in order to optimize the objective function. The variables can be seen as output values. Table 6.5 gives an overview of all variables that we use in the model.

Table 6.5: Variables used in the cream valorisation model

Variables		Description
$Xuse(t,e,p)$	$t \in T, e \in E, p \in P$	Volume of cream used to produce end product *e* on processing location *p* in time period *t*
$Xsale(e,p)$	$e \in E, p \in P$	Volume of end product *e* sold on processing location *p* during the whole time horizon
$Xproduced(t,e,p)$	$t \in T, e \in E, p \in P$	Volume of end product e produced on processing location *p* in time period *t*
$Xflow(t,s,p)$	$t \in T, s \in S, p \in P$	Volume of cream flows from supply location *s* to processing location *p* in time period *t*
$CapacityRate(t,p)$	$t \in T, p \in P$	Ratio on how much the resources is used on location *p* in time period *t*
$Xinv(t,p)$	$t \in T, p \in P$	Amount of cream that is in inventory on processing location *p* at the end of time period *t*
$CreamSurplus(p)$	$p \in P$	The surplus of cream at the end of the week. Can be used as initial inventory for the next week
$Revenue$		Revenue from sales realised during the whole time horizon
$TransportCostTotal$		Total transport costs during the whole time horizon

The objective of this model is to maximize the profit, given all sets, parameters, decision variables and constraints. The mathematical notation of this objective is as follows:

Objective

$$Profit = Revenue - TransportCostTotal$$

Where

$$Revenue = \sum_{e,p} (Margin(e) * Xsale(e,p))$$

$$TransportCostTotal = TransportCost * \sum_{t,s,p} (Distance(s,p) * Xflow(t,s,p))$$

When optimising this objective function, the model is limited by several constraints. The constraints are related to the capacity of the production location, the market, the supply of cream and the inventory of the production locations. All constraints are presented below:

Subject to the following constraints:

1. Capacity constraint

$$Xproduced(t,e,l) \leq Capacity(t,e,p) \qquad \forall t, \forall e, \forall p$$

The number of end products that will be produced on a production location in a time period cannot be more than the capacity of that location for an end product in that time period.

2. Resource capacity constraint 1

$$CapacityRate(t,p) = \sum_e \left(Xproduced(t,e,p) * \frac{1}{\max(1, Capacity(t,e,p))}\right) \quad \forall t, \forall p$$

This constraint calculates the ratio that the resources are occupied within a time period. Together with the next constraint, it prevents that the resource capacity of a production location is occupied for more than 100%. We explain this constraint by giving an example. We consider a machine that only can produce two products, product A and product B. Product A has a maximum capacity of 10 products and product B has a maximum capacity of 5 products a day. Then the following combinations can be made, as shown in Figure 6.2. The possible combinations are all positions beneath the blue line.

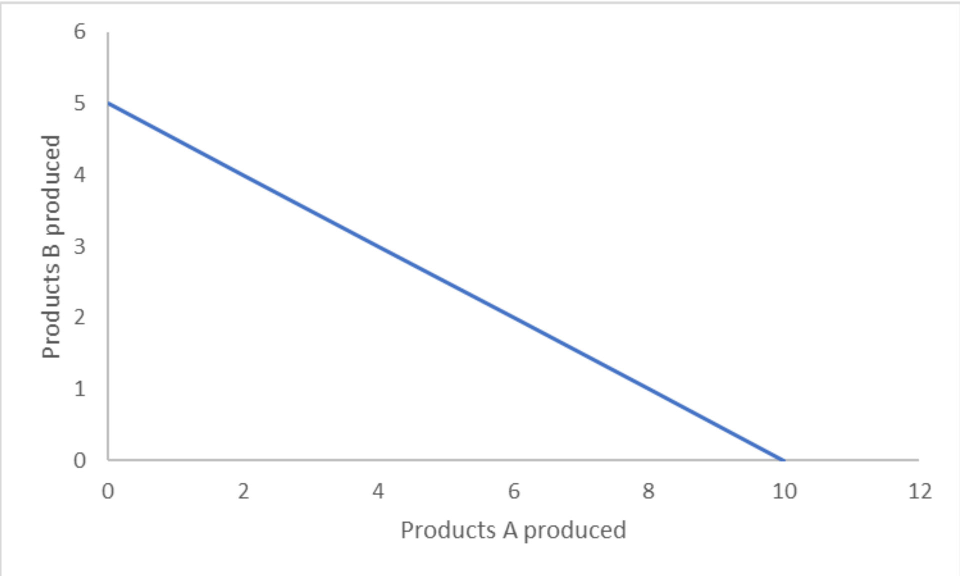

Figure 6.2: Example of the resource capacity of two orders, order A and order B

Together with the next constraint, the constraint prevents that for example 10 products of product A are made and 5 products of product B. This is not possible since the resources cannot be used twice on one day. We use the maximum value of (1,Capacity(t,e,p)), because otherwise when the capacity of a product is zero, the model gives an error, since the program cannot divide something to zero.

3. Resource capacity constraint 2

$$CapacityRate(t,p) \leq 1 \qquad \forall t, \forall p$$

The total resource capacity of a production location cannot be exceeded, and so the resource capacity can only be used once.

4. Max sale Constraint 1

$$\sum_p Xsale(e,p) \leq Demand(e) \qquad \forall e$$

The number of end products that can be sold cannot be more than the demanded number.

5. Max sale Constraint 2

$XSale(e,p) \leq \sum_t Xproduced(t,e,p) \qquad \forall e, \forall p$

There cannot be sold more end products than that there are produced.

6. Supply constraint

$\sum_p Xflow(t,s,p) = Supply(t,s) \qquad \forall t, \forall s$

All cream of supplying locations must be transported to a processing location, which prevents that the supplying locations cannot get rid of the cream.

7. Inventory constraint

$Xinv(t,p) = Xinv(t-1,p) + \sum_s Xflow(t,s,p) - \sum_e Xuse(t,e,p) \qquad t = 2,3,4,5,6,7, \forall p$

The inventory at the end of a production day is the same as the inventory at the end of the previous day plus the amount of cream that arrives that time period minus the amount of cream that is used for production within that time period.

8. Initial inventory constraint

$Xinv(t,p) = InitialInv(p) + \sum_s Xflow(t,s,p) - \sum_e Xuse(t,e,p) \qquad t = 1, \forall p$

The inventory after the first day of production is equal to the initial inventory at the beginning of the week plus the amount of cream that flows in minus what is used for production on the first day.

9. Max inventory constraint

$Xinv(t,p) \leq MaxInv(p) \qquad \forall t, \forall p$

The inventory of raw cream on a production location cannot exceed the maximum capacity of the silos.

10. Production constraint 1

$\sum_e Xuse(t,e,p)) \leq \sum_s Xflow(t,s,p) + Xinv(t-1,p) \qquad t = 2,3,4,5,6,7, \forall p$

The amount of cream that is used cannot be more than what is delivered on a processing location plus the inventory of the previous day.

11. Production constraint 2

$\sum_e Xuse(t,e,p)) \leq \sum_s Xflow(t,s,p) + InitialInv(p) \qquad t = 1, \forall p$

The amount of cream that is used on the first day cannot be more than what is delivered on the first day plus the initial inventory of a production location.

12. Production constraint 3

$XProduced(t,e,p) \leq \frac{Xuse(t,e,p)}{ProductionRate(e)} \qquad \forall t, \forall e, \forall p$

The number of produced end products is determined by the amount of cream that is used for an end product divided by the production rate.

13. Surplus Constraint

$Creamsurplus(p) = Xinv(t,p) \qquad t = 7, \forall p$

The surplus of cream at the end of the week is equal to the inventory after the last day of production.

14. Range constraints

$$Xuse(t,e,p),\ Xproduced(t,e,p),\ XFlow(t,s,p),\ Xinv(t,p), XSale(e,p) \geq 0 \qquad \forall t, \forall e, \forall s, \forall p$$

These constraints prevent the model to sell, to process or to transport a negative amount of cream or to have a negative inventory.

6.3.3 Model validation

To make sure that the model works, we validate the model. Due to various reasons, it is hard to compare the current situation with the proposed situation and hard to proof that the model works.

We have data on which orders were planned to produce and we have data on how much cream it was planned that a production location gets, but the information on where the cream is coming from, is lacking. This is because the transport planning is not computed in advantage. The transport planning is the realised plan. This makes it impossible to calculate the planned transport cost from the data. So, from the data it is not possible to compare the proposed model with the current situation.

Another option to compare the current situation with the proposed situation is by implementing the current situation in the model. This means that the situation where Milk Allocation prioritises per location in the model, instead of prioritising per order, should be implemented. However, this is hard to implement as well. This is because in the model the customer orders are not connected to a production location, because most end products can be made on multiple locations. To model the current situation anyway, we assume that the demand for butteroil is always fulfilled (if the production capacity enables that). We make this assumption since in the current situation the butteroil factory Noordwijk gets priority.

To validate the model, we simplify the model in such a way that we are able to check the optimal valorisation method by hand, a so-called toy-sized problem. In this simplified model, we use only three supplying locations (Steenderen, Gerkesklooster and Maasdam), three product types (Butter bulk Soured 10kg, Butter bulk Soured 25 kg and AMF bulk) and only the first three days of the week. Furthermore, we use the following values for the parameters, as shown in Figure 6.3.

Distance(s,l)	Noordwijk	Den Bosch	LochemButter	LochemAMF
Steenderen	169	91	28	28
Gerkesklooster	14	223	155	155
Maasdam	230	76	160	160

Supply(t,s)	Monday	Tuesday	Wednesday
Steenderen	222.57	213.51	210.43
Gerkesklooster	111.75	107.20	105.66
Maasdam	67.48	64.73	63.80

Demand(e)	
Butter bulk Soured 10 kg	130
Butter bulk Soured 25 kg	300
AMF bulk	300

Margin(e)	
Butter bulk Soured 10 kg	180
Butter bulk Soured 25 kg	120
AMF bulk	130

Capacity(t,e,l)	Noordwijk	Den Bosch	LochemButter	LochemAMF
Butter bulk Soured 10 kg	0	40	40	0
Butter bulk Soured 25 kg	0	70	70	0
AMF bulk	50	0	0	50

ProductionRate(e)	
Butter bulk Soured 10 kg	2.05
Butter bulk Soured 25 kg	2.05
AMF bulk	2.495

Max inventory	
Noordwijk	100
Den Bosch	200
LochemButter	200
LochemAMF	200

TransportCost
0.09

Initial inventory	
Noordwijk	30
Den Bosch	30
LochemButter	30
LochemAMF	30

Figure 6.3: Input parameters of the simplified version of the model

We see that the margin for Butter bulk Soured 10 kg is the highest, then AMF bulk and then Butter bulk Soured 25 kg. The margin for AMF bulk might be higher than the Butter bulk Soured 25 kg, but since the production rate for butteroil is higher, the revenue per tonne input cream is lower. Furthermore, we assume that the capacity is the same for each day, so the mentioned capacity in the figure is the capacity on Monday, Tuesday and Wednesday. The maximum inventory capacity is relatively high, which means that for this simplified model this has no influence on the results, which makes it easier to compute the solution by hand.

Now that we have determined the input values, we test the model in a software package that optimizes such models, called AIMMS. This software is comparable with OMP, which is used at FC. However, since we do not have access to OMP and we are not familiar with the programming language, we use AIMMS for this research.

Current situation

We implement the input as described above in AIMMS. We get the following output, as shown in Figure 6.4.

Xsale	Noordwijk	Den Bosch	LochemButter	LochemAMF
Butter bulk Soured 10 kg		61.05	68.95	
Butter bulk Soured 25 kg		49.19	83.55	
AMF Bulk	150.00			150.00

Capacity Rate	Noordwijk	Den Bosch	LochemButter	LochemAMF
t				
Monday	1.000	1.000	0.917	1.000
Tuesday	1.000	0.778	1.000	1.000
Wednesday	1.000	0.451	1.000	1.000

Xflow	To	Noordwijk	Den Bosch	LochemButter	LochemAMF
t	From				
Monday	Steenderen	19.64		108.18	94.75
Monday	Gerkesklooster	111.75			
Monday	Maasdam		67.48		
Tuesday	Steenderen			85.68	124.75
Tuesday	Gerkesklooster	105.66			
Tuesday	Maasdam		63.80		
Wednesday	Steenderen			88.76	124.75
Wednesday	Gerkesklooster	107.20			
Wednesday	Maasdam		64.73		

Xproduced	To	Noordwijk	Den Bosch	LochemButter	LochemAMF
t	From				
Monday	Butter bulk Soured 10 kg		29.93		
Monday	Butter bulk Soured 25 kg		17.62	64.21	
Monday	AMF Bulk	50.00			50.00
Tuesday	Butter bulk Soured 10 kg			28.95	
Tuesday	Butter bulk Soured 25 kg		31.58	19.35	
Tuesday	AMF Bulk	50.00			50.00
Wednesday	Butter bulk Soured 10 kg		31.12	40.00	
Wednesday	Butter bulk Soured 25 kg				
Wednesday	AMF Bulk	50.00			50.00

CreamSurplus	
Noordwijk	17.55
Den Bosch	
LochemButter	10.24
LochemAMF	

Profit	
€	74,701.00

Figure 6.4: Output of the simplified model in the current situation, where the cream is prioritised per location

In the current situation we see that the demand for AMF bulk is always fulfilled, since Noordwijk gets the priority above Den Bosch and Lochem. The maximum capacity of the butteroil factories allows that since the capacity for AMF bulk is 3*50 + 3*50 = 300 tonnes of end products, which is the same as the demand. Next, the Butter bulk Soured 10 kg gets the priority over the 25 variants of this product, since this product type has a higher profit margin. Therefore, the demand for Butter bulk Soured 10 kg is fully fulfilled as well. With the capacity and cream that is left, the 25 kg variant of this butter is made. Furthermore, we see that the cream is always supplied from the nearest location, for Lochem is Steenderen the closest location, for Noordwijk is Gerkesklooster the closest location and for Den

Bosch Maasdam is the closest location. It is possible to supply from the closest locations since the production locations have enough production capacity to handle all cream of the nearest supplying location or to store the cream for the production of next day.

Proposed situation

After we computed the current situation, we implement the proposed situation, where the cream is allocated with a priority per order. The orders with the highest profit margin get priority. We also implement this model in AIMMS with the same input parameters as above, as shown in Figure 6.3. Figure 6.5 shows the output of the model in the proposed situation.

Xsale	Noordwijk	Den Bosch	LochemButter	LochemAMF
Butter bulk Soured 10 kg		120.00	10.00	
Butter bulk Soured 25 kg			192.50	
AMF Bulk	142.13			108.77

Capacity Rate	Noordwijk	Den Bosch	LochemButter	LochemAMF
t				
Monday	0.843	1.000	1.000	1.000
Tuesday	1.000	1.000	1.000	1.000
Wednesday	1.000	1.000	1.000	0.175

Xflow	**To**	Noordwijk	Den Bosch	LochemButter	LochemAMF
t	**From**				
Monday	Steenderen		7.81	98.13	116.64
Monday	Gerkesklooster	111.75			
Monday	Maasdam		67.48		
Tuesday	Steenderen		12.19	76.57	124.75
Tuesday	Gerkesklooster	107.20			
Tuesday	Maasdam		64.73		
Wednesday	Steenderen			210.43	
Wednesday	Gerkesklooster	105.66			
Wednesday	Maasdam		63.80		

Xproduced	**To**	Noordwijk	Den Bosch	LochemButter	LochemAMF
t	**From**				
Monday	Butter bulk Soured 10 kg		40.00	10.00	
Monday	Butter bulk Soured 25 kg			52.50	
Monday	AMF Bulk	42.13			50.00
Tuesday	Butter bulk Soured 10 kg		40.00		
Tuesday	Butter bulk Soured 25 kg			70.00	
Tuesday	AMF Bulk	50.00			50.00
Wednesday	Butter bulk Soured 10 kg		40.00		
Wednesday	Butter bulk Soured 25 kg			70.00	
Wednesday	AMF Bulk	50.00			8.77

CreamSurplus	
Noordwijk	17.55
Den Bosch	5.08
LochemButter	66.93
LochemAMF	

Profit	
€	75,624.82

Figure 6.5: Output of the simplified model in the proposed situation, where the cream is prioritised per order

The main difference with the current situation is that the model now maximizes the production of butter. The butter factories in Den Bosch and Lochem are scheduled on maximum capacity since the capacity rate is 1 in Den Bosch and LochemButter for all three days. We also see that the Butter bulk Soured 10 kg gets priority, since the margin is the highest. After the demand for this product type is fulfilled, the butter factory starts to produce the 25 kg variant, since this product has the second highest profit margin per tonne raw cream. We see that the profit is a bit higher in the proposed situation. This is because the constraint that Noordwijk gets priority is not included.

From the output, we conclude the model works. We checked these solutions by hand and found the same output values as presented in the model. With comparing these two situations, we have proven that prioritising per order gains more profit than prioritising per location. This is always the case when butter is more valuable than butteroil. When butteroil is more profitable than butter, the model gives the same solution in the current situation and the proposed situation. Since we are interested in the proposed situation, we use from now on the proposed situation, so without the extra constraint of prioritising the production location Noordwijk.

To make sure that the model works, and the solution of the above described situation was not accidently optimal, we try multiple other scenarios and calculate these scenarios by hand as well. We test a scenario where the transport cost is higher, a scenario where the profit margin is different and a scenario where the supply is higher than the demand. The output of the tested scenarios can be found in Appendix A. In a scenario where the transport costs higher, the costs are in this scenario €0.50 instead of €0.09 per tonne per kilometre, the model always search for the nearest location. In the scenario that the margins are different, the model search for the product with the lowest profit margin and optimizes the other products, if the capacity and supply allow that. In the case that the supply is higher than the demand, the solution has a higher surplus in cream at the end of the week. In all cases, the model calculates the right optimal solutions. From this we conclude that this model works for the simplified input data and now we are able to extend the model by implementing the real-world problem of FC. We do that in Section 7.3.

6.4 Trade-off between production and transport

The trade-off between production and transport is a long-standing debate for the company. For transport planners it is the goal to keep the transportation costs low, while being as flexible as possible. This is also the case at Intra-Transport at FC, where they try to plan the day plan as accurate as possible, given the transportation constraints. However, sometimes Intra-Transport makes a transport planning which is different than the day plan to save costs. Due to this different transport planning than the day plan, it happens that production locations must change their production planning last minute or that production location cannot handle the amount of cream anymore.

In the trade-off between production and transport, not only costs must be considered, but the aspect sustainability is important as well. The last years the aspect sustainability became more and more important for FC. In the transport a lot of CO_2 is emitted, due to the fuel of the milk trucks. However, in the production of butter and butteroil sustainability is a big issue as well. Butter and butteroil are the dairy products with the second highest carbon footprint, after milk powders. When producing one kilo of end product of butter or butteroil, 7.3kg of CO_2 is emitted, while most other dairy products emit only between 1 and 3 kg of CO_2 per kilo end product (Vergé et al., 2013). This high emission is due to the fact that within the production of butter(oil) a lot of milk is needed. Next to that, the production process is intensive, because high temperatures are required in the process. This high carbon footprint makes it more important to produce the right products on the right moment. Producing products that are not ordered can lead to wastages, which negatively involves the sustainability of the company.

To put the amount of emission of production in perspective, to transport a milk truck one kilometre, this has an emission of 1.1 kg of CO_2 (VelopA B.V., 2015). To draw conclusions from these values, there has to be done more research on these subjects.

6.5 Conclusions on the solutions

In this chapter we came up with solutions to solve the cream allocation problem of FC. The main solution is the introduction of the cream valorisation model. This model allocates the available cream from cream supplying locations to cream processing locations and maximizes the profit given profit margins per customer orders. It considers aspects like machine capacity, transportation cost, storage capacity and the demand. Before we can implement this model, we have to ensure that the input values are reliable and useful. Therefore, we first have to solve the unclarities in the data and improve the day plan. After we have done this, we can implement the model. In this chapter we explained the model. The output of the model can be used to make the transportation planning. When using the output of the model, good considerations on which aspect is more important, production or transport. However, more research is needed on the trade-off between production and transport, since in this trade-off a lot of departments, policies and restrictions are involved, which makes it too extensive for this research.

Now we have introduced the solutions, we can implement these solutions into the company. In the next chapter, we come up with a plan on how to implement the solutions and give more details about the input and output variables of the model.

7. Making the model work

In this chapter we provide an answer on the fifth and last research question: "How should the solutions be implemented at FrieslandCampina?". In the chapter we use the same four steps as used in the previous chapter, namely solving the unclarities, improving the planning on day level, the cream valorisation model and making a trade-off between production and transport.

7.1 Solving the unclarities

To solve the unclarities in the data, the following actions must be undertaken.

- The difference in loading times and unloading times in the software must be solved. In the software module it is best to make an option to sort the data by the unloading times. Also, when it is in advance likely that a lot of cream must be moved to the next day, this must be communicated with the production location in time.
- Milk Logistics should clarify to all production locations what planning, and software must be used. This can be done by giving a workshop or by creating a manual with a standard way of working for the production planners.
- The standing times of cream for the different production locations should be equalised. This should be done by the global quality department, that set up the quality and safety rules within the company.
- There should be more communication between Milk Logistics and the production locations on when changes in the cream supply will occur.

7.2 Improving the planning on day level

Improving the planning on day level is an important action, before implementing the cream valorisation model. Improvements in the forecasts per day plan makes the model more useful and reliable. When improving this, the following actions are recommended for FC:

- Improving the planning on day level takes time and effort. For this purpose, we suggest that a production planner of a production location will be moved to Milk Logistics, because of the understaffing at Milk Logistics. When the day plan is more reliable, it costs less time to create a production planning, since it does not have to be adapted that often anymore. This makes it possible to move this planner to the head office.
- Include seasonality in the planning on day level. A good method to do this, is to use the seasonality indices, as described in Section 6.2. In the future the seasonality factors can be more reliable if a more advanced seasonality model is used, such as moving average. Including the seasonality in the planning on day level can be done by the extra person at Milk Logistics.

7.3 Cream Valorisation Model

In Section 6.3.3 we have validated the model for a simplified problem. Now that we have proven that this model works, we use real life data of FC to calculate the optimal valorisation. Below we elaborate on all indices and parameters that we use as input for the model for FC. We explain which values we use and how we obtain these values. The values of all indices and parameters are shown in Appendix B.

- Days

We use a time horizon of one week, so from Monday till Sunday. For this setup, we start with an empty system.

- End Products

We test the model with 9 different product categories, which are the categories that are produced the most. Table 7.1 gives an overview of the 9 categories:

Table 7.1: Product categories used to test the model

#	Butter
1	Butter bulk Soured 10 kg
2	Butter bulk Soured 25 kg
3	Butter Prestige Soured 25 kg
4	Butter Sweetened 25 kg
5	Butter Hard 25 kg
6	Butter Consumer package 250 gram
	Butteroil
7	AMF box 25 kg
8	AMF barrel 200 kg
9	AMF bulk

The categories can be extended when end products or specific customers within a product category have significant different product margins. In this case, a product category can be added to make the model more reliable. However, this increases the complexity of the model.

- Supplying locations

This set is fixed, since every week the same locations can supply cream. These supplying locations are retrieved from the allocation plan. Note that Den Bosch and Lochem are supplying locations as well, since the milk is skimmed over there as well.

- Processing locations

Same as for the supplying locations, the processing locations are fixed as well. The processing locations are Den Bosch, Noordwijk and Lochem. Again, Lochem is divided in LochemButter and LochemAMF since the capacity in the butter factory cannot be used to produce butteroil.

- Distances

These are the distances between the cream supplying and the processing locations. The distance is calculated by taking the fastest route measured by Google Maps.

- Supply

This is the amount of cream in tonnes that is released in a supplying factory on one day. Only the basic cream is involved, so not biological cream or planet proof cream since these types of cream are not within the scope of the research. Also, cream intended for external business partners is not included in the supply, since this cream does not flow into the OpCo ‘Butter and Milkpowder’. The data we use is obtained from the allocation plan for week 51 in 2019.

- Margin

The margin per product is given in euros per tonne end product. Since this information is not available for this research, we use a rough estimation. These estimations are based on the average sell price for butter and butteroil in the Netherlands calculated by ‘Productschap Zuivel’. We estimate that the sell price of the standard products is a bit lower than average, while the specialties have a sell price above average.

The profit margin that we use is the average EBITDA out of sales for food processors. The EBITDA is 15.58% of the sell price (Damodaran, 2020). To make this profit margin more accurate, the sales department of FC must share the information about the margins of each end product.

- Demand

The demand per end product is obtained from the PPC files of the three butter(oil) factories. We use the same week as for the supply. The input can be more detailed when including more end products.

- Capacity

The capacity that we use is the total capacity of an end product on a processing location a day. The capacity is calculated by the maximum cream that can be processed when producing a specific end product, the OEE and we plan some flexibility for the uncertainty. We calculate the capacity per day, because when a machine line is down for maintenance or when there are not enough personnel available to run the machine on full capacity, this can be adapted in the capacity for that specific day. Furthermore, we consider that not all products can be produced on every location by setting the capacity to zero.

- TransportCost

The transport cost is given in euros and is the cost to transport one tonne of cream, one kilometre. Since a lot of factors involve this transport costs, we did a rough estimation by taking the average cost to travel a milk truck one kilometre and divide it by the average truck load. The average price per kilometre that we use is €2.15 obtained from Panteia (2018). This is the price for a tank trucker with cooling system, such as a milk truck. The average truckload in our model is 24.5 tonne per truck, calculated by taking the total amount of cream supply divided by the total number of trucks needed. In this calculation we use the maximum truck capacity, which is 33 tonnes, and rounded the supplied cream to trucks. After calculation, the transport cost to transport one tonne of cream, one kilometre is:

$$\frac{2.15}{24.5} = 0.09 \text{ cents}$$

- ProductionRate

This parameter is the ratio on how much cream one tonne of end product consists. As described in Section 2.1.3, this is for butter 2.05 kilogram of cream per kilogram butter and as described in Section 2.1.4 2.495 kg of cream for one kilogram of butteroil.

- MaxInv

This parameter is the maximum amount of cream a processing location can have in inventory in their silos. We assume that the inventory for the butteroil factory in Lochem is the same as for the butter factory in Lochem, where in practice it is the same inventory space.

The formulated model with the given input variables and parameters was implemented in the software package AIMMS. The software is able to solve the model to optimal within a few seconds. When using different input parameters, this can go up to several minutes. The margin gained from sales given the input is €555,343. Note that this amount is only gross margin of all end products minus the transportation cost. Other costs, such as costs fixed cost from the production locations, are not included, since these costs do not have influence on the allocation process of cream. Therefore, the obtained profit is not that useful. More important is the output on how to allocate the cream (Xflow) and which products must be made (Xproduced) and sold (Xsold). The programming code of AIMMS can be found in appendix C.

The outcome of the model supports an efficient cream day plan with a planning horizon of one week. The output on the flow, the sold items and the capacity rate are the most important. Decisions made by the model can save a lot of time within the production locations, since the model calculates which products must be produced on a day, which makes it easier to come up with a production planning.

All output values are presented in Appendix D. To explain the output of the model, we elaborate on a part of the solution, as shown in Figure 7.1.

Xflow	**To**	Noordwijk	Den Bosch	LochemButter	LochemAMF
t	s				
Monday	Steenderen			13.74	
Monday	Gerkesklooster	48.54			
Monday	Maasdam		22.40		
Monday	Balkbrug			23.07	
Monday	Koln			67.48	
Monday	Workum			42.41	
Monday	Leeuwarden	105.22			
Monday	Bedum	116.15			
Monday	Lelystad			38.67	
Monday	Beilen			111.75	
Monday	Marum	51.21			
Monday	Born		15.47		
Monday	Rijkevoort		23.07		
Monday	Veghel		222.57		
Monday	Borculo			43.07	
Monday	Aalter		33.21		
Monday	Lutjewinkel		16.80		
Monday	Den Bosch		11.34		
Monday	Lochem			98.02	

Figure 7.1: Part of the output data of the cream valorisation model (values in tonnes of cream)

The figure shows the flow of the supplied cream on Monday, so the plan on how much cream must be transported from a certain supplying location to a production location. For example, on Monday the 13.74 tonnes of cream that is released in Steenderen, must be transported to the butter factory in Lochem. Furthermore, the butteroil factory in Lochem (LochemAMF) only gets 43 tonnes of cream on Monday. This means that given the machine capacity only is 8 hours of production. This is because

AMF generally have a lower profit margin per tonne cream that is needed. Also, when there is enough capacity in Noordwijk, it is more profitable to produce the AMF in Noordwijk, since there are a lot of cream supplying location in the north of the Netherlands where Noordwijk is located.

We also analyse the amount of sold end products with respect to the demand, as shown in Figure 7.2.

Xsale	Noordwijk	Den Bosch	LochemButter	LochemAMF	Total	Demand	Difference
Butter bulk Soured 10 kg		3.65	631.35		635.00	635.00	0.00
Butter bulk Soured 25 kg		530.61	504.39		1035.00	1035.00	0.00
Butter Prestige Soured 25 kg		120.00			120.00	120.00	0.00
Butter Sweetened 25 kg		61.84	380.16		442.00	442.00	0.00
Butter Hard 25 kg		330.00			330.00	330.00	0.00
Butter Consumer package 250 gram		230.00			230.00	230.00	0.00
AMF bulk	242.71				242.71	603.00	-360.29
AMF box 25 kg	298.53			161.47	460.00	460.00	0.00
AMF barrel 200 kg	370.00				370.00	370.00	0.00

Figure 7.2: Volume of sold end products, compared with the demand

The figure shows the amount of end products there are produced on all three locations and the difference with the demand. All end products, except the AMF bulk, are produced in full. This shows that the capacity of FC can handle almost all orders when the cream is allocated well. That the AMF bulk is not produced in full can be explained by the fact that this product category has the lowest profit margin per tonne cream that is processed. It shows that given the input data of the model, it is not the best option to prioritise Noordwijk, since on this location only AMF is produced.

We advise FC to implement the proposed model in OMP, the software of FC. FC should use the input values that we used and improve these values. Especially the margin and the transport costs must be improved to make the model more reliable. Now, the values these two parameters are based on rough estimations based on the average data.

This model is not only useful for FC to come up with an improved week plan, also when there are changes in the process this model can be used. This is possible by adapting the model to the days that must be calculated. For example, when Milk Logistics knows that the cream supply at the end of the week differs from the original planning on Wednesday, the time horizon of the model can be changed to a horizon from Thursday till Sunday. In this case it is important to adapt the demand as well, by removing the number of end products that already has been produced.

7.4 Trade-off between production and transport

In making right decisions in the trade-off between production and transport, we advise FC to do further research on the transportation costs and the production costs. When these costs are more reliable, better considerations whether a truck is moved or not, can be made by Intra-Transport. The considerations can be implemented in the valorisation model, for example by adding transportation constraints that only allows trucks to be transported with full truck load. Also, the carbon footprint of transportation and production is important in this trade-off since the company strives more and more to a sustainable business. Therefore, we advise FC to do more research on the carbon footprint of transportation and production as well.

7.5 Roadmap for implementation

In this chapter, we gave a lot of advice to FC to improve the situation. However, we have not been concrete on who in the company should implement the suggested improvements. In this section we come up with a roadmap for FC on how to implement the solutions and who would be responsible for those actions.

First of all, a team with people from different departments must be composed. This team should include a demand planner from the hub, an allocation planner from Milk Allocation, a transport planner from Intra-Transport and the supply chain managers of the business offices of the three butter(oil) factories. Since the team contains employees from all involved departments, all interests are considered.

The first thing that the team should do, is to equalise the standing time of cream for the different production locations. To do this, they should contact the global quality department of FC. This department is able to set up quality and safety regulations for the company.

Next, the team has to analyse the software that all production locations use and make guidelines on which software should be used. These guidelines must also include which amounts are included and which are not. For example, the team has to make clear if the cream from the locations' own skimming process is included in the amounts. When looking at the software, also the global ICT department or somebody from SAP should be contacted to solve the problem of sorting the data by unloading times instead of loading times.

Next, the team has to make clear on how the seasonality should be included in the day plan. They can use the seasonality indices, as calculated in Section 6.2.1, or they can implement a more advanced seasonality model as exponential smoothing. Milk Allocation should include the seasonality in their day plan.

The next thing which is important is the implementation of the model in OMP. The cream valorisation model is finished and ready for implementation. However, implementing and finetuning the model for FC can be a challenge if this person is not familiar with mathematical programming. A good implementation will also cost time since it is important that the model works perfect. Therefore, we suggest that the implementation is done by a project manager of FC with knowledge of mathematical programming. The project manager should work closely with the whey allocation planner since the model used in the whey network is related to the cream valorisation model.

Next, the team must move a planner from a business office to Milk Logistics, in order to get more control over and insight in changes in the supply. This planner has to be familiar with the software of OMP and must be able to work with implemented model.

At last, it is important that further research has to be done on the costs and the carbon footprint of transport and production. This subject is interesting for students, and therefore we advise the company to find students that are able to do a research with as subjects the costs and carbon footprint of transport and production within the cream supply chain.

8. Discussion and limitations

In this chapter, we discuss the strengthens and weaknesses of the model, we discuss opportunities to extend the model and discuss the assumptions and interpretations of the research.

The cream valorisation model is useful for multiple purposes. The model maximizes the profit of the company by prioritising the cream per order instead of prioritising per location, which makes it possible to raise more money out of the supplied cream. Next to that, the model provides more insight for Milk Allocation on how to allocate the cream. The output variable Xflow gives the optimal allocation of the cream from the cream supplying locations to the butter(oil) factories. The model also helps the production locations in creating an efficient production planning, since the model gives which product type should be produced every day as output. Also, when there are changes in the cream supply this model might be useful. The time horizon can be adapted and therefore it can provide the optimal solution on how to handle those changes in cream supply during the week. Together with the improvements on the input values the model decreases the deviation in cream supply by making the planning more accurate. The model also helps to produce demand-driven since it connects the customer orders to the available cream.

However, the model needs some finetuning on some aspects as well:

- In the model, we assume that the supply is known at the beginning of the week. However, in practice within the supply of cream there is a lot of uncertainty and the amount can change all the time, which makes the model less useful.
- When the supply of cream is so high that the machine and storage capacity is not enough to not handle the cream, the model will overflow, since it is not able to find a feasible solution. In practice this can also be a problem. In that case FC should sell the raw cream on the dairy market for spot prices in advance. However, in practice it almost never happens that the machine and storage capacity of all three locations is not sufficient to process all cream.
- The transport cost is calculated per tonne per kilometre. In reality this might not be feasible since the costs for a half-full truck is almost the same as the costs for a full truck. To make the transport cost more reliable, the transport cost must be connected to the number of trucks and the amount of cream must be rounded to trucks.
- In the model we use full days on when cream arrives, while in practice it matters on what time the cream arrives. In the model we assume that all cream is arriving at the start of a logistic day, which means that the cream that arrives today can be used today. In practice, it happens that cream arrives at the end of a logistic day, which means that the cream cannot be used on the same day. To overcome this limitation, the time horizon can be changed from days, into time slots of one hour.
- In the model we include the production costs in the margin of the end product, so it does not matter on which location an end product is made. This fact makes it impossible to have different production costs for different production locations. To include different production costs per location, the production costs must be considered as a decision variable. This can be connected to the variable 'Xproduction' in the model.

There are opportunities to extend the cream valorisation model, what makes the model even more useful. It can be extended by adding the following aspects:

- By including the by-product streams of the end products. When butter is produced, the margin gained by producing the residual buttermilk can be included. The profit margin of the residuals can be included in the margin of the end products of butter and butteroil.
- By adding transportation constraints. This can be done for example by adding a minimum truck load, which prevents the system from transporting half-full trucks.
- By adding the possibility to have end products on inventory for the next week.
- Now we make the assumption that cream must be transported from a supplying location on the same day as it is released. An interesting extension of the model is to include the buffer capacity of a supplying location. This can be included in the supply input parameter.

During the whole research we did various assumptions that might give a limited view on the problem. Below we discuss the assumptions and interpretations of this research:

- The main discussion is on the point of view of this research. This research is executed on the production location Lochem, and therefore most statements are made from the point of view of production. When this research was executed from the point of view of the hub or Milk Logistics, maybe other problems were discussed.
- Within the dairy supply chain there will always be a lot of uncertainty, what makes it hard to make optimal plans. Optimising the different plans by including uncertainty will increase the time that is needed to create these plans. There always have to be a good trade-off between the quality of the plans and the time invested in these plans.
- In this research we only consider the basic cream available within the company. However, it can happen that there is a surplus of Biological cream, Meadow cream, Planet Proof cream or Premium cream. When there is a surplus, this can be processed in the butter or butteroil factories, an aspect which is not included within this research.
- Within the data analysis of the supply reliability, we only consider the data from 2019, so some data can be distorted. We only considered this data, because before 2019 the PPC was calculated differently. Including this data gives a distorted view on reality.

9. Conclusion and recommendation

In this last chapter, in Section 9.1 we conclude our research and provide an answer on the main research question. Section 9.2 discusses the limitations of the research. Next, in Section 9.3 we provide recommendations for further research.

9.1 Conclusions

Within the OpCo 'Butter and Milkpowder' there is a lot of deviation in the amount of cream that is planned by Milk Logistics and what was supplied to the production locations. The problem became bigger when sales changed the way of working into completely demand driven. This puts a lot of pressure on the whole supply chain of the butter and butteroil factories. The goal of the research was to analyse the impact of the problem on the production locations, get to know the causes and to improve the situation. Therefore, we defined the following main research question:

How can FrieslandCampina organize the cream supply chain in order to improve the performance of the three butter(oil) factories?

Cream is a by-product of milk and contains 40% milkfat. To obtain cream, the milk must be skimmed, which is the separation of fat from the milk. On 20 production locations of FC the milk is skimmed, but for most production locations the cream is a residual and cannot be processed in that factory. Therefore, the cream will be transported to one the three butter and butteroil factories in Den Bosch, Lochem or Noordwijk, where the cream can be used to produce butter(oil). Within FC there are four departments involved in the allocation of cream, namely, Milk Validation and Allocation (MVA), Milk Allocation, Intra-Transport and the business office of a production location. The MVA is responsible for the plans on a longer time period. Milk Allocation makes plans on how to divide the cream for a shorter period of time, Intra-Transport makes a transportation plan on how this cream will be supplied to the cream processing location and the business office of a production location makes a production plan out of it. Next to the allocation process, the ordering process is important as well. A department called 'the hub' manages all orders and prioritises them. For this research there are two important KPIs, namely Production Plan Conformance (PPC) and the On-Time and In-Full (OTIF). The PPC calculates the performance of a factory and registers what percentage of an order is delivered and the OTIF calculates the percentage of orders are delivered on-time and in-full.

The deviation in cream supply is caused by four main root causes, namely the uncertainty, unclarities in the data, an inaccurate planning on day level and the focus on a department or location instead of focus on the whole company. In the data analysis we see some patterns. We see that the deviation in cream supply is caused on day level, because the total amount of cream that is processed in a week is accurate. Furthermore, we see that the seasonality effects are not included in the day plan and that the deviation is the biggest in Den Bosch and Lochem. The deviation in cream supply has a lot of consequences. The main consequences are high pressure on the whole cream supply chain, a time-consuming planning process, lost resource capacity and the right products cannot be made. We see that the deviation in cream supply has negatively influence on the production of products with a high profit margin.

In literature we found some useful methods on how to solve this kind of allocation problems. There has been a lot of research done in the dairy industry and many researchers analysed the characteristics of this industry. We considered these characteristics in finding solutions for this research. There are also some articles written about allocation problems for the dairy industry specifically. We decided to use a method called Mixed Integer Linear Programming (MILP) to improve the allocation process within FC.

In the solution design, we first analysed the whey supply chain, because this process has less problems in the supply chain. We saw that the whey allocation planner works with a whey valorisation model, which is a model that valorises the whey separately from the main valorisation model. This model works well and therefore we built such a model for the cream as well. The solution section consists of four steps. In the first two steps we gave advice on how to improve the input variables of the proposed model. First, the unclarities the in the data must be avoided and the communication must be improved. This can be done by solving the differences in loading and unloading times, by creating more guidelines on which software should be used, by solving the differences in standing time and by improving the communication on changes in the process. Next, the forecasts on a daily level must be improved by including seasonality, by scaling back the day plan to the total amount from the allocation plan and by paying more attention to the day plan. After these first two steps, we can implement the model, which is a MILP-model that optimises the profit given certain constraints. The goal is to connect the available cream supply to the customer orders. The main output is the flow of the cream between the cream supplying locations and the cream processing locations. After implementing the model, a trade-off between production and transport must be done. However, we do not have enough knowledge of the costs and carbon-footprint of production and transport and therefore we conclude that more research has to be done on these aspects.

9.2 Practical recommendations

In this section we give practical recommendations to FC to improve the current situation.

- We would advise to implement the cream valorisation model into OMP, the software that is already available within FC. Some input parameters were not available for this research, so we advise that people implement the real values into the model. Furthermore, the model can be extended by adding extra constraints to make the model more reliable and realistic.
- We would advise to hire a cream valorisation planner, like the whey valorisation planner in the whey supply chain. This planner can use the model and can monitor the cream supply in more detail. The person which fulfils this role can be someone who is now working as production planner at one of the production locations, since the cream valorisation can save time at the business office.
- Based on the solutions, we would advise to provide more guidelines for the standing times and create a standard way of working on the different production locations. Now production locations can make most decisions independently, which can create miscommunication.
- An option to give more insight in the cream supply to the production locations is to create a dashboard that provides information on the cream that is available at the cream supplying locations. This can lead to more understanding for the situation for the production locations and when there are changes in the cream supply, production locations can respond faster on it.
- We think that the day plan must be more important for Milk Logistics. Often this day plan is just considered as a kind of indication on the amount that can be expected a day and Milk

Logistics do not pay a lot of attention to this plan. We advise that this plan gets more priority, since this is the most important planning for the production locations.

9.3 Further research

In this research we made some exclusions to perform this research within the limited time. However, these exclusions can be interesting for further research.

- In this research we analysed the allocation of cream. So, we considered the cream supply chain from the moment that it is loaded at the cream supplying location until the cream is processed as butter or butteroil. There is a possibility that there are also opportunities to decrease the fluctuation before it is loaded into a truck, for example by buffering the cream at the supplying location. However, this part of the supply chain is not considered in this research but can be an interesting subject for further research.
- To make a good trade-off between production and transport, we need way more insight in the cost structure. It is good to do more research on this subject. In this research it is also interesting to consider the sustainability by calculating the carbon-footprint of transportation and the carbon-footprint of wastage in production due to producing products that are not ordered.
- We do not consider uncertainty in the input values of the model. Incorporating the uncertainty in the cream supply can be an interesting subject for further research. In this case, it is good to use the article written by Guan and Philpott (2011), since this research focuses on this topic.

References

Ayağ, Z., Samanlioglu, F. & Büyüközkan, G. (2013). A fuzzy QFD approach to determine supply chain management strategies in the dairy industry. Journal of Intelligent Manufacturing, 24, 1111–1122.

Banaszewska, A., Cruijssen, F. C. A. M., Claassen, G. D. H., van der Vorst, J. G. A. J., & J.L. Kampman (2013). A comprehensive dairy valorization model. Journal of Dairy Science, 96(2), 761-779.

Banaszewska, A., Cruijssen, F. C. A. M., Claassen, G. D. H., & van der Vorst, J. G. A. J. (2014). Effect and key factors of byproducts valorization: The case of dairy industry. Journal of Dairy Science, 97(4), 1893-1908.

Beber, C.L., Carpio, A.F.R., Almadani, M.I. and Theuvsen, L. (2019), "Dairy supply chain in Southern Brazil: barriers to competitiveness", International Food and Agribusiness Management Review, 22(5), 651-673.

Bhardwaj, A., Mor, R. S., Singh, S., & Dev, M. (2016). An investigation into the dynamics of supply chain practices in Dairy industry: a pilot study. Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management Detroit, Michigan, USA, Sept. 23-25, 2016, 1360-1365.

Bowonder, B., Raghu Prasad, B. R., & Kotla, A. (2005). ICT application in a dairy industry: The e-experience of Amul. International Journal of Services Technology and Management, 6(3-5), 241-265.

Geary, U., Lopez-Villalobos, N., Garrick, D.J. and Shalloo, L., 2010. Development and application of a processing model for the Irish dairy industry. Journal of Dairy Science, 93(11): 5091-5100.

Chaudhuri, A., Dukovska-Popovska, I., Subramanian, N., Chan, H.K. and Bai, R. (2018), "Decision-making in cold chain logistics using data analytics: a literature review", The International Journal of Logistics Management, 29(3), 839-861.

Chopra, S., Meindl, P. (2013). "Supply chain management (5th edition)". Pearson. ISBN: 978-0-13-274395-2.

Crainic, T. G. , & Laporte, G. (1997). Planning models for freight transportation. European Journal of Operational Research, 97, 409–438 .

Damodaran, A. (2020). Margins by Sector (US). Retrieved from: http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/margin.html.

Doganis P., Sarimveis H. (2007). Optimal scheduling in a yogurt production line based on mixed integer linear programming. Journal of Food Engineering, 80(2), 445–453.

Ebrahimi, S. R., Khoshalhan, F. & Ghaderzadeh, H. (2018). "Stochastic Optimization of Dairy Supply Chain Valorization Model by Considering Byproducts." Proceedings of the International Conference on Industrial Engineering and Operations Management Paris, France, July 26-27, 2018.

Eurostat. (2018). Agriculture, forestry and fishery statistics, 2018 edition.

Geary, U., Lopez-Villalobos, N., Garrick, D.J. and Shalloo, L., (2010). Development and application of a processing model for the Irish dairy industry. Journal of Dairy Science, 93(11): 5091-5100.

Guan, Z. & Philpott, A.B., (2011). "A multistage stochastic programming model for the New Zealand dairy industry," International Journal of Production Economics, Elsevier, 134(2), 289-299.

Gunasekaran, A., Patel, C., & McGaughey, R. E. (2004), “A framework for supply chain performance measurement”, International Journal of Production Economics, 87(3), 333-347.

Gustavsson, J., Cederberg, C., Sonesson, U., Van Otterdijk, R. and Meybeck, A., (2011). Global food losses and food waste, Food and Agriculture Organization of the United Nations, Dusseldorf.

Google Maps. (2020). Retrieved 23 June 2020 from: https://www.google.nl/maps.

FrieslandCampina, (2019). Annual report 2019.

Jouzdani, J., Fathian, M., Makui, A. et al. (2018). Robust design and planning for a multi-mode multi-product supply network: a dairy industry case study. Operational Research, 20, 1811–1840.

Kranenberg Broer Scholtens A.,(2001,16 June), UITGERUIMD. de Volkskrant. Retrieved from: https://www.volkskrant.nl/nieuws-achtergrond/uitgeruimd~bea628cd/.

Marandi, F., and S. H. Zegordi. (2017). “Integrated Production and Distribution Scheduling for Perishable Products.” Scientia Iranica 24 (4): 2105–2118.

Melo, M.T., Nickel, S., Saldanha-da-Gama, F.,(2009). Facility location and supply chain management– A review. European Journal of Operational Research, 196 (2), 401–412.

Mishra, P. K., & Shekhar, B. R. (2011). Impact of risks and uncertainties on supply chain: A dairy industry perspective. Journal of Management Research, 3(2), 1.

Misni, F. & Lee, L.S. (2017) A Review on Strategic, Tactical and Operational Decision Planning in Reverse Logistics of Green Supply Chain Network Design. Journal of Computer and Communications, 5, 83-104.

Mor, R.S., Bhardwaj, A. and Singh, S. (2018c), "Benchmarking the interactions among performance indicators in dairy supply chain: An ISM approach", Benchmarking: An International Journal, 25(9), 3858-3881.

Mor, R.S., Bhardwaj, A., Singh, S., (2018d). A structured-literature-review of the supply chain practices in dairy industry. Journal of Operations and Supply Chain Management, 11(1), 14-25.

Nemati, Y., Madhoushi, M., Ghadikolaei, A.S., (2017a). The effect of sales and operations planning (S&OP) on supply chain’s total performance: A case study in an Iranian dairy company. Computers and Chemical Engineering, 104, 323–338.

Nematollahi, M. & Tajbakhsh, A., (2020). Past, present, and prospective themes of sustainable agricultural supply chains: A content analysis. Journal of Cleaner Production, 271, 1-19.

NOS. (2011, 8 April). ‘Weer verontreinigde melk in China’. Retrieved from: https://nos.nl/artikel/231523-weer-verontreinigde-melk-in-china.html.

Pant, R.R. & Prakash, Gyan & Farooquie, Jamal. (2015). A Framework for Traceability and Transparency in the Dairy Supply Chain Networks. Procedia - Social and Behavioral Sciences, 189, 385-394.

Panteia. (2018). “Kostencalculaties in het beroepsgoederenvervoer over de weg.” Prijspeil 1-7-2018. Retrieved from: https://www.panteia.nl/index.cfm/_api/render/file/?method=inline&fileID=5B52D01F-D3BA-4170-9179D3CC1C0706B5.

Rader jr, D. J., (2010). Deterministic Operations Research: Models and Methods in Linear Optimization, Wiley, ISBN 9780470484517.

Schmidt, G. & Wilhelm, W. E. (2000) Strategic, tactical and operational decisions in multi-national logistics networks: A review and discussion of modelling issues, International Journal of Production Research, 38(7), 1501-1523.

Sel, C., Bilgen, B., Bloemhof-Ruwaard, J.M., van der Vorst, J.G.A.J., 2015. Multi-bucket optimization for integrated planning and scheduling in the perishable dairy supply chain. Computers and Chemical Engineering, 77, 59–73.

Singh, N., & Javadekar, P. (2011). Supply chain management of perishable food products: A strategy to achieve competitive advantage through knowledge management. Indian Journal of Marketing, 41, 10-22.

Srivastava, S. K. (2006). Logistics and supply chain management practices in India. The Journal of Business Perspective, 10(3), 69-79.

Talbi, E.-G. (2009). Metaheuristics: from design to implementation. John Wiley & Sons, 2009.

Van Der Pool, J. (2007). Lessons for an expanding dairy industry: An international perspective. Teagasc Nat. Dairy Conf. Kilkenny, Ireland. Teagasc, Oakpark, Co. Carlow, Ireland. P53-57

Van der Vorst, J.G.A.J., Van Kooten, O., Marcelis, W., Luning, P., Beulens, A.J.M. (2007). Quality controlled logistics in food supply chain networks: integrated decision-making on quality and logistics to meet advanced customer demands. Proceedings of the 14th International EurOMA Conference, Ankara, Turkey.

Vergé, X.P.C., Maxime, D., Dyer, J.A., Desjardins, R.L., Arcand, Y., Vanderzaag A., (2013). Carbon footprint of Canadian dairy products: Calculations and issues. Journal of Dairy Science, 96(9), 6091-6104.

Winston, W.L., (2003). Operations Research: Applications and Algorithms (4th ed.), Cengage, ISBN 9780534380588

Wouda, F., van Beek, P., van der Vorst, J., & Tacke, H. (2002). An application of mixed-integer linear programming models on the redesign of the supply network of Nutricia Dairy & Drinks Group in Hungary. OR Spectrum, 24(4), 449–465.

Appendix

A. Multiple other scenarios to validate the model

Scenario with higher transport cost

Input values are the same, except for the transport cost. The transport cost is now €0.50 per tonne per kilometre instead of €0.09. In this case the output values are as follows:

Xsale	Noordwijk	Den Bosch	LochemButter	LochemAMF
Butter bulk Soured 10 kg		110.25	19.75	
Butter bulk Soured 25 kg			175.43	
AMF Bulk	142.13			122.80

Capacity Rate	Noordwijk	Den Bosch	LochemButter	LochemAMF
t				
Monday	0.843	1.000	1.000	0.676
Tuesday	1.000	0.756	1.000	1.000
Wednesday	1.000	1.000	1.000	0.780

Xflow	**To**	Noordwijk	Den Bosch	LochemButter	LochemAMF
t	**From**				
Monday	Steenderen			168.24	54.32
Monday	Gerkesklooster	111.75			
Monday	Maasdam		67.48		
Tuesday	Steenderen			88.76	124.75
Tuesday	Gerkesklooster	107.20			
Tuesday	Maasdam		64.73		
Wednesday	Steenderen			113.13	97.30
Wednesday	Gerkesklooster	105.66			
Wednesday	Maasdam		63.80		

Xproduced	**To**	Noordwijk	Den Bosch	LochemButter	LochemAMF
t	**From**				
Monday	Butter bulk Soured 10 kg		40.00		
Monday	Butter bulk Soured 25 kg			70.00	
Monday	AMF Bulk	42.13			33.80
Tuesday	Butter bulk Soured 10 kg		30.25		
Tuesday	Butter bulk Soured 25 kg			70.00	
Tuesday	AMF Bulk	50.00			50.00
Wednesday	Butter bulk Soured 10 kg		40.00	19.75	
Wednesday	Butter bulk Soured 25 kg			35.43	
Wednesday	AMF Bulk	50.00			39.00

CreamSurplus	
Noordwijk	
Den Bosch	
LochemButter	
LochemAMF	

Profit	
€	60,120.43

Scenario with different profit margins

All input values are the same as before, except for the profit margins. The profit margins are now:

Margin(e)	
Butter bulk Soured 10 kg	150
Butter bulk Soured 25 kg	150
AMF bulk	200

With these profit margins, the solution is now:

Xsale	Noordwijk	Den Bosch	LochemButter	LochemAMF
Butter bulk Soured 10 kg		110.25		
Butter bulk Soured 25 kg			162.08	
AMF Bulk	142.13			150.00

Capacity Rate	Noordwijk	Den Bosch	LochemButter	LochemAMF
t				
Monday	0.843	0.978	1.000	1.000
Tuesday	1.000	1.000	0.315	1.000
Wednesday	1.000	0.778	1.000	1.000

Xflow	To	Noordwijk	Den Bosch	LochemButter	LochemAMF
t	From				
Monday	Steenderen			113.50	109.07
Monday	Gerkesklooster	111.75			
Monday	Maasdam		67.48		
Tuesday	Steenderen			45.26	168.25
Tuesday	Gerkesklooster	107.20			
Tuesday	Maasdam		64.73		
Wednesday	Steenderen			143.50	66.93
Wednesday	Gerkesklooster	105.66			
Wednesday	Maasdam		63.80		

Xproduced	To	Noordwijk	Den Bosch	LochemButter	LochemAMF
t	From				
Monday	Butter bulk Soured 10 kg		39.13		
Monday	Butter bulk Soured 25 kg			70.00	
Monday	AMF Bulk	42.13			50.00
Tuesday	Butter bulk Soured 10 kg		40.00		
Tuesday	Butter bulk Soured 25 kg			22.08	
Tuesday	AMF Bulk	50.00			50.00
Wednesday	Butter bulk Soured 10 kg		31.12		
Wednesday	Butter bulk Soured 25 kg			70.00	
Wednesday	AMF Bulk	50.00			50.00

CreamSurplus	
Noordwijk	
Den Bosch	
LochemButter	
LochemAMF	

Profit	
€	95,895.19

Scenario with more supply than demand

All input values are the same as before, except for the supply. Now, the supplying locations have 3 trucks of cream per day more available than before, so the supply is now as follows:

Supply(t,s)	Monday	Tuesday	Wednesday
Steenderen	312.5682	303.5063	300.432812
Gerkesklooster	201.7508	197.2009	195.657697
Maasdam	157.4772	154.7299	153.798084

The output of the solution is as follows:

Xsale	Noordwijk	Den Bosch	LochemButter	LochemAMF
Butter bulk Soured 10 kg		17.92	50.66	
Butter bulk Soured 25 kg		178.65	121.35	
AMF Bulk	150.00			150.00

Capacity Rate	Noordwijk	Den Bosch	LochemButter	LochemAMF
t				
Monday	1.000	1.000	1.000	1.000
Tuesday	1.000	1.000	1.000	1.000
Wednesday	1.000	1.000	1.000	1.000

Xflow	To	Noordwijk	Den Bosch	LochemButter	LochemAMF
t	**From**				
Monday	Steenderen			17.82	294.75
Monday	Gerkesklooster	94.75		107.00	
Monday	Maasdam		157.48		
Tuesday	Steenderen			178.76	124.75
Tuesday	Gerkesklooster	153.84		43.36	
Tuesday	Maasdam		154.73		
Wednesday	Steenderen			175.68	124.75
Wednesday	Gerkesklooster	195.66			
Wednesday	Maasdam		153.80		

Xproduced	To	Noordwijk	Den Bosch	LochemButter	LochemAMF
t	**From**				
Monday	Butter bulk Soured 10 kg				
Monday	Butter bulk Soured 25 kg		70.00	70.00	
Monday	AMF Bulk	50.00			50.00
Tuesday	Butter bulk Soured 10 kg			40.00	
Tuesday	Butter bulk Soured 25 kg		70.00		
Tuesday	AMF Bulk	50.00			50.00
Wednesday	Butter bulk Soured 10 kg		28.57		
Wednesday	Butter bulk Soured 25 kg		20.00	70.00	
Wednesday	AMF Bulk	50.00			50.00

CreamSurplus	
Noordwijk	100.00
Den Bosch	109.43
LochemButter	183.62
LochemAMF	200.00

Profit	
€	79,188.51

B. Input variables of the cream valorisation model

Indices

Days

#	Days	
1	Monday	Monday 6:00 – Tuesday 5:59
2	Tuesday	Tuesday 6:00 – Wednesday 5:59
3	Wednesday	Wednesday 6:00 – Thursday 5:59
4	Thursday	Thursday 6:00 – Friday 5:59
5	Friday	Friday 6:00 – Saturday 5:59
6	Saturday	Saturday 6:00 – Sunday 5:59
7	Sunday	Sunday 6:00 – Monday 5:59

End Products

#	Butter
1	Butter bulk Soured 10 kg
2	Butter bulk Soured 25 kg
3	Butter Prestige Soured 25 kg
4	Butter Sweetened 25 kg
5	Butter Hard 25 kg
6	Butter Consumer package 250 gram
	Butteroil
7	AMF box 25 kg
8	AMF barrel 200 kg
9	AMF bulk

Set of supplying locations

#	Supplying locations
1	Steenderen
2	Balkbrug
3	Köln
4	Workum
5	Gerkesklooster
6	Leeuwarden
7	Bedum
8	Lelystad (Farm Dairy)
9	Beilen
10	Marum
11	Maasdam

12	Born
13	Rijkevoort
14	Veghel
15	Borculo
16	Aalter
17	Lutjewinkel
18	Lochem
19	Den Bosch

Set of processing locations

#	Processing locations
1	Noordwijk
2	Den Bosch
3	Lochem

Parameters

Distances (in kilometres)

Distances (km)		Processing locations		
		Noordwijk	Den Bosch	Lochem
Cream supply locations	Steenderen	169	91	28
	Balkbrug	85	155	61
	Köln	324	176	168
	Workum	78	193	154
	Gerkesklooster	14	223	155
	Leeuwarden	41	213	144
	Bedum	39	246	149
	Lelystad (Farm Dairy)	110	117	105
	Beilen	56	189	92
	Marum	4	217	149
	Maasdam	230	76	160
	Born	305	101	182
	Rijkevoort	217	48	94
	Veghel	224	17	110
	Borculo	160	122	12
	Aalter	373	181	303
	Lutjewinkel	134	151	189
	Den Bosch	217	0	112
	Lochem	144	112	0

Supply (amount of cream in tonnes)

Data from week 51 (2019)

Supply(t,s)	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Steenderen	13.74	13.18	12.99	14.11	15.98	17.23	15.78
Balkbrug	23.07	22.13	21.81	23.70	26.84	28.94	26.50
Koln	67.48	64.73	63.80	69.33	78.51	84.64	77.52
Workum	42.41	40.68	40.09	43.57	49.34	53.19	48.72
Gerkesklooster	48.54	46.56	45.89	49.87	56.48	60.88	55.77
Leeuwarden	105.22	100.93	99.48	108.10	122.42	131.97	120.88
Bedum	116.15	111.42	109.82	119.34	135.14	145.69	133.44
Lelystad	38.67	37.10	36.56	39.73	45.00	48.51	44.43
Beilen	111.75	107.20	105.66	114.82	130.02	140.17	128.38
Marum	51.21	49.12	48.42	52.61	59.58	64.23	58.83
Maasdam	22.40	21.49	21.18	23.02	26.07	28.10	25.74
Born	15.47	14.84	14.63	15.89	18.00	19.40	17.77
Rijkevoort	23.07	22.13	21.81	23.70	26.84	28.94	26.50
Veghel	222.57	213.51	210.43	228.68	258.96	279.16	255.69
Borculo	43.07	41.32	40.72	44.26	50.12	54.03	49.48
Aalter	33.21	31.85	31.39	34.12	38.63	41.65	38.15
Lutjewinkel	16.80	16.12	15.89	17.26	19.55	21.08	19.30
Den Bosch	11.34	10.87	10.72	11.65	13.19	14.22	13.02
Lochem	98.02	94.02	92.67	100.71	114.04	122.94	112.60

Margin (in euros, per tonne end product)

Margin(e)	
Butter bulk Soured 10 kg	130
Butter bulk Soured 25 kg	170
Butter Prestige Soured 25 kg	170
Butter Sweetened 25 kg	120
Butter Hard 25 kg	200
Butter Consumer package 250 gram	150
AMF box 25 kg	160
AMF barrel 200 kg	250
AMF bulk	150

Demand (in tonnes)

Data from week 51 (2019)

Demand(e)	
Butter bulk Soured 10 kg	635

Butter bulk Soured 25 kg	1035
Butter Prestige Soured 25 kg	120
Butter Sweetened 25 kg	442
Butter Hard 25 kg	330
Butter Consumer package 250 gram	230
AMF box 25 kg	460
AMF barrel 200 kg	370
AMF bulk	603

Capacity (maximum capacity per product per day)

Capacity		Processing locations			
		Noordwijk	Den Bosch	LochemButter	LochemAMF
End products	Butter bulk Soured 10 kg	0	199	199	0
	Butter bulk Soured 25 kg	0	276	276	0
	Butter Prestige Soured 25 kg	0	205	205	0
	Butter Sweetened 25 kg	0	276	276	0
	Butter Hard 25 kg	0	226	226	0
	Butter Consumer package 250 gram	0	153	0	0
	AMF boxes	120	0	0	120
	AMF barrel 200 kg	132	0	0	132
	AMF bulk	142	0	0	142

TransportCost (euro per tonne per kilometre)

TransportCost
0.09

ProductionRate (ratio on how much cream one tonne of end product consists)

ProductionRate(e)	
Butter bulk Soured 10 kg	2.05
Butter bulk Soured 25 kg	2.05
Butter Prestige Soured 25 kg	2.05
Butter Sweetened 25 kg	2.05
Butter Hard 25 kg	2.05
Butter Consumer package 250 gram	2.05
AMF box 25 kg	2.495
AMF barrel 200 kg	2.495
AMF bulk	2.495

Max inventory (in tonnes cream at the end of a day)

Max inventory	
Noordwijk	100
Den Bosch	200
LochemButter	200
LochemAMF	200

Initial inventory

Initial inventory	
Noordwijk	30
Den Bosch	30
LochemButter	30
LochemAMF	30

C. Programming code AIMMS

```
Model Main_CreamValorisation {
    Set EndProducts {
        Index: e;
    }
    Set Days {
        Index: t;
    }
    Set SupplyLocations {
        Index: s;
    }
    Set ProcessingLocations {
        Index: p;
    }
    Parameter Supply {
        IndexDomain: (s,t);
    }
    Parameter Demand {
        IndexDomain: e;
    }
    Parameter Distance {
        IndexDomain: (s,p);
    }
    Parameter Capacity {
        IndexDomain: (t,e,p);
    }
    Parameter Margin {
        IndexDomain: e;
    }
    Parameter ProductionRate {
        IndexDomain: (e);
    }
    Parameter MaxInv {
        IndexDomain: p;
    }
    Parameter TransportCost;
    Parameter InitialInv {
        IndexDomain: p;
    }
    Variable Xuse {
        IndexDomain: (t,e,p);
        Range: nonnegative;
    }
    Variable Xsale {
        IndexDomain: (e,p);
        Range: nonnegative;
    }
    Variable Xproduced {
        IndexDomain: (t,e,p);
        Range: nonnegative;
    }
    Variable Xflow {
        IndexDomain: (t,s,p);
        Range: nonnegative;
    }
    Variable CapacityRate {
        IndexDomain: (t,p);
        Range: free;
    }
    Variable Xinv {
        IndexDomain: (t,p);
        Range: nonnegative;
    }
    Variable CreamSurplus {
        IndexDomain: p;
        Range: free;
    }
```

```
Variable Revenue {
    Range: free;
    Definition: {
        sum(e, Margin(e) * sum (p, XSale(e,p)));
    }
}
Variable TransportCostTotal {
    Range: free;
    Definition: {
        TransportCost * sum(s, sum (p, sum( t, ( Distance(s,p) * XFlow(t,s,p)))));
    }
}
Variable Profit {
    Range: free;
    Definition: {
        Revenue - TransportCostTotal;
    }
}
Constraint CapacityCon {
    IndexDomain: (t,e,p);
    Definition: {
        Xproduced(t,e,p) <= Capacity(t,e,p);
    }
}
Constraint ResourceCapCon {
    IndexDomain: (t,p);
    Definition: {
        CapacityRate(t,p) = sum(e, (Xproduced(t,e,p)) / max(1,Capacity(t,e,p)));
    }
}
Constraint ResourceCapCon2 {
    IndexDomain: (t,p);
    Definition: {
        CapacityRate(t,p) <= 1;
    }
}
Constraint MaxSaleCon {
    IndexDomain: e;
    Definition: {
        sum ( p, XSale(e,p)) <= Demand(e);
    }
}
Constraint MaxSaleCon2 {
    IndexDomain: (e,p);
    Definition: {
        Xsale(e,p) <= sum(t, Xproduced(t,e,p));
    }
}
Constraint SupplyCon {
    IndexDomain: (s,t);
    Definition: {
        sum(p, Xflow(t,s,p)) = Supply(s,t);
    }
}
Constraint InventoryCon {
    IndexDomain: (t,p) | (t<>'Monday');
    Definition: {
        Xinv(t,p) = Xinv(t-1,p) + sum(s, Xflow(t,s,p)) - sum(e, Xuse(t,e,p));
    }
}
Constraint InventoryCon2 {
    IndexDomain: (t,p) | (t='Monday');
    Definition: {
        Xinv(t,p) = InitialInv(p) + sum(s, Xflow(t,s,p)) - sum(e, Xuse(t,e,p));
    }
}
Constraint MaxInvCon {
    IndexDomain: (t,p);
```

```
        Definition: {
            XInv(t,p) <= MaxInv(p);
        }
    }
    Constraint ProductionCon {
        IndexDomain: (t,p) | (t<>'Monday');
        Definition: {
            sum(e, Xuse(t,e,p)) <= sum(s, Xflow(t,s,p)) + Xinv(t-1,p);
        }
    }
    Constraint ProductionCon2 {
        IndexDomain: (t,p) | (t='Monday');
        Definition: sum(e, Xuse(t,e,p)) <= sum(s, Xflow(t,s,p)) + InitialInv(p);
    }
    Constraint ProductionCon3 {
        IndexDomain: (t,e,p);
        Definition: {
            Xproduced(t,e,p) <= Xuse(t,e,p) / ProductionRate(e);
        }
    }
    Constraint SurplusCon {
        IndexDomain: p;
        Definition: CreamSurplus(p) = Xinv('Sunday',p);
    }
    MathematicalProgram SolveModel {
        Objective: Profit;
        Direction: maximize;
        Constraints: AllConstraints;
        Variables: AllVariables;
        Type: Automatic;
    }
    Procedure MainInitialization_full_problem {
        Body: {
            ExcelRetrieveSet("input_values3.xlsx",EndProducts,"N3:N11","InputFull");
            ExcelRetrieveSet("input_values3.xlsx",Days,"L3:L9","InputFull");

ExcelRetrieveSet("input_values3.xlsx",SupplyLocations,"H3:H21","InputFull");

ExcelRetrieveSet("input_values3.xlsx",ProcessingLocations,"J3:J6","InputFull");

ExcelretrieveTable("input_values3.xlsx",Supply(s,t),"Q3:W21","P3:P21","Q2:W2","Inpu
tFull");

ExcelRetrieveParameter("input_values3.xlsx",Demand(e),"Z3:Z11","InputFull");

ExcelretrieveTable("input_values3.xlsx",Distance(s,p),"C3:F21","B3:B21","C2:F2","In
putFull");

ExcelretrieveTable("input_values3.xlsx",Capacity(t,e,p),"AF4:BO10","AE4:AE10","AF2:
BO3","InputFull");

ExcelRetrieveParameter("input_values3.xlsx",Margin(e),"AC3:AC11","InputFull");

ExcelRetrieveParameter("input_values3.xlsx",ProductionRate(e),"C26:C34","InputFull"
);

ExcelRetrieveParameter("input_values3.xlsx",MaxInv(p),"F26:F29","InputFull");

ExcelRetrieveParameter("input_values3.xlsx",InitialInv(p),"I26:I29","InputFull");

ExcelRetrieveParameter("input_values3.xlsx",TransportCost,"K26:K26","InputFull");
        }
    }
    Procedure PostMainInitialization;
    Procedure MainExecution {
        Body: {
            MainInitialization_full_problem;
            solve SolveModel;
```

```
        }
    }
    Procedure PreMainTermination {
        Body: {
            return DataManagementExit();
        }
    }
    Procedure MainTermination {
        Body: {
            return 1;
        }
    }
}
```

D. Output variables of the cream valorisation model

XSale

Xsale	Noordwijk	Den Bosch	LochemButter	LochemAMF	Total	Demand	Difference
Butter bulk Soured 10 kg		3.65	631.35		635.00	635.00	0.00
Butter bulk Soured 25 kg		530.61	504.39		1035.00	1035.00	0.00
Butter Prestige Soured 25 kg		120.00			120.00	120.00	0.00
Butter Sweetened 25 kg		61.84	380.16		442.00	442.00	0.00
Butter Hard 25 kg		330.00			330.00	330.00	0.00
Butter Consumer package 250 gram		230.00			230.00	230.00	0.00
AMF bulk	242.71				242.71	603.00	-360.29
AMF box 25 kg	298.53			161.47	460.00	460.00	0.00
AMF barrel 200 kg	370.00				370.00	370.00	0.00

Capacity Rate

Capacity Rate	Noordwijk	Den Bosch	LochemButter	LochemAMF
t				
Monday	1.000	0.663	0.828	0.100
Tuesday	1.000	0.741	1.000	0.041
Wednesday	1.000	1.000	1.000	0.021
Thursday	1.000	0.719	1.000	0.026
Friday	1.000	0.886	1.000	
Saturday	1.000	1.000	0.955	0.468
Sunday	1.000	0.705	0.595	0.688

Profit

Profit
€ 555,343.11

Cream surplus

CreamSurplus	
Noordwijk	
Den Bosch	
LochemButter	
LochemAMF	

Xproduced

Xproduced	p	Noordwijk	Den Bosch	LochemButter	LochemAMF
t	e				
Monday	Butter bulk Soured 25 kg		182.86	228.39	
Monday	AMF box 25 kg	120.00			12.02
Wednesday	Butter bulk Soured 10 kg			199.00	
Wednesday	AMF bulk	89.58			
Wednesday	Butter Consumer package 250 gram		153.00		
Wednesday	AMF box 25 kg	44.30			2.55
Tuesday	Butter bulk Soured 10 kg			199.00	
Tuesday	Butter Hard 25 kg		167.42		
Tuesday	AMF box 25 kg				4.97
Tuesday	AMF barrel 200 kg	132.00			
Thursday	Butter bulk Soured 10 kg			199.00	
Thursday	AMF bulk	16.79			
Thursday	Butter Hard 25 kg		162.58		
Thursday	AMF box 25 kg	9.45			3.15
Thursday	AMF barrel 200 kg	106.00			
Friday	Butter bulk Soured 25 kg		158.15	276.00	
Friday	AMF bulk	136.34			
Friday	Butter Consumer package 250 gram		47.84		
Friday	AMF box 25 kg	4.78			
Saturday	Butter bulk Soured 10 kg			34.35	
Saturday	Butter Prestige Soured 25 kg		120.00		
Saturday	Butter Sweetened 25 kg		61.84	215.81	
Saturday	Butter Consumer package 250 gram		29.16		
Saturday	AMF box 25 kg	120.00			56.18
Sunday	Butter bulk Soured 10 kg		3.65		
Sunday	Butter bulk Soured 25 kg		189.61		
Sunday	Butter Sweetened 25 kg			164.35	
Sunday	AMF box 25 kg				82.59
Sunday	AMF barrel 200 kg	132.00			

Xflow

Xflow	To	Noordwijk	Den Bosch	LochemButter	LochemAMF
t	s				
Monday	Steenderen			13.74	
Monday	Gerkesklooster	48.54			
Monday	Maasdam		22.40		
Monday	Balkbrug			23.07	
Monday	Koln			67.48	
Monday	Workum			42.41	
Monday	Leeuwarden	105.22			
Monday	Bedum	116.15			
Monday	Lelystad			38.67	
Monday	Beilen			111.75	
Monday	Marum	51.21			
Monday	Born		15.47		
Monday	Rijkevoort		23.07		
Monday	Veghel		222.57		
Monday	Borculo			43.07	
Monday	Aalter		33.21		
Monday	Lutjewinkel		16.80		
Monday	Den Bosch		11.34		
Monday	Lochem			98.02	
Wednesday	Steenderen			12.99	
Wednesday	Gerkesklooster	45.89			
Wednesday	Maasdam		21.18		
Wednesday	Balkbrug			15.45	6.36
Wednesday	Koln			63.80	
Wednesday	Workum			40.09	
Wednesday	Leeuwarden	99.48			
Wednesday	Bedum	109.82			
Wednesday	Lelystad			36.56	
Wednesday	Beilen			105.66	
Wednesday	Marum	48.42			
Wednesday	Born		14.63		
Wednesday	Rijkevoort		21.81		
Wednesday	Veghel		210.43		
Wednesday	Borculo			40.72	
Wednesday	Aalter		31.39		
Wednesday	Lutjewinkel		15.89		
Wednesday	Den Bosch		10.72		
Wednesday	Lochem			92.67	
Tuesday	Steenderen			13.18	
Tuesday	Gerkesklooster	46.56			
Tuesday	Maasdam		21.49		
Tuesday	Balkbrug			22.13	
Tuesday	Koln			64.73	
Tuesday	Workum			28.27	12.41
Tuesday	Leeuwarden	100.93			
Tuesday	Bedum	111.42			
Tuesday	Lelystad			37.10	
Tuesday	Beilen			107.20	
Tuesday	Marum	49.12			
Tuesday	Born		14.84		
Tuesday	Rijkevoort		22.13		
Tuesday	Veghel		213.51		
Tuesday	Borculo			41.32	
Tuesday	Aalter		31.85		
Tuesday	Lutjewinkel		16.12		
Tuesday	Den Bosch		10.87		
Tuesday	Lochem			94.02	
Thursday	Steenderen			14.11	
Thursday	Gerkesklooster	49.87			
Thursday	Maasdam		23.02		
Thursday	Balkbrug			15.85	7.85
Thursday	Koln			69.33	
Thursday	Workum			43.57	
Thursday	Leeuwarden	108.10			
Thursday	Bedum	119.34			
Thursday	Lelystad			39.73	
Thursday	Beilen			114.82	
Thursday	Marum	52.61			
Thursday	Born		15.89		
Thursday	Rijkevoort		23.70		
Thursday	Veghel		228.68		
Thursday	Borculo			44.26	
Thursday	Aalter		34.12		
Thursday	Lutjewinkel		17.26		
Thursday	Den Bosch		11.65		
Thursday	Lochem			100.71	
Friday	Steenderen			15.98	
Friday	Gerkesklooster	56.48			
Friday	Maasdam		26.07		
Friday	Balkbrug			26.84	
Friday	Koln			78.51	
Friday	Workum			49.34	
Friday	Leeuwarden	100.90		21.52	
Friday	Bedum	135.14			
Friday	Lelystad			45.00	
Friday	Beilen			130.02	
Friday	Marum	59.58			
Friday	Born		18.00		
Friday	Rijkevoort		26.84		
Friday	Veghel		258.96		
Friday	Borculo			50.12	
Friday	Aalter		38.63		
Friday	Lutjewinkel		19.55		
Friday	Den Bosch		13.19		
Friday	Lochem			114.04	
Saturday	Steenderen			17.23	
Saturday	Gerkesklooster	60.88			
Saturday	Maasdam		28.10		
Saturday	Balkbrug			28.94	
Saturday	Koln			84.64	
Saturday	Workum			53.19	
Saturday	Leeuwarden	28.60		103.37	
Saturday	Bedum	145.69			
Saturday	Lelystad			48.51	
Saturday	Beilen				140.17
Saturday	Marum	64.23			
Saturday	Born		19.40		
Saturday	Rijkevoort		28.94		
Saturday	Veghel		279.16		
Saturday	Borculo			54.03	
Saturday	Aalter		41.65		
Saturday	Lutjewinkel		21.08		
Saturday	Den Bosch		14.22		
Saturday	Lochem			122.94	
Sunday	Steenderen			15.78	
Sunday	Gerkesklooster	55.77			
Sunday	Maasdam		25.74		
Sunday	Balkbrug				26.50
Sunday	Koln			70.76	6.76
Sunday	Workum			48.72	
Sunday	Leeuwarden	81.31		39.57	
Sunday	Bedum	133.44			
Sunday	Lelystad				44.43
Sunday	Beilen				128.38
Sunday	Marum	58.83			
Sunday	Born		17.77		
Sunday	Rijkevoort		26.50		
Sunday	Veghel		255.69		
Sunday	Borculo			49.48	
Sunday	Aalter		38.15		
Sunday	Lutjewinkel		19.30		
Sunday	Den Bosch		13.02		
Sunday	Lochem			112.60	