INVENTORY CONTROL AT GROLSCH

A master thesis which analyzes inventory control at Grolsch and proposes a model to determine optimal levels of safety stock.

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This thesis concludes my Master in Industrial Engineering and Management at the University of Twente. Over the course of six months I performed research into inventory control at Grolsch which has resulted in a tool to determine optimal levels of safety stock. Right from the start, my welcome at Grolsch has been nothing but friendly and kind and I would like to thank them for giving me the opportunity to perform my thesis there, at the Supply Chain Planning department.

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"Knowledge is in the end based on acknowledgement"
- Ludwig Wittgenstein

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Management summary

This research was performed at the Grolsche Bierbrouwerij Nederland B.V. (Grolsch). At Grolsch, inventories have been increasing systematically, at times beyond the limits of the warehouse. This has resulted in the need for external storage. In 2017, this external storage was used at the harbour in Enschede with costs of approximately 50,000 euros. If nothing is done, these costs are expected to increase to 85,000 euros for 2018. Because transportation to and from the harbour does not add any value, the question has risen if inventory can be reduced to avoid this need. Because research on optimal batchsizes and production frequencies has been done recently, this research has focused primarily on safety stock. The central research problem has therefore been defined as follows:

To analyze past and present production planning decisions and to develop a tool that will determine optimal amounts of safety stock while maintaining target service levels.

Root cause analysis

We have started this research by uncovering the root causes behind the increase in inventory. We have concluded that a shift of sales from low to peak season has caused the most significant increase in inventory in peak season. We have concluded that this root cause cannot be tackled within the scope of this research so our focus has been on another root cause namely increased batch sizes.

Analysis of production planning decisions

From our root cause analysis, we have determined that increased batch sizes have caused 16% of stock increase in the peak period. These increased batch sizes have (partly) been the result of changes in the production plans of line 4 and 7 which the SCP department has made early 2017. We have concluded that this has resulted in savings on ramp up and ramp down time, maintenance and cleaning and changeover time. In short, these benefits weigh up to the increase in inventory.

Classification

Besides the root causes for an increase in inventory, we have also concluded that a faulty classification of inventory has led to inventories being unnecessarily high. This was dealt with by introducing a new kind of classification. We have updated the current classification and added the E class for export products. In addition, we have formulated an additional classification. We have named this additional classification a Supply Chain oriented (SCC) classification. The SCC takes into account six criteria which determine the degree in which production of a product can be scaled up/down or brought forward/postponed. The result is a combined classification of ABCDEX which denotes the commercial importance of a product and 0, 1, 2 which denotes the production flexibility of a product where 0 is flexible and 2 is inflexible. We have then concluded that most safety stock should be attributed to commercially important product as well as inflexible product. In summary, A2 products receive relatively high levels of safety stock whereas C0 products receive little. Using this classification, we were able to place safety stock more accurately. This leads to a decrease in stockouts and obsoletes and thus costs, with the same total inventory.

Safety stock model

Using the classification rules we have proposed a new method of safety stock determination. This method uses the production flexibility as well as the ABCDEX classification of a product to determine a Cycle Service Level (CSL). The CSL denotes the chance of a stockout during the lead time. This CSL is then used to determine the amount of safety stock. The cycle stock follows from a production plan which is inputted into the model. Knowing the cycle- as well as safety stock, we can determine total stock, the expected number of stockouts and obsoletes. Knowing the expected number of stockouts, a stock availability is calculated. Knowing the total inventory, inventory costs can be calculated using a newly proposed formula. This formula includes costs of capital, internal relocations and external inventory costs. For the stockout- and obsolete costs we have also proposed formulas. These formulas are the result of decision trees which note all possible outcomes of an obsolete/stockout occurrence. We have then reduced these decision trees to a percentage of the products profit as final costs. This is 29% for obsolete costs and 35% for stockout costs.

Results

We have shown that we can improve the old way of determining safety stock. With approximately the same inventory and stock availability we can lower yearly total costs by more than 7%. We conclude that current levels of inventory and stock availability are close to optimal however, total costs can still be reduced by shifting safety stock between products. This leads to a decrease in both obsolete costs as well as stockout costs.

In short, we began this research with the aim of reducing inventory, however we conclude that this should not be pursued. Instead, the allocation of inventory to products should be optimized. This also means that harbour storage cannot be avoided but costs for this do not weigh up to the increase in stockout costs when lowering inventory.

Recommendations

We recommend Grolsch to start using the new type of safety stock determination and update it at least twice a year and preferably each quarter. Moreover, for the short term we advise Grolsch to look into the possibilities of dispatching from the harbour to reduce transport costs. Ideally, this is realized in the summer of 2018. For the medium term, we advise to create a business case for RFID tracking to investigate its feasibility. Also, we advise to research possibilities of product postponement to reduce production complexity. Finally, for the long term, we would like to stress the importance to keep up with the market trend towards new, innovative beers and the importance of inter departmental cooperation to reduce forecast bias.

Table of contents

Acknowledgements III
Management summary V
Glossary IX
List of tables and figures XI
1. Introduction 1
1.1. Supply Chain Planning department 1
1.1.1. Tactical planning 1
1.1.2. Scheduling 1
1.1.3. Brewing and filtration 2
1.1.4. Material planning 2
1.2. Finance department 3
1.3. Demand planning department 3
1.4. Warehouse department 3
1.5. Reason behind research 4
1.6. Problem formulation 8
1.7. Research goal and questions 8
1.8. Scope and limitations 9
1.9. Deliverable 9
1.10. Method and planning 10
2. Current situation 13
2.1. Root cause analysis 13
2.1.1. Too much safety stock 14
2.1.2. Increased sales 14
2.1.3. NPD/Delisting 16
2.1.4. Forecast bias 16
2.1.5. Production error 17
2.1.6. Batch size 17
2.1.7. Conclusion 19
2.2. ABC classification 20
2.3. Inventory control policy and safety factor determination 22
2.3.1. Days of cover and safety stock 22
2.3.2. Stock availability and Ready Rate 23
2.3.3. Production batch sizes and frequencies 24
2.4. Conclusion 25
3. Literature review 27
3.1. Inventory classification 27
3.2. Inventory control and cycle stock 28
3.3. Customer service aspects of safety stock 30
3.4. Financial aspects of safety stock 31
3.5. Conclusion 33
4. Determining costs 35
4.1. Inventory costs 35
4.1.1. Holding costs 35
4.1.2. Internal relocations 36
4.1.3. External inventory costs 38
4.1.4. Total inventory costs 38
4.2. Obsolete costs 41
4.3. Stockout costs 43
4.4. Conclusion 46

5. Analysis of production planning decisions ... 47
5.1. Production line 4 ... 48
5.2. Production line 7 ... 49
5.3. Production line 8 ... 50
5.4. Conclusion ... 51
6. Updated classification ... 53
6.1. Updated ABC classification ... 53
6.2. Supply Chain oriented Classification (SCC) ... 54
6.2.1. Vertical flexibility ... 55
6.2.2. Horizontal flexibility ... 57
6.2.3. Flexibility rules ... 58
6.3. Combined classification ... 60
6.4. Conclusion ... 61
7. Model formulation ... 63
7.1. Requirements, constraints and desires. ... 63
7.2. Model specification ... 64
7.3. Model validation ... 65
7.4. Conclusion ... 66
8. Model evaluation ... 67
8.1. Comparison ... 67
8.2. Sensitivity analysis ... 68
8.3. Conclusion ... 69
9. Qualitative recommendations ... 71
9.1. NPD ... 71
9.2. RFID tracking ... 72
9.3. Product postponement ... 72
9.4. Inter departmental cooperation ... 73
9.5. Ship from harbour ... 73
9.6. Conclusions ... 73
10. Conclusion ... 75
10.1. What has caused Grolsch' inventories to rise? ... 75
10.2. What does Grolsch' current ABC inventory classification look like? ... 75
10.3. What inventory control policies are used at Grolsch? ... 75
10.4. How are inventory control parameters determined at Grolsch? ... 75
10.5. How can inventory be classified? ... 76
10.6. Which types of inventory control policies are described in literature ... 76
10.7. What is the relation between safety stock and finance? ... 76
10.8. What is the relation between safety stock and customer service? ... 76
10.9. What requirements and constraints are there for a safety stock model? ... 77
10.10. How can we improve the current inventory control methods? ... 77
10.11. How do we ensure the validity of a new model? ... 77
10.12. What are costs and service levels associated with the new model and how does this score compared to the old methods? 77
10.13. What is the effect of marginally increasing/decreasing target service levels? ... 78
11. Discussion & further research ... 79
12. Literature ... 81
Appendix I. Expected external inventory costs ... A
Appendix II. Analytical Hierarchical Process (AHP) ... B

Glossary

Word or abbreviation	Meaning
CBS	Central Bureau of Statistics
CO	Changeover
COV	Coefficient of variation
CSL	Cycle Service Level
DoC	Days of cover: the amount of forecasted sales that need to be covered by the inventory on hand.
FE	Factory efficiency
FTE	Full Time Equivalent
HL	Hectoliters
KPI	Key Performance Indicator
M&C	Maintenance & Cleaning
ME	Machine efficiency
MTD	Month To Date
MTF	Make To Forecast / Make to Stock
MTO	Make To Order
NPD	New Product Development
Off trade	Groceries, retailers, etc
On trade	Bars, restaurants, etc
Pal	Pallets
SCP	Supply Chain Planning
Shelf life	The time a product is allowed to remain in inventory
SKU	Stock Keeping Unit
SS	Safety Stock
YTD	Year To Date

List of tables and figures

Figure 1.1. Brewing process
Figure 1.2. Warehouse layout
Figure 1.4. External inventory
Figure 1.6. Expected cost reduction
Figure 2.4. Root causes of stock increase in peak season
Figure 2.5. Current inventory classification
Figure 2.6. Production throughput process.
Figure 3.1. Decision tree for evaluating shortage costs (Oral et al, 1972)
Figure 4.1. Correlation between inventory and value of inventory
Figure 4.2. Correlation between inventory and weekly internal relocations
Figure 4.3. QQ plot of total weekly inventory
Figure 4.4. Inventory costs of each root cause
Figure 4.5. Decision tree for obsolete costs
Figure 4.6. Distribution of obsolete costs as percentage of profit
Figure 4.7. Decision tree for stockout costs
Figure 4.8. Distribution of stockout costs as percentage of profit
Figure 5.1. Production plan changes
Figure 6.1. Old and new classification comparison
Figure 6.2. Production flexibility
Figure 6.3. Production flexibility of SKU 91135
Figure 6.4. Distribution of production flexibility over 2017
Figure 7.1. Safety stock model process
Figure 7.2. QQ plot of total weekly demand
Figure 9.1 Growth of breweries in the Netherlands (CBS)

Table 2.1. Current inventory classification
Table 2.2. Pilot/Agile/Scale classification
Table 2.3. Example of opening days of cover during a week
Table 3.1. Inventory control policies
Table 4.1. Chi-sqare test results
Table 4.2. Costs of empty shelf depending on the duration of the stockout
Table 5.1. Production changes analysis line 4
Table 5.2. Production changes analysis line 7
Table 5.3. Production changes analysis line 8
Table 6.1. SKU changes from old to new classification
Table 6.2. Pairwise comparison of supplier criteria
Table 6.3. Results of supplier flexibility analysis
Table 6.4. Pairwise comparison of flexibility criteria
Table 6.5. Results of the MCA for the standard pilsner
Table 6.6. CSL per class for ABC and SCC combined classification
Table 7.1. Chi-sqare test results
Table 7.2. Model output and actual values for 2017
Table 8.1. First model output using new method of safety stock determination
Table 8.1. Improved model output using new method of safety stock determination
Table 8.3. CSL matrix for optimal results
Table 8.4. Model output where stock availability is improved by 0.1% and 0.2% respectively
Table 8.5. Model output where inventory is reduced by 1000 pallets and 2000 pallets respectively

1. Introduction

In the framework of my study Industrial Engineering and Management at the University of Twente, I performed research at the Grolsche Bierbrouwerij Nederland B.V. (Grolsch). Here, I looked into inventory control and safety stock determination. Grolsch is a Dutch brewery that is a subsidiary of Asahi Group Holdings as of 2016. Grolsch not only produces the well-known brand Grolsch, they also produce brands such as Kornuit, De Klok, Amsterdam, Tyskie and Lech. The division of these beers is roughly 60 percent domestic over 40 percent export. Within the domestic market, on trade accounts for roughly 30 percent and 70 percent is off trade. This research is performed at the Supply Chain Planning (SCP) department in cooperation with the Finance, Warehouse and Demand Planning departments over the course of 6 months.

1.1. Supply Chain Planning department

The SCP department is responsible for the tactical planning and scheduling of the production lines and can be further divided into four sub departments.

1.1.1. Tactical planning

Tactical planning is done by two people who create a production plan for the coming 2 to 78 weeks. This plan is completely verified and updated once a week but is also continuously checked to accommodate any changes or uncertainties that have arisen. Naturally, the first weeks are rather fixed and the plan becomes more rough the further along they plan. Input for this plan consists of a demand forecast and production capacity. Besides this, they also need to take into account safety stocks, minimal batch sizes and maximum shelf lifes. Their output consists of a plan that shows how much beer of each Stock Keeping Unit (SKU) needs to be produced per week. This output is the input for the scheduling department.

1.1.2. Scheduling

When it is known how much hectolitres (HL) of each SKU needs to be produced each week, one scheduler creates an operational plan for each week in detail. For this, he takes into account the production capacity, setup- and changeover times, required (preventive) maintenance and production line restrictions. The output is a detailed production plan that shows per day and down to the minute which SKU is produced on which line as well as a filtration plan to facilitate this. This is needed by the next two sub departments

1.1.3. Brewing and filtration

In order to accommodate the production plan on the lines, the person responsible for brewing and filtration needs to ensure that the beer is on time in a Bright Beer (BB) tank from where it can go to the production lines. Before the final beer is in a BB tank, several steps need to be taken that are displayed in Figure 1.1.

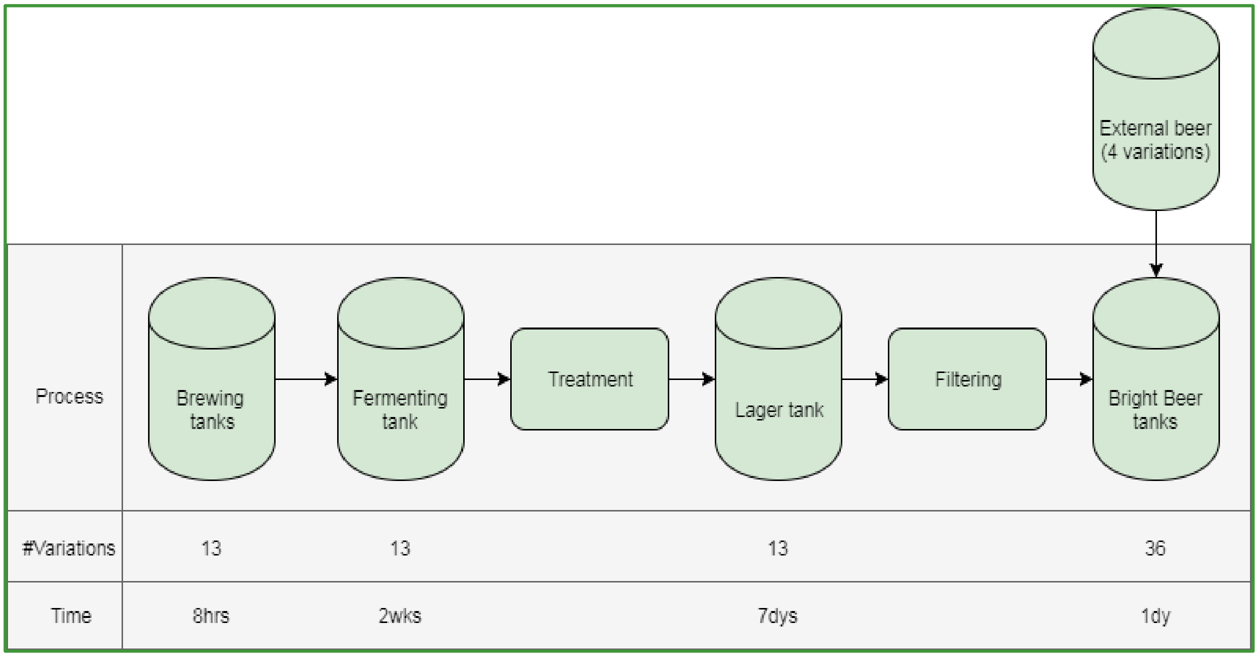

Figure 1.1. Brewing process

As can be seen from the figure, the total time needed to produce beer is approximately 3 weeks.

1.1.4. Material planning

The last piece of the puzzle consists of material planning. Beer can be filled into kegs, bottles or cans. Bottles or cans might need further packaging in the form of plastic, carton or crates. These materials need to be sufficiently available and at the production lines in time. Two persons are responsible for this at the SCP department and they keep tight relations with suppliers to ensure materials get delivered on time and in full.

1.2. Finance department

At Grolsch, a distinction is made between commercial finance and operations finance. Most relevant to this research are the people that make up the operations finance department. They create operational budgets and control whether the current expenses are in line with the budgets of this year. Moreover, they carefully monitor cost drivers and regularly report Key Performance Indicators (KPIs) such as fixed and variable production costs, beer losses, machine and factory efficiency and FTE's to upper management.

1.3. Demand planning department

Within demand planning, two persons are responsible for the creation of a demand forecast. This is done by analysing historical data of the last two to three years. This historical consumer data forms the baseline. Next, this baseline is corrected for changes in weather and, most important, promotions. Whereas a few years ago, a major client of Grolsch had approximately 12 promotions a year, this has increased to 16 per year. Given the fact that promotions are often only communicated a week in advance, the task of creating a reliable forecast has therefore become increasingly difficult.

1.4. Warehouse department

The warehouse department is responsible for storing all goods, both raw materials and finished products, optimally. The warehouse for finished goods can hold a theoretical maximum of 22,376 pallets however, the practical limit lies around 19,500 because some moving space is required too. The complete area for finished goods is displayed in Figure 1.2. The warehouse is split up into a **fast moving** area, **export** area and **domestic** area. Lately, the practical limit of 19,500 pallets is more and more reached and exceeded causing the warehouse to use storage from locations that were originally not designated as finished goods storage, such as the green locations at the far right. Now that these areas begin reaching maximum capacity too, they resort to storage at the harbour in Enschede.

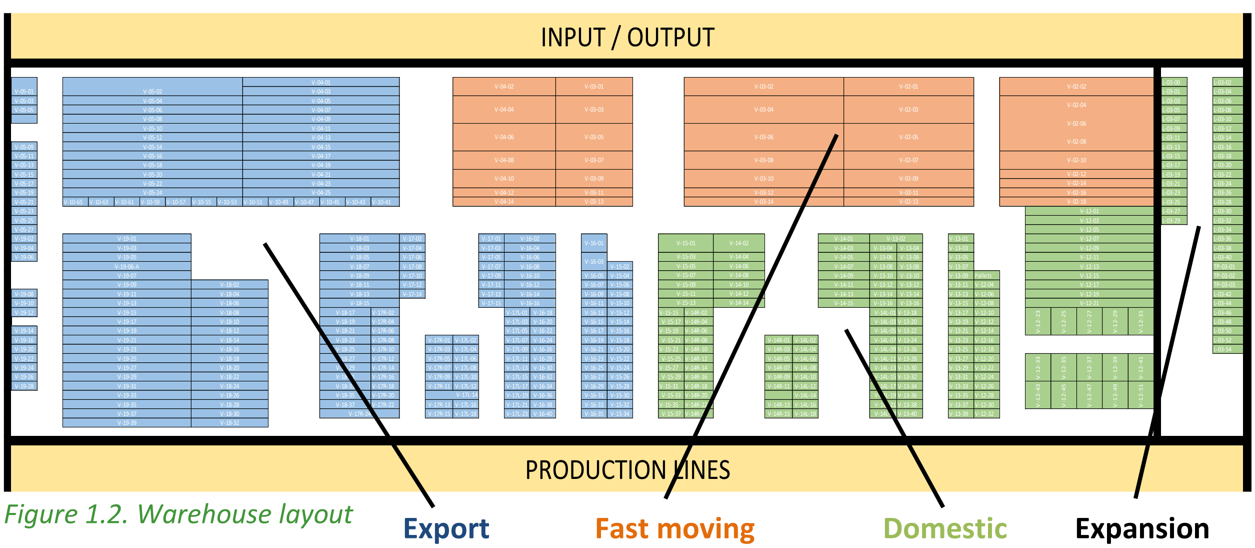

Figure 1.2. Warehouse layout

1.5. Reason behind research

The practical limit for the warehouse at Grolsch lies around 19,500 pallets. In the past year, inventories have risen steadily and often exceeded this limit. On average, in 2017 inventory increased by 18% compared to 2016.

High levels of inventory are costly for several reasons. In Chapter 4 we will go into detail of all the costs which Grolsch faces when inventory rises. For now, we focus on one particular cost factor, namely external inventory costs.

When inventory rises beyond the limits of the warehouse, Grolsch has to resort to storage at the harbour in Enschede. As can be seen from Figure 1.4, ever since March of this year, storage at the harbour has been used and from July onwards this storage has been constantly increasing. Compared to storage at the brewery, harbour storage is inefficient and expensive because, due to technical reasons, goods cannot be transported from the harbour to customers yet but have to go back to the brewery before being dispatched. This is time and costs spent on transportation and handling that do not add any value. Total costs for external storage in the harbour has been approximately 50,000 euros in 2017.

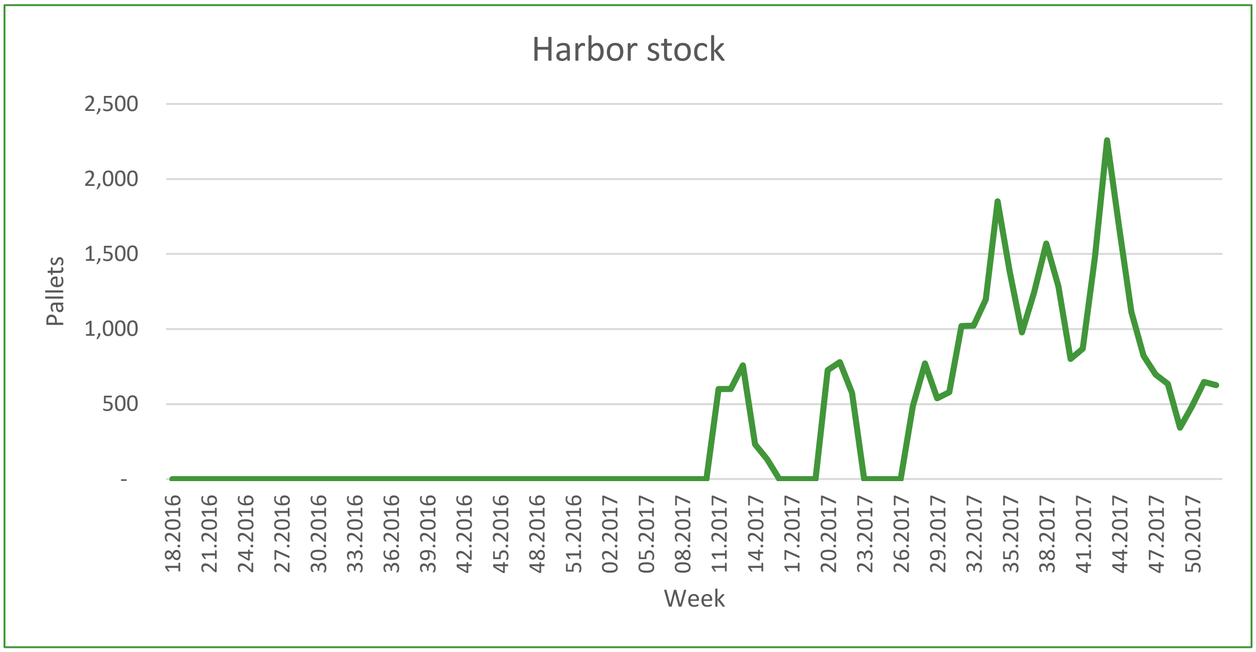

Figure 1.4. External inventory

In order to estimate expected costs for the future we use the sales forecast for 2018. The amount of stock can also be described as the amount of forecasted sales in weeks that are covered with it. This cover varies from roughly 2 weeks up and till 3 weeks. In summer, sales are highest and thus this cover is small whereas in winter this cover is high. Also, in the period leading up to the summer, this cover is relatively high because of strategic stock build up. During peak periods, production capacity is not sufficient to keep up with demand. In order to prevent out of stocks, production is therefore scaled up before peak periods in anticipation of these high levels of sales. This is what is meant with strategic stock build up.

We assume that the number of weeks of forecasted sales that are covered with the inventory is highest at the start and end of the year and lowest in the middle of the year. To calculate this cover per week we choose to create a parabola equation as described in formula 1.1. The reason for choosing this particular equation is that its symmetrical, meaning that the first half of the year, the days of cover decreases similarly as how it increases the second half of the year. This corresponds to the data of the past two years.

$$\#weeks\ of\ forecasted\ sales\ covered\ by\ stock = a(x-26)^2 + b \qquad (1.1)$$

In formula 1.1, x denotes the week of the year, 26 describes week 26; the middle of the year, b will denote the lowest point and a will follow from substituting the highest point. Total forecasted sales for 2018 are similar to 2017. It is not expected to increase or decrease significantly, nor does it show significant shifts in peak or low periods. It is therefore safe to assume that the average inventory will remain the same as well if nothing else is done. If we use a value of 2.2 weeks for b; the minimum and a value of 3 weeks for the maximum, average inventory over 2018 amounts to 18,415 pallets, the same as for 2017.

The equation then becomes the following:

$$\#weeks\ of\ forecasted\ sales\ covered\ by\ stock = 0.00133(x-26)^2 + 2.2 \qquad (1.2)$$

We assume that demand, and therefore stock level, is normally distributed with mean μ and standard deviation σ. From historic data we have also calculated the standard deviation.

Using the formula to calculate expected stockouts during a cycle we can also calculate the expected number of pallets that will exceed 19,500 given the expected stock level. We assume that this is the amount that will be stored in the harbour. Given the expected weekly stock level in the harbour we can calculate the required time and the amount of trucks needed for harbour transport to obtain expected costs. Detailed calculations of this can be found in Appendix I.

The expected total costs for external storage is approximately 85,000 euros for 2018. The reason that expected costs rise in 2018 is due to the fact that external storage was not used in the first 10 weeks of 2017 whereas this will be a realistic possibility in 2018 if no interventions take place.

When we are able to achieve a reduction in inventory, the first few pallets of reduction cause major savings whereas this effect reduces until harbour storage has become unnecessary and costs for external storage become zero. To illustrate this effect, we have made the same calculations for reductions in inventory ranging from 0 to 6,000 pallets. This can be seen in Figure 1.6. At a reduction of 1,000 pallets, total costs amount to approximately 50,000 euros; the same as 2017. With a reduction of 3,000 pallets, overall chance of external storage is less than 5% with only one week which has a chance higher than 15% of harbour storage. We expect that with some slight production changes, harbour storage can be avoided in this week and we therefore expect to be able to eliminate harbour storage completely if we can achieve a reduction of approximately 3,000 pallets.

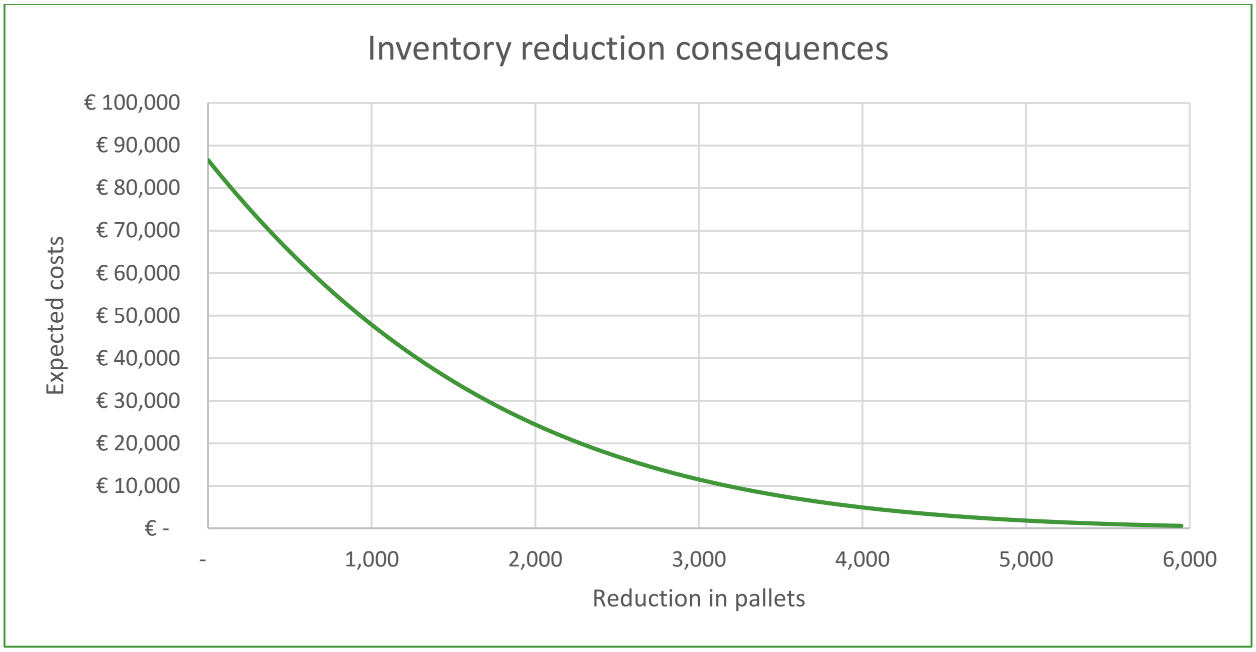

Figure 1.6. Expected cost reduction

In this section, we have shown that if nothing is done, costs are expected to increase by 35,000 euros. If we can achieve a reduction of 1,000 pallets, we can ensure costs will remain the same for 2018. If we can achieve a reduction of 3,000 pallets, we expect harbour storage to become redundant and savings on external inventory costs in 2018 will amount to 85,000 euros. Besides this, other variable costs will decrease as well with every pallet that is reduced. This is further illustrated in Chapter 4.

1.6. Problem formulation

Over the past two years, Grolsch' inventories have risen beyond the limits of the warehouse. When the maximum capacity of the warehouse is reached and exceeded, extra costs have to be made by storing goods in the harbour. Grolsch therefore wishes to optimize these inventories but at the same time service towards its customers and production efficiency may not drop below target levels.

1.7. Research goal and questions

Now that the problem is clearly defined, we can formulate our research goal:

To analyze past and present production planning decisions and to develop a tool that will determine optimal amounts of safety stock while maintaining target service levels.

To achieve this goal, the following research questions are used:

1. Current situation

1.1. What has caused Grolsch' inventories to rise?
1.2. What does Grolsch' current ABC inventory classification look like?
1.3. What inventory control policies are used at Grolsch?
1.4. How are inventory control parameters determined at Grolsch?

2. Literature

2.1. How can inventory be classified?
2.2. Which types of inventory control policies are described in literature
2.3. What is the relation between safety stock and finance?
2.4. What is the relation between safety stock and customer service?

3. Model formulation and development

3.1. What requirements and constraints are there for an inventory model?
3.2. How can we improve the current inventory control methods?
3.3. How do we ensure the validity of a new model?

4. Model implementation and evaluation

4.1. What are costs and service levels associated with the new model and how does this score compared to the old methods?
4.2. What is the effect of marginally increasing/decreasing target service levels?

1.8. Scope and limitations

The amount of inventory that ends up in the warehouse is a factor of many different things. In the scope of this research it is not possible to investigate all these factors. Our research deals with Finished Goods (FG) inventory. The brewing process will not be investigated as it is working around 60% capacity and has seldom been a reason for production issues. Also, storage for raw materials is merely a fraction of the total warehouse and shall therefore not be further looked into. In addition, Grolsch produces both on a Make to Order (MTO) as well as a Make to Forecast (MTF) system. In literature, the MTF system is better known as Make to Stock. Because the demand for MTO products is known and fixed, safety stock is not needed for these products and all MTO products will not be taken into consideration. Next, within the scope of this research, forecasting techniques will not be researched. Forecasting is done by the Demand Planning department that uses sophisticated tools. It will be very time consuming to fully comprehend the techniques used in these tools and it is expected that optimization of them will not lead to significant improvements. Finally, this research will focus mainly on safety stock. Recently, optimal production batches and frequencies (and with it cycle stock) have been researched in depth and will not likely be changed again. We will analyze these decisions with regards to inventory consequences but we will not try to optimize these parameters again.

1.9. Deliverable

The final deliverable to Grolsch will be twofold. First of all, this research will provide a cost analysis of production planning decisions that are made in the past. This research aims to uncover the savings as well as the expenses that have been realized by the decisions of the SCP department.

The second deliverable this research aims to provide, is a prototype tool. In order to help the SCP department with determining optimal amounts of safety stock, a model will be developed. Input for this model will be a demand forecast, service level targets and production parameters. The output will consist of safety stock per SKU, an average stock availability and total costs. When this tool is developed it will be compared to other methods including the one that is currently used. Along with this tool, a sensitivity analysis will be performed that shows the costs of marginally increasing or decreasing the service level.

1.10. Method and planning

As stated before, this research will be conducted over the course of six months. It is therefore vital to plan this time well. In this section you find the method that is used to answer each research question.

1. **Current situation**

1.1. What has caused Grolsch' inventories to rise?

First of all, we will interview warehouse managers and production planners to gain insights into the root causes of Grolsch' rising inventories. The result of this will be a list of possible root causes. Next, we will analyse historical data to determine whether each possible cause has attributed to the rising inventory as well as the degree in which they have done so. This is done in Section 2.1.

1.2. What does Grolsch' current ABC inventory classification look like?

The current ABC classification has been made by the people from the Demand Planning and Sales departments. Many products however, are unclassified. We will therefore uncover which products are classified and why, as well as the grounds for determining a products classification. Moreover, we will calculate, among other things, the percentage of items and revenues belonging to each classification in order to determine whether Grolsch' classification is in line with current practices. This is done in Section 2.2.

1.3. What inventory control policies are used at Grolsch?

The SCP department uses several tools to determine the levels of safety stock for each SKU. We will study the workings of these tools to uncover the underlying calculations and uncover what it does and does not take into account. This is done in Section 2.3.

1.4. How are inventory control parameters determined at Grolsch?

This research question will also be answered by interviewing the people from the SCP department. In the recent past they have performed research on optimal production batches and frequencies and therefore know exactly which parameters have influenced their decisions and how they are determined. This is done in Section 2.3.

2. **Literature**

2.1. How can inventory be classified?

All common ways of inventory classification will be researched in literature and an overview of their advantages and disadvantages will be made. With this we hope to find the method that is most suitable for Grolsch. This is done in Section 3.1 as well as Chapter 6.

2.2. Which types of inventory control policies are described in literature

Similar to inventory classification, many different kinds of inventory control policies exist in literature. We will investigate which policy is most similar to Grolsch' current practices and research its advantages as well as disadvantages. This is done in Section 3.2.

2.3. What is the relation between safety stock and customer service?

By researching literature that determines safety stock based on customer service we hope to find an answer to this question. Together with the previous research question we can then determine the best balance for Grolsch between safety stock from a financial perspective and safety stock from a customer service perspective. This is done in Section 3.3.

2.4. What is the relation between safety stock and finance?

By researching literature that approaches inventory from a financial perspective, we hope to find knowledge to help us in determining optimal amounts of safety stock to create the balance between costs of high levels of inventory and costs of stockouts due to too little inventory. This is done in Section 3.4.

3. Production planning decisions

3.1. What are the effects of the historic production planning decisions?

In the beginning of 2017, production plans for line 4 and 7 have been changed. By comparing data from before and after this implementation we hope to determine the changes in efficiency as well as savings and costs which this has caused. With this analysis, we hope to determine whether or not these production planning decisions have caused savings and were thus justified. This is done in Chapter 5.

4. Model formulation and development

4.1. How can we evaluate different levels of safety stock?

In order to determine the optimal amounts of safety stock, we need ways of evaluating safety stock. We will propose formulas of evaluating inventory, stockouts and obsoletes to be able to calculate total expected costs corresponding to a level of safety stock per product. We will do this by combining methods from literature and input from experienced managers. This is done in Chapter 4.

4.2. What requirements and constraints are there for an inventory model?

By studying the current tools as well as by interviewing all users of the current model, we hope to uncover all requirements it should meet and constraints it should incorporate. By ways of prototyping we can let users try out a new model which will then most likely result in feedback as to what is missing. This is done in Section 7.1.

4.3. How can we improve the current inventory control methods?

When it is known how the current tools work, we will study literature on safety stock determination to determine which method comes closest to practice. We will then analyse alternatives and see what options we have to improve the current inventory model. From each option we will analyse its advantages and disadvantages and finally choose the best among them. This is done in Section 7.2.

4.4. How do we ensure the validity of a new model?

First of all, we will try to enclose the current model in certain rules and inventory control policies to be able to simulate the current way of safety stock determination. This simulation will be run on historical data to check whether the result of the simulation is in line with the actual levels of stock and associated costs. When we have made sure this simulation is a reliable representation of the truth we have ensured the validity of the model. We can then change certain input parameters such as the Days of Cover to create a valid new model. This is done in Section 7.3.

5. Model implementation and evaluation

5.1. What are costs and service levels associated with the new model and how does this score compared to the old methods?

From research question 2.3 and 2.4 we will have equations in determining costs and service levels from certain input parameters. With this, we can easily calculate costs and service levels from both old as well as new models. This is done in Section 8.1.

5.2. What is the effect of marginally increasing/decreasing target service levels?

By performing a sensitivity analysis, we will calculate costs of marginally increasing or decreasing target service levels at various new prototype models. This is done in Section 8.2.

2. Current situation

The following chapter provides information on the current practices at Grolsch. We start in Section 2.1. with a root cause analysis to find out why Grolsch' inventories have risen in comparison to 2016 or why they may be high in general to answer research question 1.1. Next, we research Grolsch' current ABC classification to provide an answer to research question 1.2. Finally, we analyze the current inventory control methods and safety factor determination in Section 2.3 to answer research question 1.3 and 1.4.

2.1. Root cause analysis

As was shown in Chapter 1, average inventory for 2017 was 18,415. The historic deviation of the inventory level is 1,679 pallets which means that there have been peaks where inventory has reached and exceeded the practical limit of 19.500. Not surprisingly, these peaks occurred in peak season. Due to this, external storage in the harbour was needed at that time. Before we can try to reduce Grolsch' inventories it is paramount to uncover what has caused Grolsch' inventories to rise. To do so, we compare the peak season of 2017 with the peak season of 2016. We chose to compare peak season and not the whole year because it is during this time that increased inventory really matters. An increase in inventory at this time means that the limits of the warehouse may be reached and exceeded and external inventory costs are made. We define peak season to range from week 14 up and till week 39. Average inventory in 2016 was 15,254 pallets during this time and in 2017 this was 19,087. This is an increase of 3,833 pallets or 25%. To uncover the root causes behind this increase we have started by interviewing managers of the SCP department, warehouse department and demand planning department. In addition, we have explored possible root causes from literature and practice as well. The possible root causes that have resulted from this can be categorized as follows:

1. Too much cycle stock
    - 1.1. Caused by increased sales
        - 1.1.1. Increased sales overall
        - 1.1.2. Shift of sales from low season to peak season
    - 1.2. Caused by adding new products (NPDs) faster than delisting old ones
    - 1.3. Caused by not selling all which was forecasted
    - 1.4. Caused by producing more than was planned
    - 1.5. Caused by producing in larger batches
2. Too much safety stock
    - 2.1. Caused by a faulty classification

As can be seen, the reasons for rising inventory are all related to cycle stock whereas inventories may also be too high in general due to safety stock. We shall start with the latter.

2.1.1. Too much safety stock

Safety stock is determined by means of a Days of Cover (DoC) criterion. How this works exactly will be explained in Section 2.3. This parameter is partly based on the ABC classification of a product. This classification has not been updated in the last two years. It can therefore not explain a rise in inventory but it may be a reason why inventory is too high in general. With an inaccurate and outdated classification, safety stock is placed at the wrong products. Also, when too many products are marked as important, safety stock is unnecessarily high. Section 2.2. will provide more information on Grolsch' current ABC classification and Chapter 5 will deal with updating Grolsch' classification.

2.1.2. Increased sales

Perhaps the most logical explanation would be an increase in sales. Naturally, when sales systematically increase, stock increases accordingly. We make the distinction between an overall increase in sales and the shift of sales from low to peak season. In the latter case, sales may not have increased throughout the year but it has shifted to peak season.

Overall sales increase

To calculate the effect an overall sales increase has on stock increase, we only look at products that lie in inventory for some time. This excludes tank beer SKUs that are directly filled into a tank. Of these products, 415,500 pallets were sold in 2016 whereas in 2017 this was 410,500. We conclude that overall sales have not increased and is therefore not cause for an increase in inventory.

Increased sales in peak season

The fact that sales of beer are higher in summer than in winter is not surprising and has always been the case. However, in 2017 this difference has become greater.

It is clearly visible that in 2017 the peak in summer is higher and the lowest point in winter is lower compared to 2016. In short, the past year, sales have shifted more towards high season. In fact, this is not an isolated event of the past year but experts within Grolsch confirm that this trend has been happening for a while.

To illustrate this seasonality shift we can calculate that in 2016, 13% of annual sales was sold in the time period ranging from week 1 up and till week 8. 17% was sold in the time period ranging from week 21 up and till week 28. In 2017, this shifted to 11% and 20% respectively.

Naturally, the higher levels of sales in peak season still need to be produced however, there are certain limits to production that are very costly to increase. A solution is therefore to make use of strategic stock build up. This means that before peak periods, production is scaled up in anticipation of these high sales. Due to capacity constraints as well as obsolete risks, production cannot be brought forward too much. It is for these reasons that the trend of greater differences between low and high season causes extra planning challenges and increased levels of stock during high season as well as some weeks in advance.

During this time, inventory may have to be stored in the harbour causing extra costs, whereas in winter, savings are not significant due to the fact that there is always a minimum number of personnel and thus costs. Moreover, when sales shift towards a peak, variation increases which causes the predictability of sales to decrease. This causes a less accurate forecasting which may result in higher safety stocks or more stockouts.

In 2016, on average 7,695 pallets were sold weekly in peak season. In 2017, this was 8,320 pallets. This is an increase of 625 pallets weekly. Using formula 1.2 we can calculate the average number of weeks that are covered by the stock during peak season. This is 2.3 weeks.

Knowing this, we can conclude that the increased sales of 625 pallets weekly during peak season has caused a stock increase of 1,438 pallets. This is 37% of total stock increase.

2.1.3. NPD/Delisting

As is the case with any company manufacturing products, over time some products are added and some products are discontinued. At Grolsch, new products are called New Product Development (NPD) and when discontinuing a product, we speak of delisting a product. Another part of the explanation for a rise in inventory, is that the stock of NPDs grows faster than the stock of delisted products shrinks.

In peak season of 2017, 17 SKUs were newly added to the portfolio and 23 were delisted. However, the stock of the NPDs amounted to 758 pallets weekly whereas the stock of delisted products was only 545 pallets.

This difference of 213 pallets is 6% of total stock increase.

2.1.4. Forecast bias

We define forecast bias to be the actual sales minus the forecasted sales. When sales are higher than forecasted, the warehouse is drained and inventory decreases. Especially when this happens a few weeks in a row, the effect on the warehouse can become quite significant. This has occasionally happened in 2016 whereas in 2017 this has not happened as often.

Unfortunately, no accurate historic forecast can be retrieved for export products but we assume these products have little effect on total forecast bias.

We conclude that in peak season of 2016, sales were systematically under forecasted whereas in 2017 sales were over forecasted. This means that in peak season of 2016, inventories have decreased due to unexpected sales whereas in 2017, products have remained on stock because forecasted sales did not occur.

The difference in forecast bias of 678 pallets is 18% of total stock increase.

2.1.5. Production error

We define production error to be the actual production minus planned production. When production is lower than planned, less products end up on stock and inventory decreases. This is what regularly happened in 2016 whereas it happened less in 2017. Naturally, deviating from a plan is not desirable and can cause, among other negative aspects, a higher risk of stockouts because products are not ready when expected. The fact that this error shows a relative increase is therefore actually a positive thing and should not be reverted. It has however, caused a stock increase of 714 pallets.

We conclude that production error has improved in the past year. This means that in 2017 there was a better adherence to the production plan causing more planned products to actually end up on stock than in 2016. Even though it has caused a stock increase, the fact that this error has improved in 2017 is therefore actually beneficial.

We do note however; it has been cause for a relative stock increase of 714 pallets which is 19% of total stock increase.

2.1.6. Batch size

When batch sizes increase, stock will increase by half of the batch size. For example, when producing 100 pallets per week, stock decreases from 100 to 0 and stock is therefore 50 pallets on average. When doubling this batch size to 200 pallets, average stock will be 100 pallets regardless of production frequency. Early last year, the SCP department has critically reviewed its planning for production lines 4, and 7. This has changed several things in their planning, one of which is an increased average batch size. They have done so in order to achieve higher production efficiencies.

We compare the new and old plans for production lines 4 and 7. Total volume in the old and new situation is equal and it does not include any NPDs or delisted products. Changes between them can therefore fully be attributed to increased batch sizes.

For line 4, batch sizes have increased by 24% on average. This has caused a stock increase of 505 pallets. For line 7, batch sizes have increase by 3% on average. This has caused a stock increase of 118 pallets.

The production plan of line 8 has also been reviewed and changed. The stock increase of this cannot be calculated exactly however, because a precise old and new plan does not exist. We could check the difference in planned batch size but it will also include the effects of sales increase, forecast accuracy and production error.

We conclude that stock increase due to larger batch sizes on line 4 and line 7 is 623 pallets. This corresponds to 16% of total stock increase.

We note that these calculations are based on production plans. The adherence to these plans is not checked within the scope of this research and may be an interesting aspect for further research. We will check however, whether or not the higher production efficiencies were achieved and if they weigh up against this rise in inventory. This is done in Chapter 5.

2.1.7. Conclusion

We have determined the degree in which each root cause has contributed to stock increase during peak season. This is summarized in Figure 2.4.

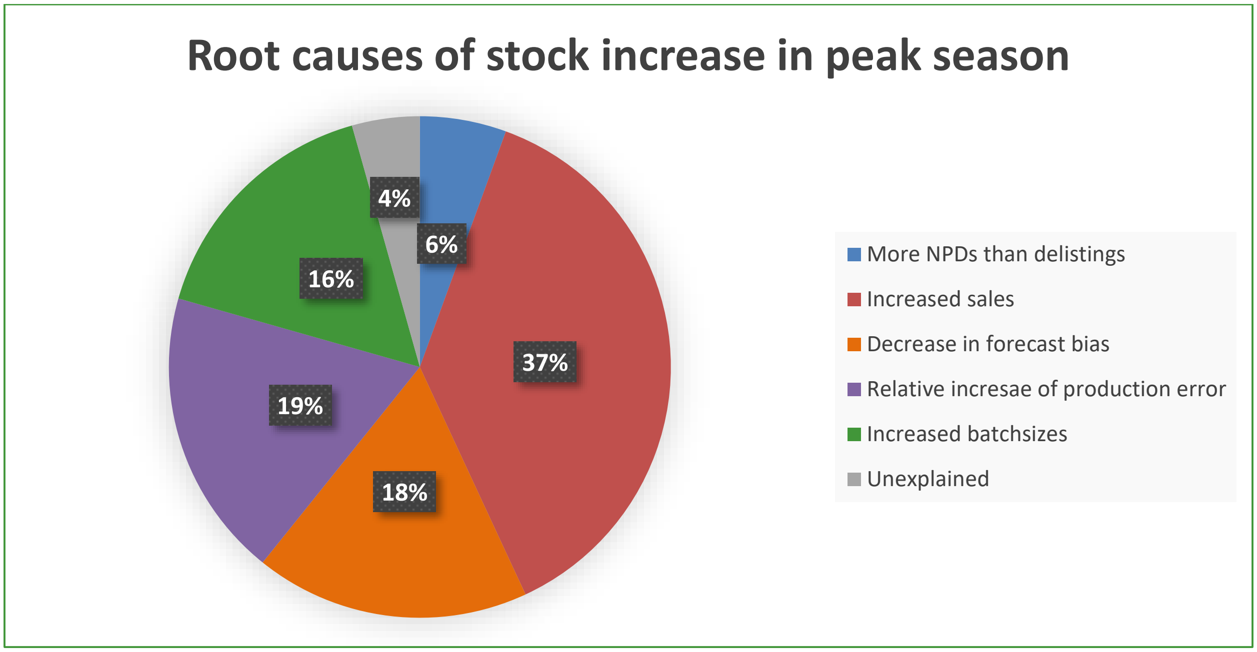

Figure 2.4. Root causes of stock increase in peak season

The smallest root cause is due to the fact that more NPDs have been added to the portfolio than have been removed from it. Today's market is more demanding than ever and asks for high varieties, fast response to changes and being highly innovative. Introducing new products often is therefore key to survival and may be worth some extra inventory. Also, the forecast bias is not shockingly large and will be impossible to reduce completely as we are living in a stochastic world. Our focus will therefore not lie on these two aspects however; we will discuss them a little further in Chapter 9.

Next, we have seen that the reduced production error is in fact favorable and should not be changed.

The increase in sales during peak season has the most significant effect. Unfortunately, we cannot influence when customers buy products (at least not within the scope of this research). This cause will therefore not be a part of further research.

This leaves us with one major root cause that can be influenced, which is batch size. As said before, the SCP has made some major changes to this last year and will therefore not easily revert their decisions. Therefore, we do not go into detail of optimal batch sizes and production frequencies. We will however, check whether the benefits of these changes were achieved and whether or not they weigh up to the increase in inventory. This will be done in Chapter 5.

Besides the root causes for rising inventory we suspect that inventory may be too high in general due to inaccurate classification of SKUs and therefore inaccurate placement of safety stock. This will be further researched in the next section as well as Chapter 6.

2.2. ABC classification

Grolsch uses an ABC classification to distinguish between the importance of its products.
This classification is based on sales data but heavily supplemented by experience and insights from the people of the Demand Planning and Sales departments. It is not precisely known when this classification was completely revised and updated last but it is estimated that this was about two years ago. Contrary to what the name suggests, there are actually five classes in the ABC classification at Grolsch:

A. Products that are most important to Grolsch.
B. Products that are fairly important to Grolsch.
C. Products that are less important to Grolsch.
D. Products that are produced on a MTO basis.
X. Unclassified products.

The division of products in 2017 is shown in Table 2.1.

Classification	#SKUs	Average stock '17 (pal)	Profits '17 (x1000€)
A	13%	39%	53%
B	8%	5%	3%
C	3%	1%	1%
D	8%	3%	2%
X	67%	52%	40%
Total	100%	100%	100%

Table 2.1. Current inventory classification

As can be seen in Table 2.1, 2/3rds of products are unclassified which take up more than half of the warehouse. These unclassified products are mainly (84%) export products and NPDs. Export products are sold by means of a transfer price which means their margin is low. Also, orders for export products arrive some weeks in advance, are therefore more predictable and require less safety stock. It would therefore not be accurate to classify them along with domestic products in the same way. NPDs are new products of which it is not yet known how they should be classified. However, given the fact that the classification has not been updated in a while, it is likely that some of these NPDs have matured and could now be given a classification. This will help in reducing overall inventory because most NPDs receive high levels of safety stock similar to class A products. This is because when introducing new products, stockouts are highly undesirable. It is highly likely, that many of these NPDs have now matured and may not contribute to profits as much to receive an A classification.

As can also be seen in Table 2.1, the majority of classified products are classified as A; most important. This is not in line with theory and the classic 80/20 rule of Pareto. This rule states that class A products should be a select few, usually around 20 percent, that cause 80 percent of the revenues. Instead, there are more A products than B and C combined while their revenues are nowhere close to 80%.

This large number of A products may explain why Grolsch' stock availability (SA) has significantly improved. As can be seen from Figure 2.5, the whimsicality of this KPI has reduced greatly in the last year and the stock availability has not once dropped below 95%.

In fact, the Year to Date (YTD) SA for the domestic market is at 99.4% while the target lies at 98.3%. For the export market this is 98.9% compared to a target of 97.5%.

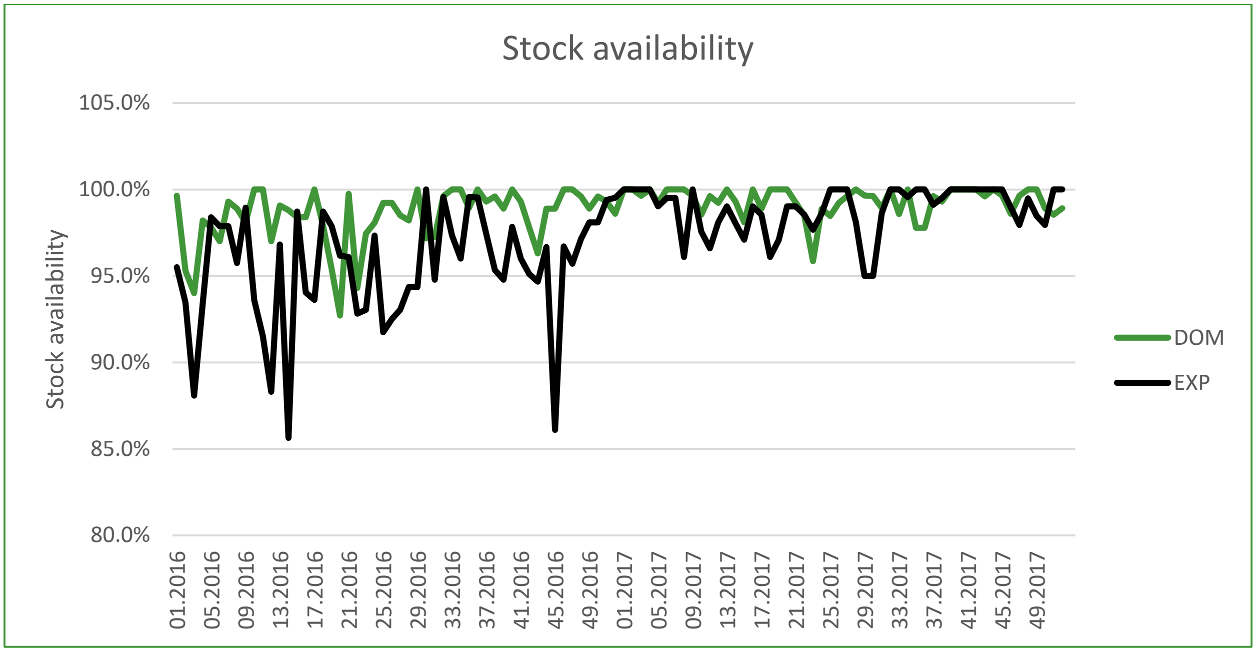

Figure 2.5. Current inventory classification

It can be argued that a significant amount of current class A products may actually be classified as B or C, resulting in less safety stock. This may reduce stock availability but the gap of more than 1% between the actual levels and the targets gives us some latitude. This will be examined in Chapter 6.

Next to the ABC classification, there exists another strategic classification at Grolsch. In this classification products may receive any of the following three classifications:

- Pilot: Products with annual sales less than 1,500HL
- Agile: Products with annual sales more than 1,500HL but less than 10,000HL
- Scale: Products with annual sales over 10,000HL

The division for this classification can be found in Table 2.2.

Classification	#SKUs	Average stock '17 (pal)	Profits '17 (x1000€)
Scale	24%	74%	83%
Agile	40%	22%	16%
Pilot	36%	4%	2%
Total	100%	100%	100%

Table 2.2. Pilot/Agile/Scale classification

This classification is more in line with the theory and the classic 80/20 rule but it is not used to determine safety stock of products so it has no effect on our level of inventory. Moreover, both classification methods are based only on sales and do not take into account production parameters or inventory holding costs.

2.3. Inventory control policy and safety factor determination

As said in Chapter 1, the people from tactical planning create a production plan for the coming 2 to 78 weeks. This plan is completely updated once a week but is regularly changed throughout the week as well to accommodate any unexpected sales or production changes. Production is planned by means of a minimal Days of Cover (DoC) criterion. This parameter describes the minimal number of days of forecasted demand that needs to be covered by on-hand inventory at the end of the week. As soon as inventory is expected to drop below this criterion, production will be planned in that specific week or before so this does not happen. Grolsch therefore uses a Reorder Point (ROP) that is determined by the DoC criterion. Because in theory the inventory is checked once a week, Grolsch' inventory control policy has most similarities to a (R,s,S) system. This means that with an interval of *R*, in our case 1 week, it is checked whether inventory is below a certain point *s*, in our case described by the DoC criterion. If this is the case, an amount will be ordered/produced such that total inventory is raised to a level *S* again. In our case, this level *S* is not composed of a certain amount of pallets but rather determined in such a way that the DoC for that particular product is not excessively large nor is it below the criterion that is set.

In this section we start by explaining the relation between this DoC parameter and safety stock. Subsequently, we explain Grolsch' way of measuring service towards the customer and finally, we discuss production batch sizes and frequencies.

2.3.1. Days of cover and safety stock

Production at Grolsch runs mostly from Monday to Friday. We assume that production is finished at the end of the day and the chance that production is planned on a specific day is equal for every day. In other words, production lead time is uniformly distributed with possible values from 1 to 5 and equal probabilities 0.2. The expected production lead time is simply the average of the possible values; in our case 3 days. The DoC parameter includes this expected production lead time as well as some safety buffer. If a certain product has a minimal DoC of 5 days, it means that at the end of the week, inventory should be sufficient to cover the next 5 working days. 3 of these days is expected production lead time which can be considered as cycle stock. This leaves us with 2 days of safety stock. In other words, safety stock at Grolsch is the DoC minus 3 days, multiplied by the forecasted daily demand. To simplify our calculations slightly, we approximate safety stock using the average weekly demand denoted by μ instead of the forecasted daily demand. Naturally, the DoC criterion is also converted to weeks by dividing it by 7 days. This is shown in formula 2.1.

$$\text{SafetyStock} = \frac{\text{DoC}-3}{7} * \mu \qquad (2.1)$$

DoC: Days of Cover
μ: Weekly demand

The DoC criterion is loosely based on ABC classification but also adjusted by experience and insights. The reason for these adjustments are clear because, as we have seen in the previous section, the ABC classification has not been updated for approximately two years. When new products are introduced they simply receive the same DoC parameter as a similar SKU.

2.3.2. Stock availability and Ready Rate

To measure service towards its customer, Grolsch uses the KPI stock availability. Each morning, the people from the tactical planning department check the amount of products that have sufficient inventory to cover demand for that day. This percentage of total products is listed as the stock availability (SA) for that day. The SA over a certain time period is simply the average SA of all days within that time period. This is similar to what in the literature is described as a Ready Rate. The ready rate describes the fraction of time during which stock is positive. To give an example, suppose opening days of cover for a certain week is as described in Table 2.3.

	Monday	Tuesday	Wednesday	Thursday	Friday	Ready Rate
Product 1	5.51	0.90	2.37	3.71	2.73	80%
Product 2	2.25	6.41	7.64	2.54	9.94	100%
Product 3	9.46	0.53	0.10	5.30	3.85	60%
Product 4	4.57	4.64	3.89	5.50	6.88	100%
Stock Availability	100%	50%	75%	100%	100%	85%

Table 2.3. Example of opening days of cover during a week

When at the beginning of the day, the DoC for a product is smaller than 1 it means the demand for that day cannot be met in full with the on hand inventory. These occasions are marked in red. SA for each day is defined as the number of products with sufficient stock divided by the total number of products. Total SA is the average over all days and amounts to 85%. The Ready Rate lists the fraction of time that each product has sufficient stock. This is determined for each product and the average over all products amounts to 85% as well. Let us denote x_{ij} as follows:

$$x_{ij} = \begin{cases} 0 \text{ if } DoC < 1 \text{ for product } i \text{ on day } j \\ 1 \text{ if } DoC \geq 1 \text{ for product } i \text{ on day } j \end{cases} \tag{2.2}$$

Let the number of products range from i=1 to n and the number of days from j=1 to m. It follows that Stock Availability is defined as follows:

$$\text{SA} = \frac{1}{m} * \sum_{j=1}^{m} \left(\frac{1}{n} * \sum_{i=1}^{n} x_{ij}\right) \tag{2.3}$$

The ready rate is defined as follows:

$$\text{Ready Rate} = \frac{1}{n} * \sum_{i=1}^{n} \left(\frac{1}{m} * \sum_{j=1}^{m} x_{ij}\right) \tag{2.4}$$

It can easily be seen that both equations can be rewritten to the following:

$$\text{Stock availability} = \text{Ready Rate} = \frac{1}{n} * \frac{1}{m} * \sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \tag{2.5}$$

2.3.3. Production batch sizes and frequencies

Production is always done in batches. For each batch there is a certain time period that is needed before everything is running smoothly at full capacity. We define this as the ramp-up. After this time production runs in a so called steady-state. Production is concluded by a ramp-down meaning that production slowly comes to a halt. After this, the next product may be produced so a changeover takes place. This is illustrated in Figure 2.6.

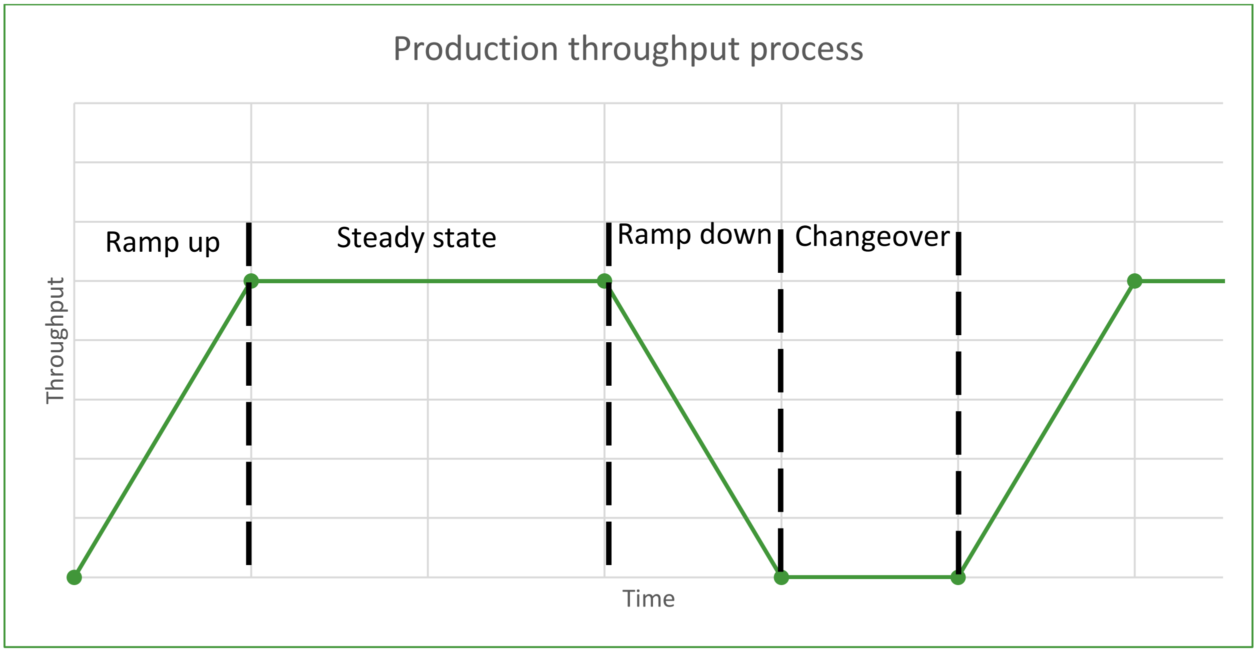

Figure 2.6. Production throughput process.

Machine efficiency is greatest during the steady-state. As was said before, the SCP has recently made changes to production plans for line 4, 7 and 8. The main reasons for doing this is to reduce changeover time and increase the steady-state time causing greater machine efficiency. As has already been proven in Section 2.1, a downside of this is that is has caused inventories for these products to rise. In Chapter 5, we will investigate whether the benefits of efficiency outweigh the drawback of risen inventories.

Finally, at Grolsch, certain products need to be grouped into families for production reasons. Changing one SKUs frequency therefore results in a need to change other SKUs frequencies too. This causes the optimal EOQ calculations to become quite complex. In the past year, extensive research has been done at Grolsch to determine the optimal production frequencies given these restrictions. We therefore assume that the results of this are (near) optimal and treat these frequencies per SKU as fixed input.

2.4. Conclusion

In this chapter it has been shown that the major root cause for Grolsch' risen inventories is increased sales during peak season. Precisely because most inventory costs are incurred during this time, this root cause is quite significant. Unfortunately, we cannot influence when customers buy our product (at least not within the scope of this research) so little can be done about this root cause.

We have also shown that recently it has been decided to increase batch sizes for certain products to achieve greater production efficiencies and that this has caused stock to increase as well. In Chapter 4 we research if these greater efficiencies have indeed been achieved and if they weigh up to the drawback of increased inventory.

In Section 2.2 we have shown that Grolsch' current ABC classification has too many products marked as A. This may be a reason for too high levels of safety stock and therefore we will update this classification in Chapter 6 in order to achieve a reduction in safety stock.

Finally, in Section 2.3 we have seen Grolsch' current inventory policy and way of determining safety stock. Moreover, we have proven that Grolsch' KPI stock availability is similar to what in the literature is described as a Ready Rate.

3. Literature review

Before we can research improvements for Grolsch' inventory classification and safety stock determination, it is vital to comprehend all theory behind it. In this chapter, all relevant theory of inventory classification and control is researched. We start by exploring all kinds of inventory classification methods in Section 3.1 to answer research question 2.1. In Section 3.2 and 3.3 we explore the relation between customer service, finance and safety stock to answer research questions 2.3 and 2.4. Finally, Section 3.4. deals with different kinds of inventory control policies and the corresponding ways of determining safety stock. This will provide an answer for research question 2.2.

3.1. Inventory classification

One commonly used technique for classifying inventory is by means of an ABC analysis. This analysis, sometimes also called Pareto analysis, is partly based on the law of Italian economist Vilfredo Pareto who observed that 20 percent of the Italian population owned 80 percent of the land (Pareto, 1935). For inventory classification, classical ABC analysis says that roughly 20 percent of the products account for 80 percent of the annual dollar usage. The SKUs in this group will get an A classification. The next group, having a B classification, are roughly the next 30 percent of items that account for 15 percent of annual dollar usage. The remainder, 50 percent of products accounting for only 5 percent of annual dollar usage, receive a C classification.

Next, most methods describe a fixed service level per class. Arguments for which class should receive the highest service level vary. Armstrong (1985) argues that A items should have the highest service levels because availability of these items is paramount. For C items he says that stockouts should be risked so that they can earn a reasonable rate of return. On the other hand, Knod and Schonberger (2001) claim that for C items it is not worth the effort to deal with stockouts and they should therefore receive the highest service level. (Teunter, Babai & Syntetos, 2010).

This traditional ABC analysis is only influenced by the costs and sales of the product. Extensions and adaptations of this analysis are widely researched and include other criteria such as revenues or profits (Silver, Pyke & Thomas, 2016), lead time and criticality (Chen, 2008), and availability and commonality (Flores & Whybark, 1987). Moreover, classification need not be restricted to single criteria or three classes (Ultsch, 2002). According to Graham (1987), multiple classes are often used but are usually limited to six at the most. Also, a number of authors argue for the use of multiple criteria and use methodologies such as Weighted Linear Programming (Ramanathan, 2006; Zhou & Fan, 2007), AHP (Flores, Olson & Dorai, 1992) and Fuzzy classification (Chu, Liang & Liao, 2008).

Zhang et al (2001), were among the first to implement inventory classification focused on minimizing overall inventory investment. With their method they were able to achieve a 20 – 25% smaller inventory investment whilst remaining the same customer service levels.

Subsequently, in their paper, Teunter, Babai & Syntetos (2010) propose a new cost criterion for ABC analysis in combination with fixed cycle service levels per class. This method takes criticality into account and they proof that it outperforms traditional ABC analysis as well as the method from Zhang et al.

They rank SKUs by the criterion of $\frac{b*D}{h*Q}$ where b stand for the shortage cost, D describes the demand volume, h the holding cost and Q the order size. Next, they show that class A should be the first 20% of this criterion with the highest service level. Class B should be the next 30% and class C the last 50% with decreasing service levels. Their results show that this method results in almost half the safety stock costs compared to traditional demand value and demand volume criteria. (Teunter, Babai & Syntetos, 2010).

3.2. Inventory control and cycle stock

Inventory control has a direct relation with ordering quantities. Harris (1913) was the first to present a formula for optimal production ordering quantities. This formula is denoted below.

$$Q^* = \sqrt{\frac{2DK}{h}} \quad (3.1)$$

D: Annual demand
K: Fixed costs per order or setup
h: Annual holding costs per unit
Q: Optimal order quantity*

The formula follows logically from the fact that total costs are calculated as follows:

$$TC = \frac{DK}{Q} + \frac{hQ}{2} + PD \quad (3.2)$$

D: Annual demand
K: Fixed costs per order or setup
h: Annual holding costs per unit
P: Purchase price per unit
Q: Ordering quantity
TC: Total costs

Other than ordering this fixed quantity Q, we can also choose to have a variable lot size. In this case, rather than ordering a fixed amount, we order as much as needed to raise inventory to a fixed level. In both cases we again have two choices. We can either review our inventory status periodically or continuously (Silver et al, 2016). This can be summarized by Table 3.1.

	Periodic review	Continuous review
Fixed lot size	(R,s,Q)	(s,Q)
Variable lot size	(R,s,S) or (R,S)	(s,S)

Table 3.1. Inventory control policies

In this table **R** stands for the review period, **s** denotes the reorder point and **S** denotes the Order-up-to level.

A (R,s,Q) policy means inventory is checked with frequency **R** and **Q** is ordered if inventory is below **s**.
A (s,Q) policy means that **Q** is ordered as soon as inventory drops below **s**.
A (R,S) policy means that with frequency **R**, inventory is raised to the level **S**.
A (R,s,S) policy is similar to (R,S) except that inventory may be unchanged during **R** and therefore nothing is ordered.
A (s,S) policy means that as soon as inventory drops below **s**, inventory is raised to the level **S**.

Safety stock is defined as the average inventory level just before a replenishment order arrives. Because of demand and supply uncertainties, this stock is needed to act as a buffer should demand be higher than expected or supply lower than expected. It should be enough to cover these fluctuations until the next replenishment order arrives. This period is defined as the replenishment lead time in case of continuous review and replenishment lead time plus review period for periodic review. Therefore, less safety stock is needed for continuous review compared to periodic.

Safety stock rises both when the target level of having no stockouts increases as well as when variation in demand or lead time increases. The formula for safety stock determination under continuous review is given below.

$$Safety\ Stock = z * \sigma_D * \sqrt{L} \qquad (3.3)$$

z: *Safety factor*
σ_D: *Standard deviation of demand*
L: *Lead time*

When dealing with periodic review we also need to cover the uncertainty during the review period *R* causing the safety stock formula to change to the following equation.

$$Safety\ Stock = z * \sigma_D * \sqrt{L + R} \qquad (3.4)$$

z: *Safety factor*
σ_D: *Standard deviation of demand*
L: *Lead time*
R: *Review period*

While the standard deviation, lead time and review period are fixed input parameters, the safety factor is variable. How it can be determined is explained in the next section.

In Section 2.3. we have seen that the production plan is completely updated once a week but is regularly changed throughout the week as well to accommodate any unexpected sales or production changes. We therefore assume we are dealing with continuous review and will use formula 3.3 to calculate safety stock.

3.3. Customer service aspects of safety stock

When determining safety stock from a customer service approach, we have three common methods. We can specify either a P_1, P_2 or P_3 measure per item or group of items. The P_1 measure describes the Cycle Service Level (CSL), the P_2 measure the Fill rate and the P_3 measure the Ready Rate.

The CSL describes the fraction of replenishment cycles in which a stockout does not occur. It is measured by calculating the chance that demand during a replenishment cycle is less or equal to the mean demand plus the safety stock. For continuous review, formulas are as follows:

$$CSL = P(X_L \leq \mu_L + SS) \tag{3.5}$$

X_L: Demand during the lead time
μ_L: Mean demand during the lead time
L: Lead time
SS: Safety stock
CSL: Cycle Service Level

$$z = \Phi^{-1}(CSL) \tag{3.6}$$

z: Safety factor
CSL: Cycle Service Level

The fill rate describes the percentage of demand that was fulfilled directly from inventory. To compare: when a customer desires 100 products during a replenishment cycle and 80 of them can be delivered from stock, the fill rate is 80% whereas the CSL will be 0% (Silver et al, 2016). In order to find the actual fill rate one uses the following equation:

$$fillrate = 1 - \frac{Expected\ shortage\ at\ the\ end\ of\ a\ replenishment\ cycle}{Expected\ demand\ in\ a\ replenishment\ cycle} \tag{3.7}$$

To find the expected shortage at the end of a replenishment cycle we use the following formula:

$$ESC = \sigma_L * G(z) \tag{3.8}$$

$$G(z) = \varphi(z) - z[1 - \Phi(z)] \tag{3.9}$$

σ_L: Standard deviation of demand during the lead time
z: Safety factor
ESC: Expected shortage at end of replenishment cycle

The ready rate describes the fraction of time during which there is some stock on the shelf. Under Poisson demand, this measure is equal to the Fill Rate (Silver et al, 2016).

3.4. Financial aspects of safety stock

As has been said before, high levels of inventory are costly for several reasons. In literature, the costs of inventory are often expressed as inventory holding costs. This covers all costs such as cost of capital, personnel, inventory losses and handling, that are incurred for holding one unit for a certain time period. Besides this, when dealing with perishable goods there are obsolete costs to consider as well. When products are not sold within their shelf life their value decreases. When this happens they may be sold at a discount or destroyed completely.

To calculate the expected amount of obsoletes we can use the theory from the Newsvendor problem which dates back to the economist Edgeworth from 1888. The model describes the optimal level of inventory where the tradeoff is made between not having enough inventory and thus facing stockouts and having too much and thus facing obsoletes. The amount of obsoletes can be obtained by firstly calculating the expected amount of shortage. This is done using formula 3.8 with the shelf life instead of the lead time.

$$ESC_S = \sigma_S * G(z) \qquad (3.10)$$

σ_S: Standard deviation of demand during the shelf life
z: Safety factor
ESC_S: Expected shortage at end of the shelf life

Knowing the expected lost sales *ESC,* as well as the mean demand μ, the expected amount that will be sold is simply as follows:

$$Expected\ sales\ in\ shelflife = \mu_S - ESC_S \qquad (3.11)$$

μ_S: Mean demand during shelf life
ESC_S: Expected shortage at end of the shelf life

Knowing this, we can calculate the expected leftover inventory with the following formula:

$$Expected\ leftover\ inventory\ (obsoletes) = Q - Exp.sales\ in\ shelflife \qquad (3.12)$$

Q: Average batchsiz

In short, the formula to determine the expected number of obsoletes after the shelf life is as follows:

$$\#Obsoletes = Q - (\mu_S - [\sigma_S * G(z)]\ ) \qquad (3.13)$$

One might think that financially it is best to have as little safety stock as possible. However, this also increases the chance of shortages which results in additional costs. Therefore, in order to determine safety stock from a financial perspective we need to evaluate the costs of stockouts. Silver et al present four possibilities for this ranging from B_1 to B_4.

B_1 specifies a fixed cost per stockout occasion where it does not matter how much of the product is out of stock or how long the product is out of stock. In their paper, Oral et al (1972) come up with a method to determine these costs. They firstly evaluate shortage costs by means of a decision tree that is displayed in Figure 3.1.

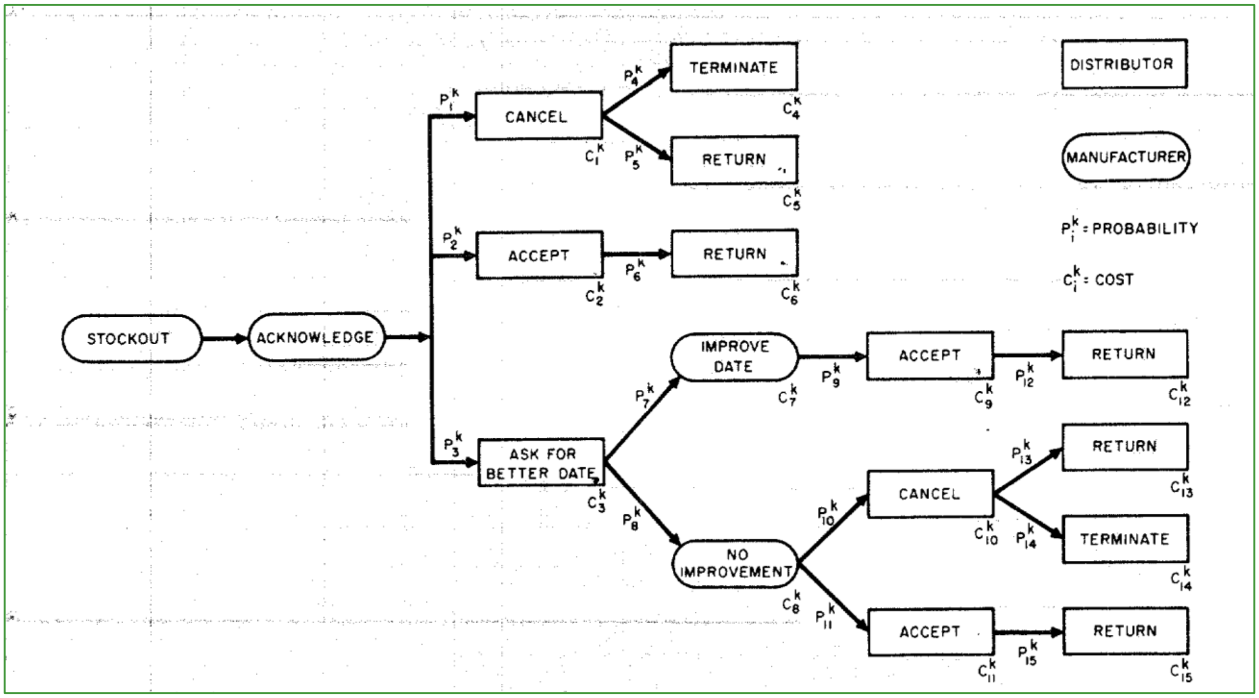

Figure 3.1. Decision tree for evaluating shortage costs (Oral et al, 1972)

This decision tree shows every possible response of a customer to a stockout. Each response *n* has a cost C_n^k and probability P_n^k per item *k* of happening. By summing all probabilities*costs one arrives at a total expected stockout cost for item *k*. It will be very time consuming and costly to repeat this process for every single product which is why Oral et al attempted to find a correlation between the shortage costs and the gross profit per item. This correlation seemed to be clear with a correlation coefficient of 0.942.

More extensive measures consist of using B_2, where one includes the amount that is short, B_3 where one includes the amount as well as the duration during which an item is short and B_4 where a charge is incurred for each customer line item that is backordered.

3.5. Conclusion

This chapter has provided us with the necessary theoretical knowledge to tackle our research problems. Section 3.1. has shown the method of traditional ABC analysis as well as its shortcomings. In addition, it has illustrated a few methods that incorporate more criteria and score better in terms of total inventory investment.

In Section 3.2, we have seen formulas for optimal ordering quantities and the costs associated with this. Several choices for inventory control policies have been provided and for each option, the formula for calculating required amounts of safety stock has been given. We have concluded that for our research formula 3.3 is best suitable where we determine the safety factor k by determining a CSL per class.

In Section 3.3, we have seen three measures of determining safety stock from a customer service perspective. In Section 2.3.2. it was already proven that Grolsch uses the third measure, namely the Ready Rate. Because we assume our demand is Poisson distributed, this measure equals the Fill Rate which we shall use from here on.

Section 3.4. has dealt with the financial aspects of safety stock. It has shown methods to determine safety stock from a financial perspective and it has provided us with a method to evaluate shortage costs.

4. Determining costs

In the chapters after this one, we are going to compare alternatives and analyze trade-offs between stock and production efficiencies. To prevent comparing apples to oranges we need to monetize a couple of things first. We start by creating one formula to calculate total inventory costs. Next, we use a similar method as was described in Section 3.3 to determine obsolete as well as stockout costs.

4.1. Inventory costs

Inventory costs are a factor of many different costs. We make the distinction between fixed costs, which will remain the same in the near future, and variable costs which will change with every pallet of inventory more or less. For our research we only look at variable inventory costs. At Grolsch, we have identified several variable cost factors.

4.1.1. Holding costs

First of all, there is a cost of capital. The value of the inventory is invested in the stored goods that lie in the warehouse and cannot be invested otherwise. Naturally, the value of inventory is heavily correlated by the amount of inventory as can be seen in Figure 4.1.

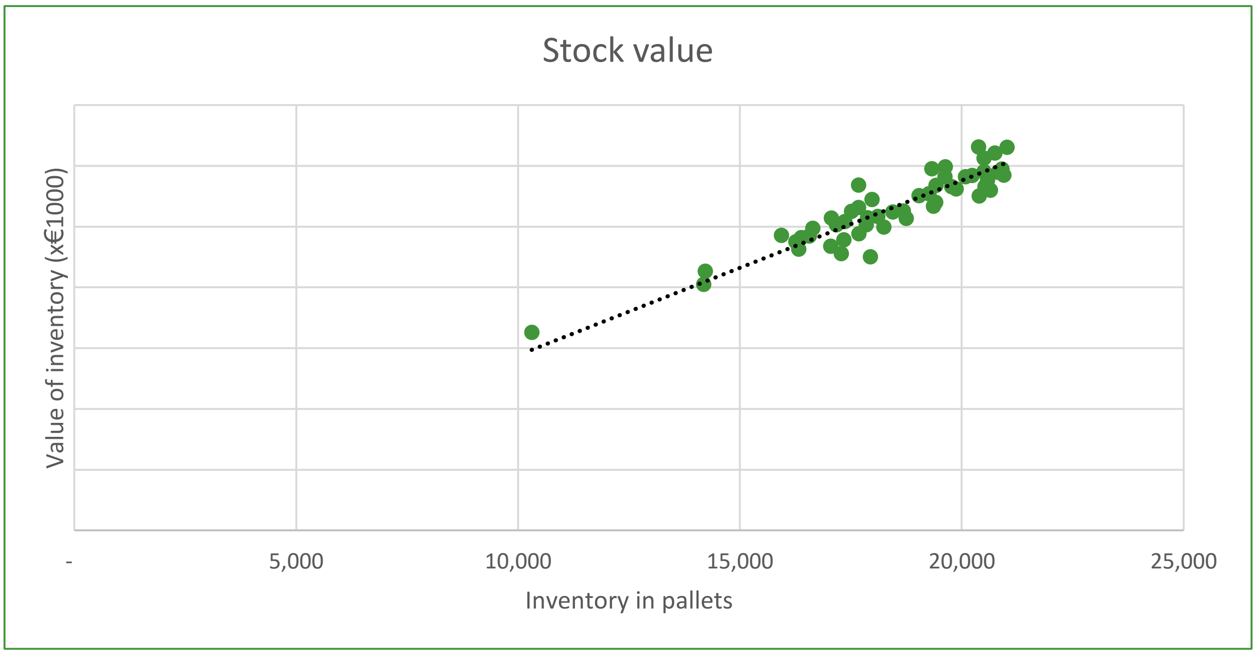

Figure 4.1. Correlation between inventory and value of inventory

The weekly costs of capital can be calculated as follows:

$$\text{Weekly costs of Capital} = CC_w * \text{CP} * \text{I} \qquad (4.1)$$

CC_w: WACC weekly rate
CP: Cost of one pallet
I: Weekly inventory level in pallets

4.1.2. Internal relocations

Many employees are hired on a permanent basis and can therefore be considered as fixed costs. However, it is mainly the forklift truck (FLT) drivers that are hired with a temporary or flex contract. One can imagine that in peak periods, transportation needs are greater and extra FLT drivers will have to be hired whereas in winter, inventory is low and less FLT drivers are needed. As said before, forecasted sales are similar in 2018 so production output will be similar as well. FLT drivers for this will therefore not be needed less in 2018. However, not only do the number of FLT drivers depend on sales and production, there is another interesting activity that takes up more and more of their time when inventory rises. This is internal relocations. The fuller the warehouse gets, the more difficult it is to find a suitable location for a pallet coming out of production. For example, the fast moving area may still have some space but the domestic area is full. When a slow moving domestic product comes out of production, a faster moving item will first have to be relocated from the domestic to the fast moving area before the pallet coming out of production can be placed in the domestic area. These internal relocations correlate with total inventory levels as can be seen in Figure 4.2.

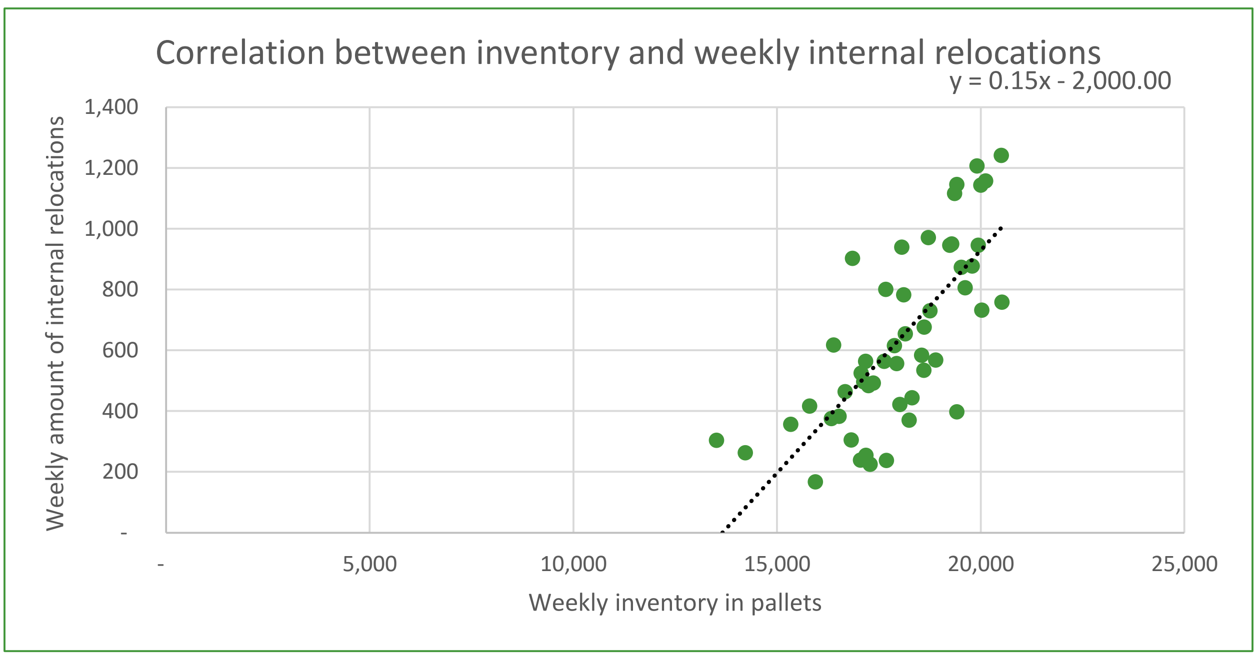

Figure 4.2. Correlation between inventory and weekly internal relocations

We assume that internal relocations up and till 500 per week can be done by the fixed personnel at no additional costs. This corresponds to an inventory level of 16,667 pallets. After this, personnel costs will increase as follows:

$$\text{Weekly personnel costs} = (aI - b) * T_p * R \qquad if\ I > 16.667 \qquad (4.2)$$

a: *Slope coefficient, in this case 0,15 (see trend line equation)*

b: *Constant, in this case 2000 (see trend line equation)*

I: *Weekly inventory in pallets*

T_p: *Time in hours to relocate one pallet*

R: *Hourly rate of personnel*

4.1.3. External inventory costs

The last variable cost factor consists of external inventory costs. When inventory rises beyond the limits of the warehouse, Grolsch has to resort to storage at the harbour in Enschede. In Section 1.5 we have shown that expected costs for this in 2018 are 85.000 euros. The formula to calculate these costs per pallets is shown in formula 4.3.

$$\text{Ext. inv. costs per pallet} = \frac{T_t * R + C_o + (1-E)C_o}{P_t} \quad (4.3)$$

T_t: *Time it takes for a trip to the harbour and back*
R: *Hourly rate of personnel*
C_o: *Costs for a one-way trip*
E: *Transportation efficiency*
P_t: *Number of pallets per truck*

The holding costs in the harbour and at the brewery are equal. This formula only describes the time and transport costs of bringing one pallet to the harbour and is therefore independent of the time which pallets spend in the harbour.

This rate should be multiplied by the expected number of pallets that need to be transported to the harbour. This equals the expected number of pallets to exceed 19,500 (the practical limit of the warehouse). To calculate this expected harbour storage, we use the following formulas.

$$Exp. harbor\ storage\ H = \sigma_I * G(z) \quad (4.4)$$

$$G(z) = \varphi(z) - z[1 - \Phi(\mathrm{z})] \quad (4.5)$$

$$z = \left(\frac{19{,}500 - \mu_I}{\sigma_I}\right) \quad (4.6)$$

μ_I: *Mean inventory level in pallets*
σI: *Standard deviation of inventory level (historically 1,679)*

These formulas may only be used if inventory is normally distributed. In the next section we prove that this is indeed the case.

4.1.4. Total inventory costs

As was concluded in the previous section, we first need to ensure our inventory is normally distributed.

To do so, we create a QQ plot and perform a Chi-square test. The QQ plot is displayed in Figure 4.3 and the results of the Chi-square test are displayed in Table 4.1

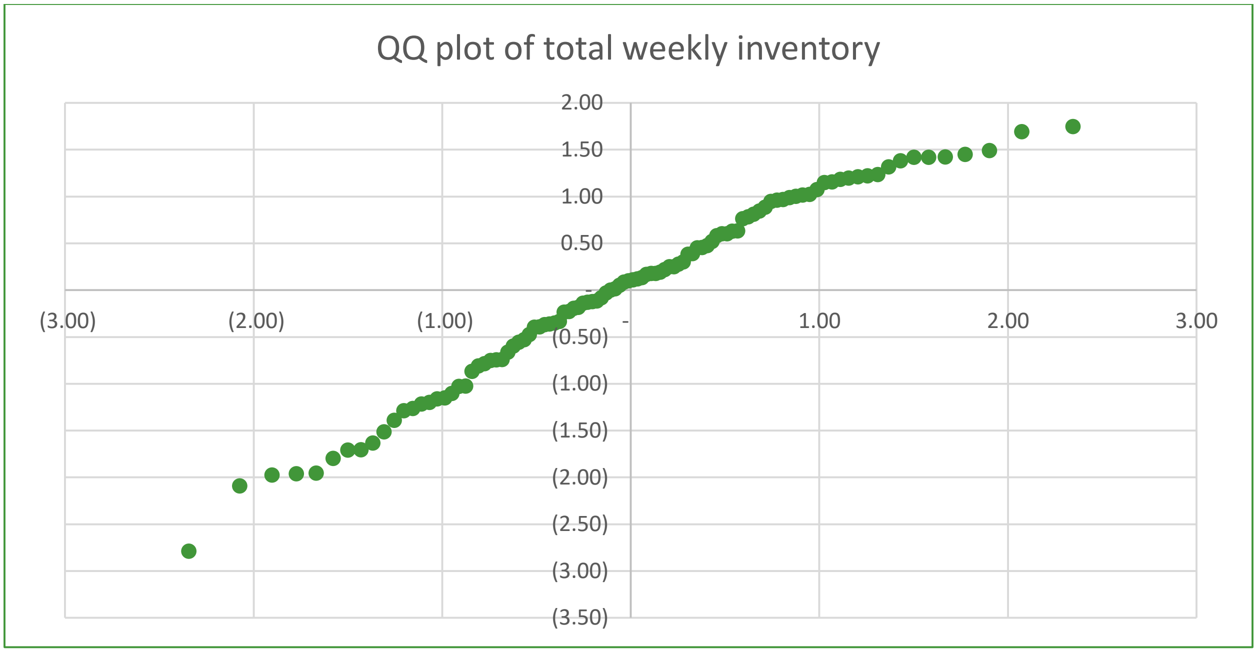

Figure 4.3. QQ plot of total weekly inventory

Chi-square test	
df	14
Mean	118,410
st.dev.	15,455
Chi sq.	0.69
alpha	1.0%
Critical value	4.66

Table 4.1. Chi-sqare test results

Since our test statistic is 0.69 which is smaller than the critical value of 4.66 we can assume our inventory is normally distributed and formulas 4.4 up and till 4.6 will hold.

Total inventory cost then follows from the sum of formulas 4.1 to 4.3 where formula 4.3 is multiplied by the expected harbour storage *H*:

$$\text{Weekly costs of Capital} = CC_w * \text{CP} * \text{I} \tag{4.1}$$

$$\text{Weekly personnel costs} = \begin{cases} 0 \; if \; I < 16{,}667 \\ (aI - b) * T_p * R \; otherwise \end{cases} \tag{4.2}$$

$$\text{Ext. inv. costs per pallet} = H * \frac{T_t * R + C_o + (1-E)C_o}{P_t} \tag{4.3}$$

The sum of these three formulas equate to the following:

$$C_I = (CC_w * \text{CP} * \text{I}) + \begin{cases} 0 \; if \; I < 16{,}667 \\ (aI - b) * T_p * R \; otherwise \end{cases} + (H * \frac{T_t * R + C_o + (1-E)C_o}{P_t}) \tag{4.7}$$

CC_w: *WACC weekly rate*
CP: *Cost of one pallet*
I: *Weekly inventory level*
a: *Slope coefficient*
b: *Constant*
T_p: *Time in hours to relocate one pallet*
R: *Hourly rate of personnel*
T_t: *Time it takes for a trip to the harbour and back*
C_o: *Costs for a one-way trip*
E: *Transportation efficiency*
P_t: *Number of pallets per truck*
H: *Expected harbour storage*
C_i: *Total weekly inventory costs*

From here onwards, formula 4.7 will be used to assess changes in inventory.

Knowing the total inventory costs for 2017, we can now determine the costs of each root cause. We do this simply by multiplying the percentage of each root cause by the total yearly costs.

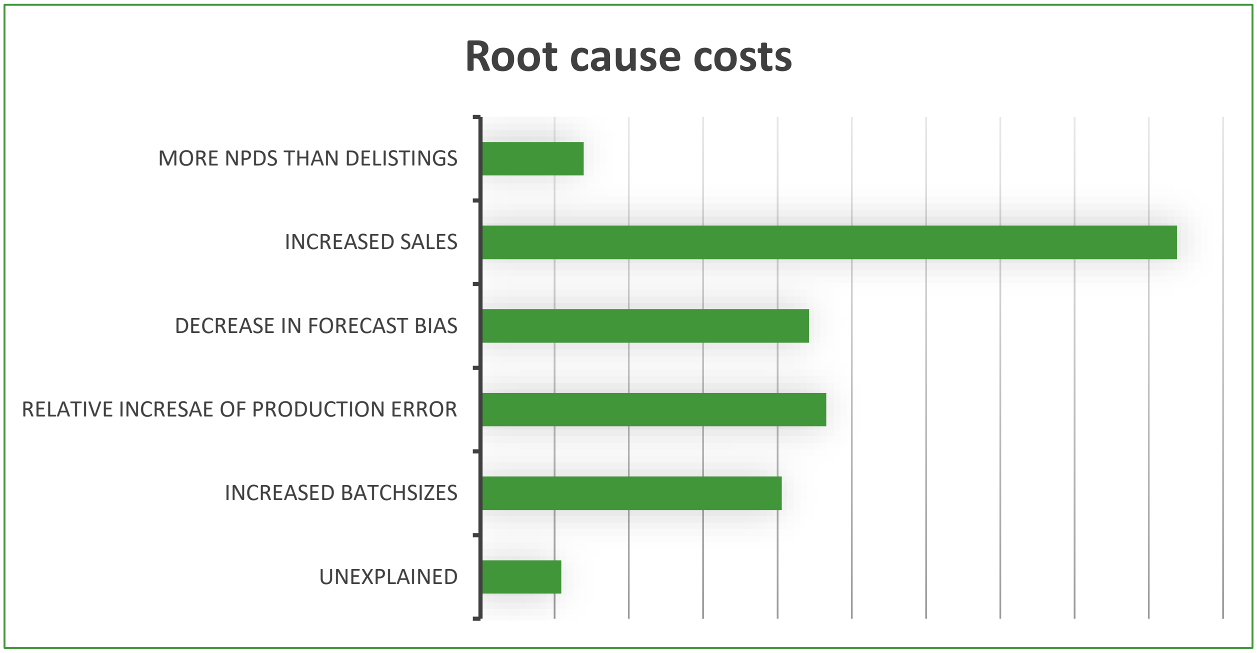

Figure 4.4. Inventory costs of each root cause

4.2. Obsolete costs

When a product passes its shelf life it does not necessarily mean it is destroyed. The shelf life at Grolsch is 30 percent of the due date of the product. This ensure the customer always has a minimal of 70% of the due date left. This rule is set by Grolsch itself and breaking it has no legal consequences. However, Grolsch' customers are accustomed to this rule and may not accept a product with less than 70 percent due date remaining. We make the distinction between products that have an age between 30% and 60% of the due date and products over 60% due date. We assume that the former group can always be sold however a discount may need to be given. When a product exceeds 60% due date, there is a chance that it needs to be destroyed. Costs for this are 45 euros per pallet. Besides this, the cost price of the product should also be taken into account.

In summary, we can create the following decision tree where the light green squares denote the probabilities (left) and costs (right):

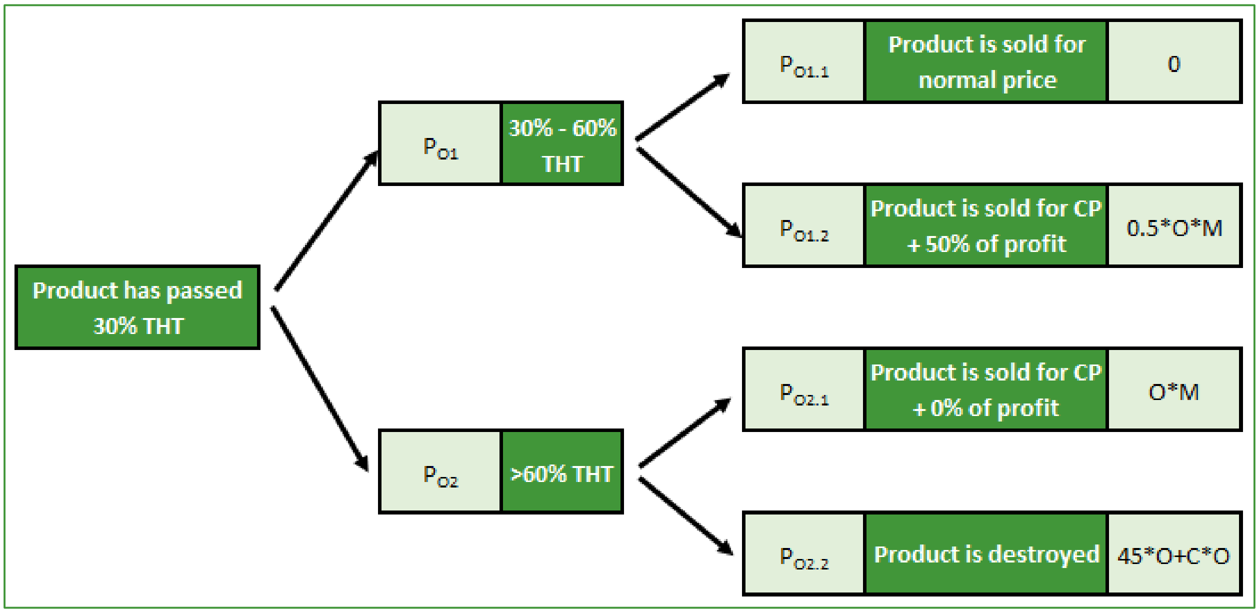

Figure 4.5. Decision tree for obsolete costs

In Figure 4.5, *O* denotes the amount of obsoletes in pallets, *M* the margin per pallet and *C* the cost price per pallet. The probabilities, denoted by P, are not known exactly. We have therefore asked the opinion of two experts on this subject to estimate these. Both the expert in demand planning as well as the SCP expert agree that these probabilities equate to a 80:20 chance as follows:

- P_{O1}: 80%
  - $P_{O1.1}$: 80%
  - $P_{O1.2}$: 20%
- P_{O2}: 20%
  - $P_{O2.1}$: 80%
  - $P_{O2.2}$: 20%

It would be preferable if these probabilities could be based on actual data. Unfortunately, this data has not been recorded. For now we will therefore use the estimation of the experts and advice Grolsch to start recording this data as soon as possible.

When multiplying probabilities and costs we can create the following formula:

$$C_o = (0.24 * M + 0.04 * C + 1.8) * O \qquad (4.8)$$

O: *Amount of obsoletes in pallets*
M: *Margin on the pallet*
C: *Cost price of the pallet*
C_o: *Cost of obsolete per pallet*

When applying this formula to all products it appears that the vast majority of products have obsolete costs equal to 29% of their profit as can be seen by Figure 4.6.

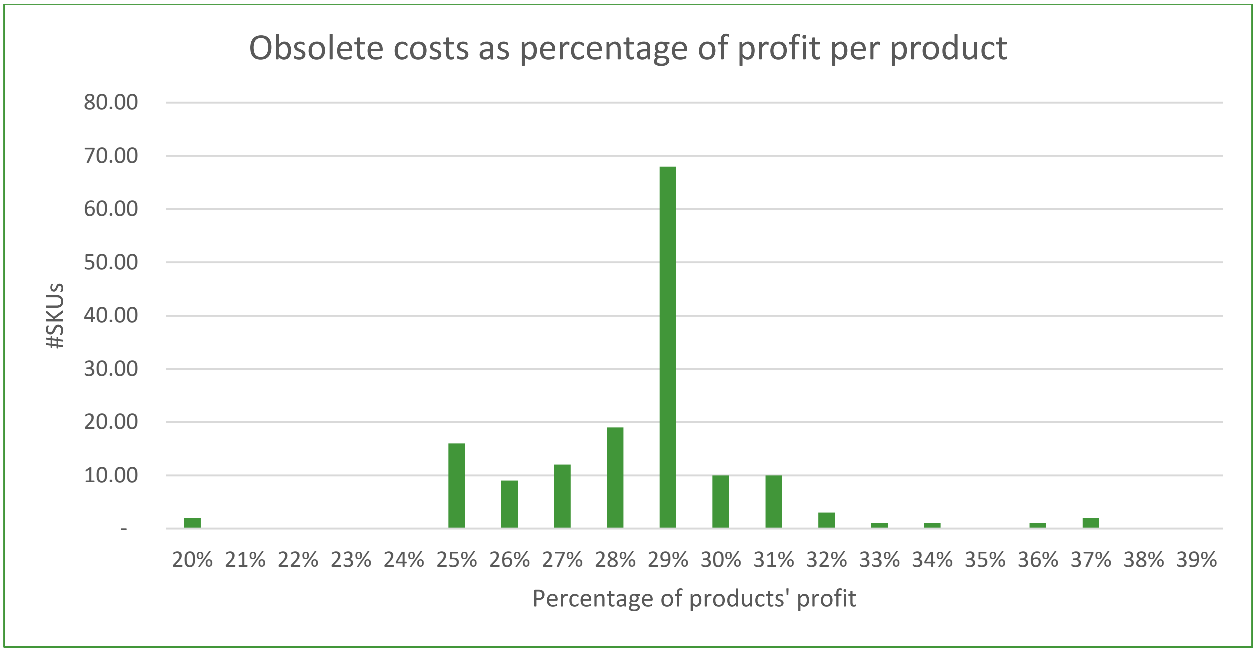

Figure 4.6. Distribution of obsolete costs as percentage of profit

For simplicity reasons we therefore use 29% of the products profit as the cost per obsolete.

4.3. Stockout costs

Costs which a company faces when a stockout occurs varies greatly. Besides possible costs such as fines and extra delivery costs, intangible costs such as reputation damage and customer loss may occur as well. In order to estimate costs for a stockout we follow a similar approach as the article by Oral et al (1972) which was explained in Chapter 3. We use the B_2 stockout costs measure which does take into account the amount of stockout but does not take into account the duration of the stockout.

When a stockout occurs, extra work takes places in all cases. Several departments as well as the customer need to be notified that delivery will not be possible. On average, this extra work takes up one hour per order.

Next, there are three possibilities. In most cases the SKU can be replaced with a similar SKU and the original SKU is simply shipped with the next delivery. In this case, no other transportation costs are incurred.

It may also be that the item is critical and a rush delivery needs to take place as soon as the product is available again.

In the unlikely event that a customer cancels the entire delivery no transportation costs are incurred.

For each of these three options it may be that the shelves at Grolsch' customer are empty which may lead to lost sales. If the delivery is cancelled, chances of this are 100% because the product will never make it to the shelf. Costs in this case is the amount of stockout multiplied by the profit that would have been made on the product.

The chances and costs of an empty shelf when the product is delivered later is slightly harder to determine. Because the customer always has some safety stock as well, deliveries that are postponed by a short period of time will not lead to empty shelves. On average, customers of Grolsch have one day of safety stock so stockouts that last for a day or less do not lead to empty shelves. If the delivery is postponed by more than a day we expect that this will lead to lost sales for the duration of the stockout minus 1 day (the safety stock of the customer).

When a customer faces a stockout, it does not necessarily mean all potential sales of this customer are immediately lost. The customer may simply wait until the product is available again and make its purchase. The question then becomes twofold: What percentage of customers facing a stockout are willing to wait and for how long are they willing to wait on average? It is highly difficult to answer this question accurately and we therefore rely on the opinion of experts again. Their best estimate is that half of the customers which face a stockout are willing to wait but only for a maximum of one day. Summarized, this means that a stockout of one day or less has no costs. A stockout which lasts between 1 and 2 days has costs equal to 50% of the profit on the amount of stockout. A stockout which lasts for more than 2 days has 100% lost sales for the duration of the stockout minus 2 days and 50% lost sales on the last day.

Historically, the number of days of a stockout is distributed as is shown in the first three columns of Table 4.2. Costs for each duration is shown in columns 4 and 5 where *M* denotes the margin per pallet and *S* the amount of stockout in pallets.

#Days	Occurence	Costs	Costs*Probability
0-1	52%	0	0
1-2	27%	0.5MS	0.135MS
2-3	8%	1MS+0.5MS	0.120MS
3-4	6%	2MS+0.5MS	0.150MS
4-5	6%	3MS+0.5MS	0.210MS
Total	**100%**		**0.615MS**

Table 4.2. Costs of empty shelf depending on the duration of the stockout

With this information we can create a decision tree which is shown in Figure 4.7. Again, the light green squares on the left denote probabilities and the light green squares on the right denote the costs for each scenario.

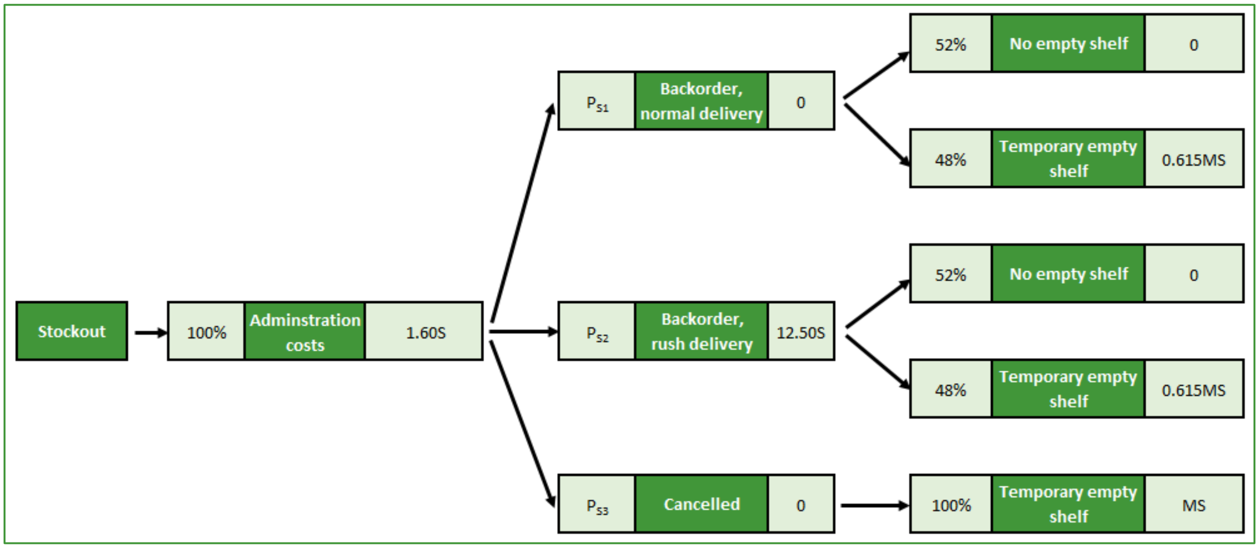

Figure 4.7. Decision tree for stockout costs

We have asked the same experts to give their best estimate of the probabilities and results are as follows:

- P_{S1}: 77%
- P_{S2}: 20%
- P_{S2}: 3%

When multiplying these probabilities and costs we can create the following formula:

$$C_s = (4.1 + 0.317 * M) * S \tag{4.9}$$

M: Margin on the pallet
C_S: Cost of stockout per pallet

This formula does not include any intangible costs such as reputation damage as this cannot be monetized within the scope of this research. We do note that actual stockout costs may be higher due to this.

We apply this formula on all products and create the following distribution

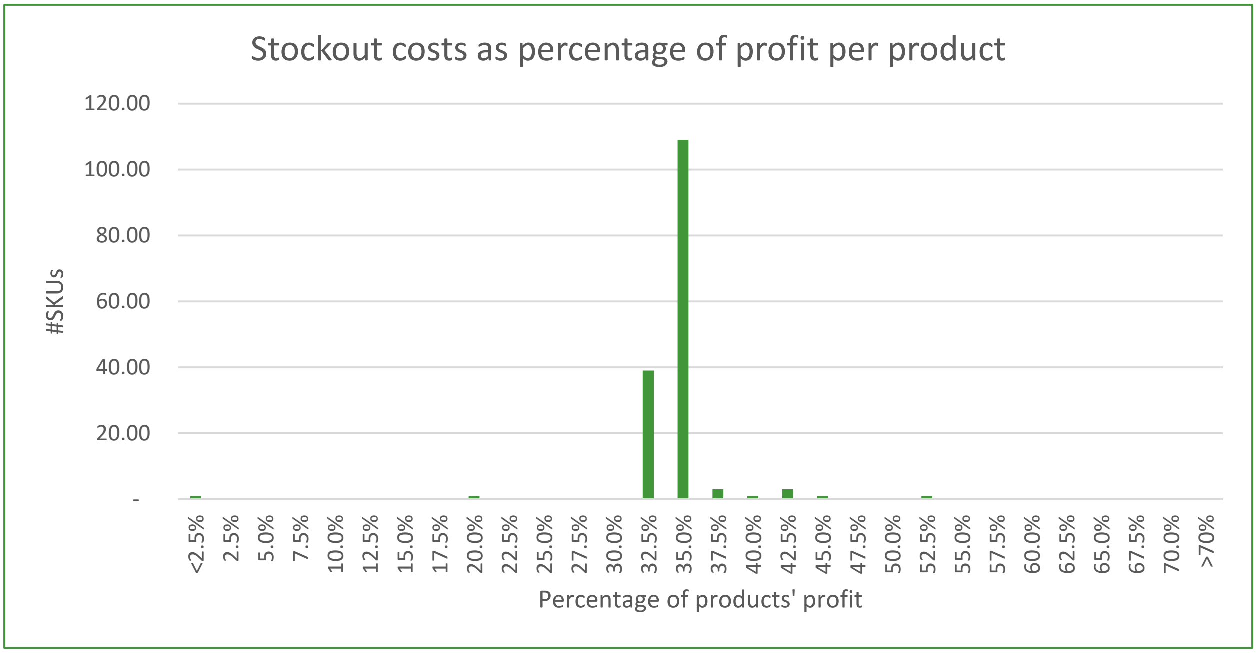

Figure 4.8. Distribution of stockout costs as percentage of profit

As can be seen in Figure 4.8, stockout costs can be simplified as 35% of the products profit.

Besides these tangible costs for administration, transportation and lost sales, there are a number of intangible costs. When an empty shelf occurs, customers may switch to a competitor and damage is done to the reputation of Grolsch. Moreover, customers may fine Grolsch when stockouts occur too often and service level agreements are not met. These fines are not included in this calculation.

4.4. Conclusion

In this chapter we have determined formulas to evaluate our safety stock model. In Section 4.1 we have shown that inventory at Grolsch is normally distributed and inventory costs can be calculated using formula 4.7.

In Section 4.2 we have created a decision tree to determine the expected costs for obsoletes. We have concluded that obsolete costs can be approximated as 29% of the products' profit.

In Section 4.3 we have created a slightly more extensive decision tree to determine the expected costs when facing a stockout. We have concluded that stockout costs can be approximated as 35% of the products' profit.

5. Analysis of production planning decisions

As has been explained in Section 2, last year the SCP department has made major changes to the production plans of lines 4, 7 and 8. In this chapter we analyze these changes to find out whether the benefits of this outweigh the rise in inventory. Simplified, Figure 5.1 shows what the SCP department has tried to do. As is clear from the figure, the major consequence of the production planning changes are larger batch sizes.

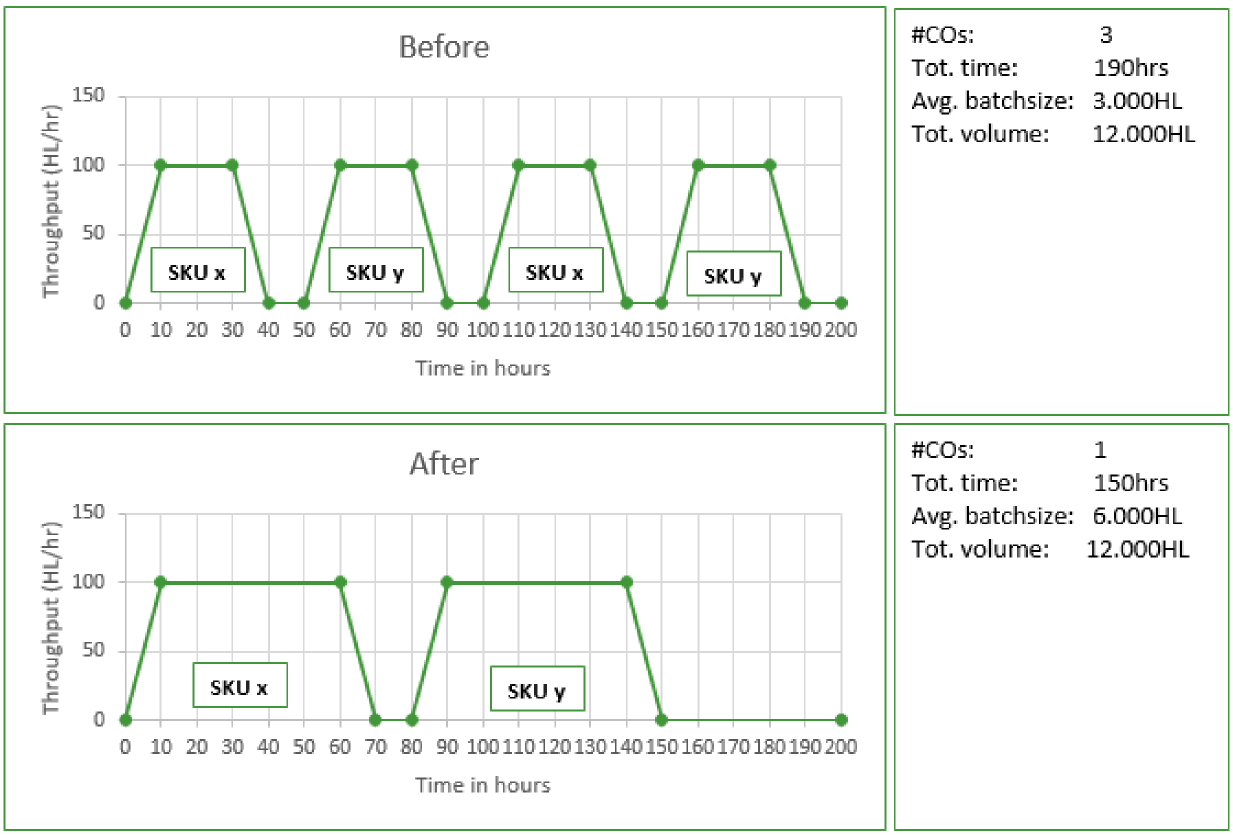

Figure 5.1. Production plan changes

We identify three major benefits. First of all, due to smarter planning, the number of changeovers decreases. Second, due to larger batch sizes, less batches are needed and thus total ramp up and ramp down time decreases. Lastly, because of the two previous benefits, the same amount can be produced in less time. This results in less weeks of production throughout the year. Every time a line is not up and running, we save costs of maintenance and cleaning (M&C). The one drawback of these changes is increased cycle stock due to greater batch sizes.

In the next sections we perform a detailed analysis of the benefits and drawback per line.

5.1. Production line 4

The average batch size of line 4 has increased with 35 pallets. Multiplied by 12 products this is an increase of 420 pallets. After correction for the increase in sales, this has caused a stock increase of 115 pallets. We use formula 4.7 to calculate total costs using the average of 18,415 pallets and subsequently an average of 18,300 pallets (18,415 - 115). The difference shows us the costs of the extra 115 pallets.

The weekly extra costs amount to 246 euros which is a yearly extra cost of 12.628 euros.

Total changeover time for 2016 was 107 hours with 19 different products being produced. We make the assumption that changeover time is correlated with the number of products being produced because changeovers are always needed when switching to another product but may not be needed when switching to another batch. Since the number of products in 2017 was 16 (84% of 2016), we expect total changeover time to be 90 hours (0.84*107). In fact, in 2017, total changeover time has been 86 hours. We therefore conclude that due to the SCP decisions, total changeover time has reduced with 4 hours. Hourly production costs for line 4 amount to 1,065 euros. The benefit of reduced changeover time therefore amounts to yearly savings of 3,849 euros.

In 2016, line 4 produced a total of 274 batches. Because total production volume decreased from 241,972HL to 226,807HL (94%) we would expect that in 2017 257 batches (0.94*274) were needed. In fact, a total of 253 batches were produced. On average, 0.21 hours are spent on ramp up and ramp down time for line 4. This means that a decrease of 4 batches saves 0.8 hours of ramp up and ramp down time. Again we multiply this by the production costs of line 4 to achieve savings of 856 euros.

Due to the decrease in changeover time and number of batches, it may be that less production weeks are needed within a year. In 2016, line 4 was up and running for a total of 4,022 hours. Because total production volume decreased with 94% we would expect that in 2017 3,770 hours (0.94*4,022) are needed. In fact, line 4 has been operational for 3,563 hours, 207 hours less. The average factory hours per week are 104 hours. This means that 2 weeks have been saved (207/104).

When line 4 is operational, on average 9.73 hours per week are spend on M&C. The extra benefit of reduced changeover time and number of batches is therefore another 19 hours (2*9.73). Again, we multiply this by the production costs of 1.065 and we arrive at savings of 20,604 euros.

In summary, due to the planning decisions of the SCP department, inventory costs have increased with 12,628 euros. Savings in changeover time amount to 3,849 euros, savings in ramp up and ramp down time amount to 856 euros and savings in M&C amount to 20,604 euros. We arrive at net savings of 12,681 euros.

5.2. Production line 7

The average batch size of line 7 has increased with 18 pallets. Multiplied by 29 products this is an increase of 522 pallets. After correction for the increase in sales this has caused a stock increase of 306 pallets. Similarly to the previous section we calculate the extra inventory costs which amount to 31,800 euros.

Total changeover time for 2016 was 490 hours with 42 different products being produced. Since the number of products in 2017 was 379 (76% of 2016), we expect total changeover time to be 373 hours (0.77*490). In fact, in 2017, total changeover time has been 379 hours. Total changeover time has increased with 6 hours. Hourly production costs for line 7 amount to 824 euros. The additional costs of increased changeover time therefore amount to 4,988 euros.

In 2016, line 7 produced a total of 548 batches. Because total production volume decreased from 303,808HL to 246,941HL (81%) we would expect that in 2017 445 batches (0.81*548) were needed. In fact, a total of 376 batches were produced. On average, 0.20 hours are spent on ramp up and ramp down time for line 7. This means that a decrease of 69 batches saves 14 hours of ramp up and ramp down time. Again we multiply this by the production costs of line 7 to achieve savings of 11,441 euros.

In 2016, line 7 was up and running for a total of 5,254 hours. Because total production volume decreased with 81% we would expect that in 2017 4,271 hours (0.81*5,254) are needed. In fact, line 7 has been operational for 3,934 hours, 336 hours less. The average factory hours per week are 109 hours. This means that 3.1 weeks have been saved (336/109).

When line 7 is operational, on average 10.69 hours per week are spend on M&C. The extra benefit of reduced changeover time and number of batches is therefore another 33 hours (3.1*10.69). Again, we multiply this by the production costs and we arrive at savings of 27,099 euros.

In summary, due to the planning decisions of the SCP department, inventory costs have increased with 31,800 euros. Increased changeover time have led to another 4,988 euros. Savings in ramp up and ramp down time amount to 11,421 euros and savings in M&C amount to 27,099 euros. We arrive at net savings of 1,752 euros.

5.3. Production line 8

The average batch size of line 8 has increased with 18 pallets. Multiplied by 49 products this is an increase of 522 pallets. After correction for the increase in sales this has caused a stock increase of 412 pallets. Similarly to the previous section we calculate the extra inventory costs which amount to 41,530 euros.

Total changeover time for 2016 was 415 hours with 61 different products being produced. Since the number of products in 2017 was 63 (103% of 2016), we expect total changeover time to be 429 hours (1.03*415). In fact, in 2017, total changeover time has been 354 hours. Total changeover time has decreased with 75 hours. Hourly production costs for line 8 amount to 429 euros. The benefit of reduced changeover time therefore amounts to yearly savings of 31,978 euros.

In 2016, line 8 produced a total of 814 batches. Because total production volume increased from 987,149HL to 1,105,250HL (112%) we would expect that in 2017 911 batches (1.12*814) were needed. In fact, a total of 713 batches were produced. On average, 0.20 hours are spent on ramp up and ramp down time for line 8. This means that a decrease of 198 batches saves 28 hours of ramp up and ramp down time. Again we multiply this by the production costs of line 8 to achieve savings of 11,915 euros.

In 2016, line 8 was up and running for a total of 5,925 hours. Because total production volume increased with 112% we would expect that in 2017 6,634 hours (1.12*5,925) are needed. In fact, line 8 has been operational for 5,417 hours, 1,217 hours less. The average factory hours per week are 121 hours. This means that 10 weeks have been saved (1,217/121).

When line 8 is operational, on average 13.42 hours per week are spend on M&C. The extra benefit of reduced changeover time and number of batches is therefore another 135 hours (10*13,42). Again, we multiply this by the production costs and we arrive at savings of 58,045 euros.

In summary, due to the planning decisions of the SCP department, inventory costs have increased with 41,530 euros. Savings in changeover time amount to 31,978 euros, savings in ramp up and ramp down time amount to 11,915 euros and savings in M&C amount to 58,045 euros. We arrive at net savings of 60,408 euros.

5.4. Conclusion

All lines have achieved great savings on ramp up and ramp down time as well as fewer time spent on maintenance and cleaning. Moreover, lines 4 and 8 have significantly reduced their changeover time. Because line 7 has had a major drop in volume, they were unable to achieve the same efficiency as 2016. Due to this, changeover time has increased. However, due to savings in ramp up/down time and maintenance and cleaning, the changes which the SCP department made for this line are still justified.

A summary and allocation of all costs and savings for each line can be found in Table 5.1 up and till Table 5.3.

Line 4	2016	2017	Change
Stock	18,300	18,415	
#Products	19	16	84%
#Batches	274	253	
Volume (HL)	241,972	226,807	94%
Factory hours	4,022	3,563	
CO time (hrs.)	107	86	
Exp. CO time (hrs.)		90	-4
Exp. Batches		257	-4
Exp. Fact. Hours		3,770	-207
Production costs (€)	1065.00		
Avg. M&C time	9.73		
Avg. Ramp- up/down time	0.21		
Avg. Fact. Hours/week	103.91		-1.99
Yearly extra inventory costs	€ 486,909	€ 499,537	€ 12,628
Less CO savings			-€ 3,849
Less Batches savings			-€ 856
Less Weeks savings			-€ 20,604
Net savings			**-€ 12,681**

Table 5.1. Production changes analysis line 4

Line 7	2016	2017	Change
Stock	18,109	18,415	
#Products	42	32	76%
#Batches	548	376	
Volume (HL)	303,808	246,941	81%
Factory hours	5,254	3,934	
CO time (hrs.)	490	379	
Exp. CO time (hrs.)		373	6
Exp. Batches		445	-69
Exp. Fact. Hours		4,271	-336
Production costs (€)	824.00		
Avg. M&C time	10.69		
Avg. Ramp- up/down time	0.20		
Avg. Fact. Hours/week	109.38		-3.08
Yearly extra inventory costs	€ 467,737	€ 499,537	€ 31,800
Less CO savings			€ 4,988
Less Batches savings			-€ 11,441
Less Weeks savings			-€ 27,099
Net savings			**-€ 1,752**

Table 5.2. Production changes analysis line 7

Line 8	2016	2017	Change
Stock	18,003	18,415	
#Products	61	63	103%
#Batches	814	713	
Volume (HL)	987,149	1,105,250	112%
Factory hours	5,925	5,417	
CO time (hrs.)	415	354	
Exp. CO time (hrs.)		429	-75
Exp. Batches		911	-198
Exp. Fact. Hours		6,634	-1,217
Production costs (€)	429.00		
Avg. M&C time	13.42		
Avg. Ramp- up/down time	0.14		
Avg. Fact. Hours/week	120.66		-10.08
Yearly extra inventory costs	€ 458,007	€ 499,537	€ 41,530
Less CO savings			-€ 31,978
Less Batches savings			-€ 11,915
Less Weeks savings			-€ 58,045
Net savings			**-€ 60,408**

Table 5.3. Production changes analysis line 8

6. Updated classification

In Section 2.4, the current ABC classification as well as an alternative classification was examined. It has been shown that Grolsch' current ABC classification misrepresents the actual situation. In Section 3.1 we have provided an overview of theoretical methods for inventory classification. In this chapter we first update Grolsch' traditional ABC classification with the most recent data of 2017. Next, we formulate a Supply Chain oriented Classification (SCC). This classification should show which products are easily manipulated with production and therefore have some safety incorporated in their process. Products that have this property are flexible and therefore require less physical safety stock. Products lacking flexibility may need higher levels of safety stock. With the combination of traditional ABC analysis as well as the SCC we determine a customer service level that serves as input for the final safety stock model. By doing this we hope to position safety stock very accurately at those products that are generating significant revenues and/or are inflexible in their production planning. We expect this to lead to an overall decrease of safety stock while still maintaining target service levels.

6.1. Updated ABC classification

As is explained in Section 2.4 there are currently 5 classes in the traditional ABC analysis. Besides A, B and C there is D for MTO products and X for unclassified products. Because export products are sold by means of a transfer price, they have low margins. It is for this reason that it is difficult (and perhaps unfair) to include them in an ABC analysis based on revenues. The vast majority of export products that are not produced on a MTO basis are therefore currently unclassified. We would like to change this by adding an extra class designated to export products and conveniently name this class E. By doing this we restrict class X solely to NPDs. This has the advantage of providing more insight into NPDs and more easily recognize when NPDs mature and should move from a X classification to an A, B or C classification.

Table 6.1 shows the amount of SKUs that have transitioned from one class to another and Figure 6.1 shows a graphical comparison between the A, B and C classes of the new classification and the traditional one.

↓Old/New→	A	B	C	D	E	X
A	13	12	5	0	0	0
B	0	3	11	0	2	2
C	0	2	4	1	0	0
D	0	0	0	14	4	0
E	0	0	0	0	0	0
X	2	3	18	29	45	45

Table 6.1. SKU changes from old to new classification

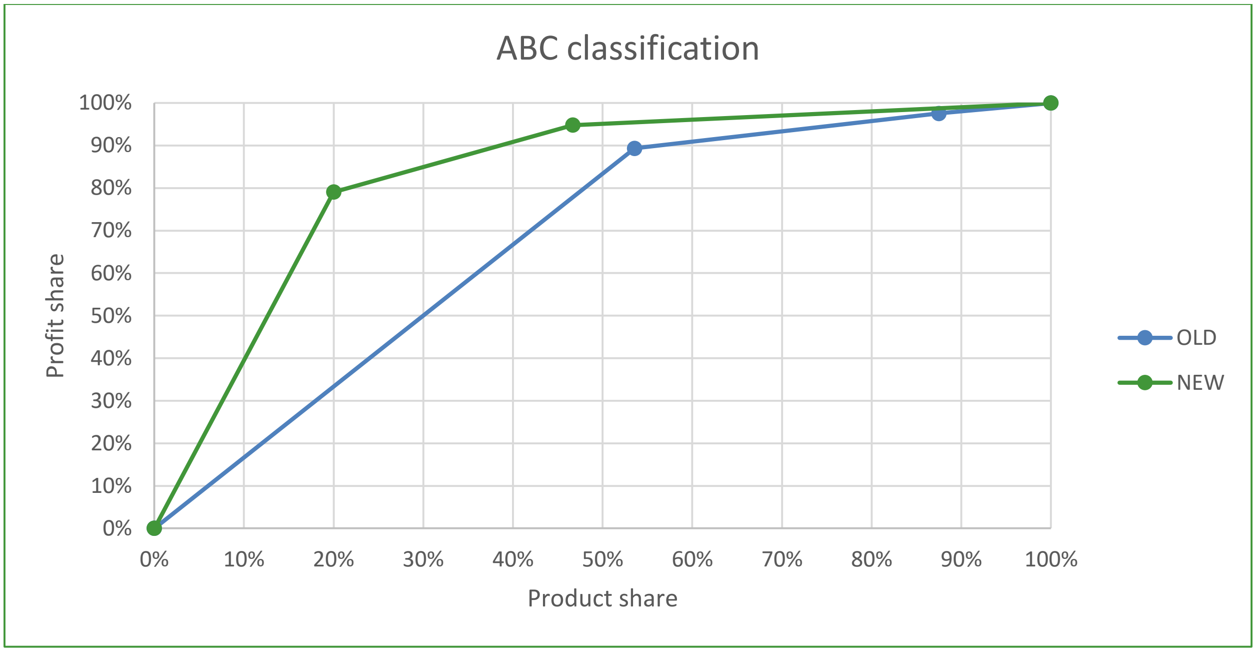

Figure 6.1. Old and new classification comparison

As can be seen from the graph, we can achieve the same profits with less than half of the products. This gives a more accurate representation of which SKUs are the core profit generators. Moreover, when looking at A, B and C classes only, it can be calculated that none of the products have received a higher classification whereas 59% have received a lower classification. This means that more than half of the products were classified too high and changing this will have a direct influence on the levels of safety stock.

6.2. Supply Chain oriented Classification (SCC)

Besides revenues, there are other things to take into account when deciding on a products classification and thus its safety stock. Simplified, we can distinguish between two types of safety. So far, we have discussed physical safety stock that lies on stock in case of unexpectedly high sales or unexpectedly low production output. Besides this, there is a degree of safety incorporated within the supply chain process. Some SKUs are more easily manipulated on the short term than others and are more responsive to changes from the environment. Figure 6.2 denotes the average batch size by Q and shows two axes of flexibility for any SKU. We note that this shows short term flexibility which takes place roughly 48 hours before production. The degree in which a SKU can move horizontally and vertically within this pane determines how flexible its production is. SKUs that are highly flexible require less physical safety stock because production can be changed last minute without any problems. SKUs that lack this kind of safety within their production process may need more physical safety stock. In Section 6.2.1 we discuss the vertical flexibility and in Section 6.2.2 we discuss horizontal flexibility. Finally, in Section 6.2.3 we describe the method we use to determine whether a given SKU is scored 0 (very flexible), 1 (somewhat flexible) or 2 (completely inflexible).

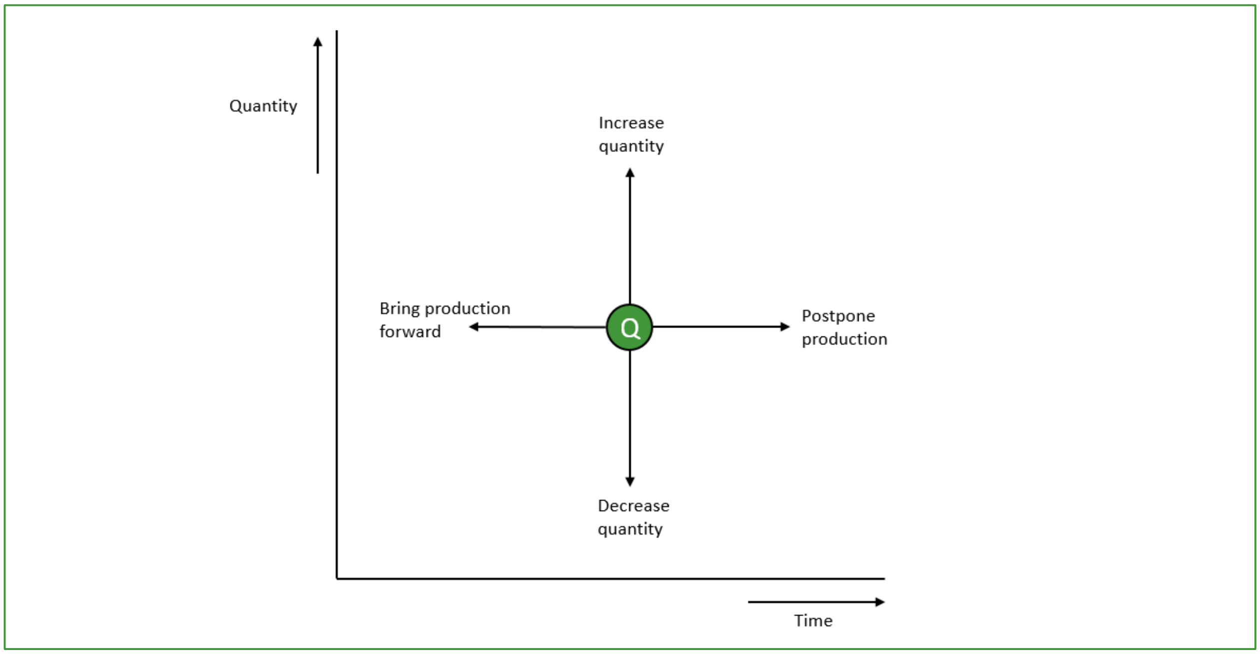

Figure 6.2. Production flexibility

6.2.1. Vertical flexibility

When deciding to change production quantity on the short term, we need to take into account three criteria that determine the degree of vertical flexibility. We call these criteria the Vertical Criteria (VC).

VC1: Material flexibility

First of all, if we want to increase our quantity, required materials, need to be present or quickly need to be ordered. The degree in which this can be done is determined by the supplier. Therefore, we perform a Multi Criteria Analysis (MCA) to determine which suppliers are flexible and which are not. We use four criteria to score our suppliers:

M1: Lead time in weeks
M2: Distance to Grolsch in kilometers
M3: Percentage delivered on time and in full ranging from 0 to 100%
M4: Amount of inventory on stock, scored from 1 to 5 assessed by the materials manager.

We start by determining the weights of these criteria. For this we use the theory of the Analytical Hierarchy Process (AHP) to make pairwise comparisons between the criteria. We have asked the materials planner as well as the materials manager to do this. The result can be found in Table 6.2. A detailed explanation of the AHP method can be found in Appendix II.

i↓ | j→	M1	M2	M3	M4	Weight
M1	1.00	1.00	1.00	7.00	32%
M2	1.00	1.00	1.00	7.00	32%
M3	1.00	1.00	1.00	7.00	32%
M4	0.14	0.14	0.14	1.00	5%

Table 6.2. Pairwise comparison of supplier criteria

1: The two criteria are of equal importance
3: Criterion i is slightly more important than j
5: Criterion i is highly more important than j
7: Criterion i is very highly more important than j
9: Criterion i is extremely more important than j

Next, all suppliers are scored on each criterion. The results are then linearly standardized on a scale from 0 to 1 where the worst score receives a 0 and the best score a 1. These standardized results are finally multiplied by the weight of the criteria to receive a final score from 0 to 1 for each supplier. Results can be found in Table 6.3.

Supplier	Scores				Standardized				Score
	C1	C2	C3	C4	C1	C2	C3	C4	
Supplier 1	2	175	99	4	0.06	0.07	0.00	0.50	0.06
Supplier 2	10	825	99	5	1.00	0.49	0.00	0.00	0.47
Supplier 3	5	450	99	3	0.41	0.25	0.00	1.00	0.25
Supplier 4	4	175	99	3	0.29	0.07	0.00	1.00	0.16
Supplier 5	1.5	325	99	3	0.00	0.16	0.00	1.00	0.10
Supplier 6	10	200	95	5	1.00	0.08	0.44	0.00	0.49
Supplier 7	1.5	75	94	3	0.00	0.00	0.56	1.00	0.22
Supplier 8	10	1075	95	5	1.00	0.66	0.44	0.00	0.67
Supplier 9	2.5	900	90	3	0.12	0.54	1.00	1.00	0.57
Supplier 10	4	1600	99	4	0.29	1.00	0.00	0.50	0.43

Table 6.3. Results of supplier flexibility analysis

For SKUs that have multiple suppliers, the supplier with the lowest score is chosen as this will be the bottleneck.

VC2: Shift utilization

The second criterion for vertical flexibility is shift utilization. Naturally, when we increase the batch size of a SKU, production of other SKUs will be delayed. When a line is fully occupied in a week, this will become problematic. The normal amount of shifts per week is nine for line 1 and fifteen for the others. Shift utilization will be scored by subtracting the planned amount of shifts from this normal amount of shifts. The result is then the amount of shifts we have as slack. Naturally, the more slack the higher the score as scaling up production becomes easier.

VC3: Batch stepsize

Our last item to consider is the step size of which we can increase the batch size. For some SKUs we cannot simply produce a few hectoliters more. This has to do with compounds that are added to the beer. Compounds are certain ingredients that are added during brewing. At the moment, it is highly difficult to use a fraction of a compound so instead, production quantities are always an integer multiple of the required compound. The higher this step size is, the more difficult it is to increase production quantity.

6.2.2. Horizontal flexibility

The degree in which production of a SKU can be brought forward or postponed is again determined by three factors. We call these criteria the Horizontal Criteria (HC). Because production lines play an important role, we firstly note that each SKU is only produced on one line. Moreover, we make the assumption that when a line is up and running in a week, the full week is utilized.

HC1: Line availability

First of all, the amount of weeks a production line is up and running during a year should be taken into consideration. If a production line is planned out before and after the week of production, naturally we cannot bring production forward or postpone production more than a week. We define this line availability simply as the number of weeks the line is up and running during a time period divided by the total weeks in that time period. The higher this percentage is, the easier it is to change the timing of production.

HC2: Changeover costs

Next, operating costs of each production line have an impact as well. At first, one might say that changing the timing of production for a SKU has no impact on total time, however it does when taking into account changeovers. We can assume that planned production has optimized sequences of SKUs to ensure changeovers are minimal. If we change this sequence, total changeover time will increase. Naturally, this impact is greater for lines with high operating costs. To measure this, we determine the average changeover time per SKU and multiply it with the operating cost of its production line. The higher this result is, the costlier it is to change timing of production.

HC3: Production frequency

The third factor is production frequency. The more often a product is produced, the easier it is to change production timing. Slightly confusing, production frequency at Grolsch is defined as the average number of weeks in between production rather than a rate. Therefore, when speaking of an increased frequency, the product is produced less often and the rate is lower. If a product is produced every week, it is easier to change timing of production.

6.2.3. Flexibility rules

From the vertical and horizontal flexibility sections we have seen six unique criteria. These criteria do not play an equally important role so we have asked six people from the SCP department to weigh them. Again, we use the theory from AHP to make pairwise comparisons between the six criteria and calculate a weight for each of them. Results are found in Table 6.4.

VC1: **Material flexibility** (Table 6.3)
VC2: **Shift utilization** (amount of shifts of slack)
VC3: **Batch stepsize** (hectoliters of step size)
HC1: **Line availability** (percentage of total number of weeks)
HC2: **Changeover costs** (euros)
HC3: **Production frequency** (#weeks between production)

i↓ | j→	VC1	VC2	VC3	HC1	HC2	HC3	Weight
VC1	1.00	5.00	7.00	5.00	5.00	7.00	51%
VC2	0.20	1.00	3.00	1.00	1.00	3.00	13%
VC3	0.14	0.33	1.00	0.33	0.33	1.00	5%
HC1	0.20	1.00	3.00	1.00	1.00	3.00	13%
HC2	0.20	1.00	3.00	1.00	1.00	3.00	13%
HC3	0.14	0.33	1.00	0.33	0.33	1.00	5%

Table 6.4. Pairwise comparison of flexibility criteria

All agree that the supplier(s) plays the most important role. This is because it is the only criterion that is a hard constraint. When there are no materials, it is simply not possible to produce earlier or more whereas for the other criteria it may be more expensive, take more time or be inefficient but it is still possible.

To determine for each SKU whether it is scored 0 (very flexible), 1 (somewhat flexible) or 2 (completely inflexible) we perform a MCA again. We multiply the standardized scores on each criterion by the weight of the criterion. This results in a score from 0 to 1. A score below 0.33 means the SKU is very flexible, a score between 0.33 and 0.66 means the product is somewhat flexible and a score above 0.66 means it is completely inflexible.

As an example, Table 6.5. shows the complete process for the standard pilsner (SKU 91135) for the first quarter of 2018.

Criterion	Score	Standardized score	Multiplied by criterion weight
VC1	Bottleneck supplier = Supplier 10	0.43	0.22
VC2	2.54 shifts slack	0.77	0.10
VC3	Beer increment = 1	0.00	0.00
HC1	11 out of 13 weeks up	0.17	0.02
HC2	Changeover time = x hrs Line costs = y euros Score = 1208 (x * y)	0.52	0.07
HC3	Production frequency = 1	0.00	0.00
Final score			0.41
Flexibility			1 (somewhat flexible)

Table 6.5. Results of the MCA for the standard pilsner

From Table 6.4. we can see that vertical flexibility has a combined weight of 69% and horizontal flexibility a combined weight of 31%. We can create a figure where horizontal flexibility is displayed on the horizontal axis ranging from 0 to 0.31 and vertical flexibility is displayed on the vertical axis ranging from 0 to 0.69. Any combination between the two that is lower than 0.33 results in a score of 0 and any combination higher than 0.66 scores a 2. This is displayed in Figure 6.3. along with our example product.

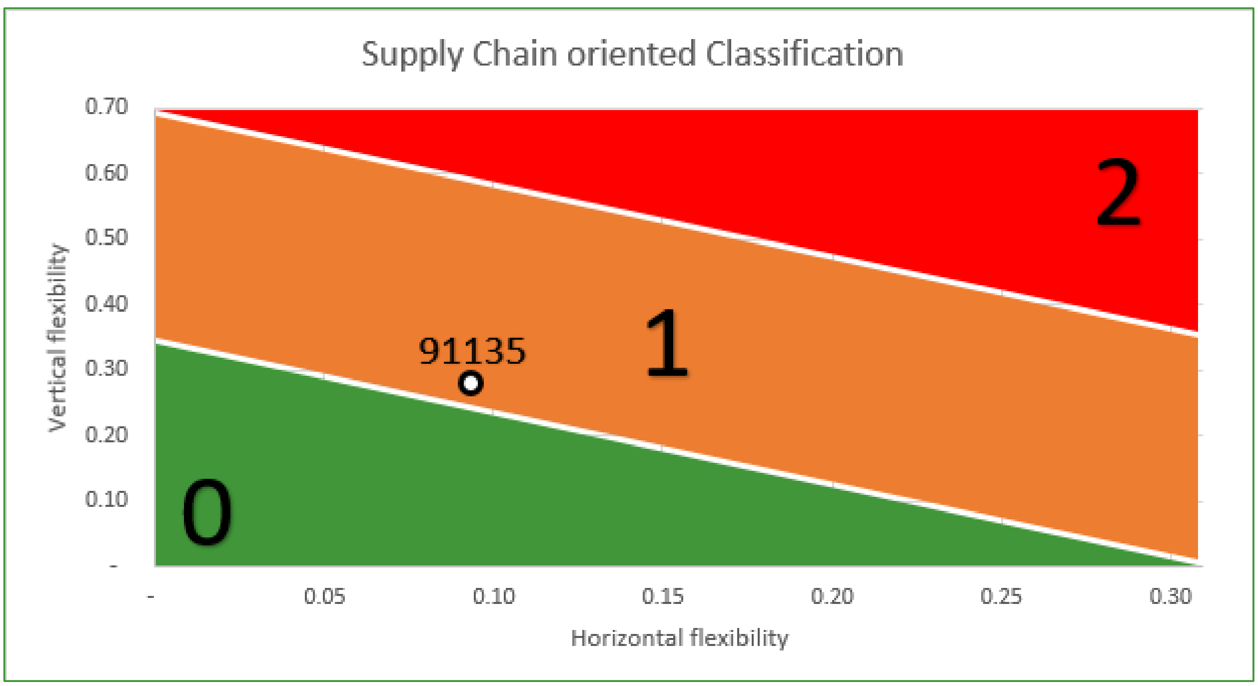

Figure 6.3. Production flexibility of SKU 91135

We determine the production flexibility for each SKU and results can be found in Figure 6.3.

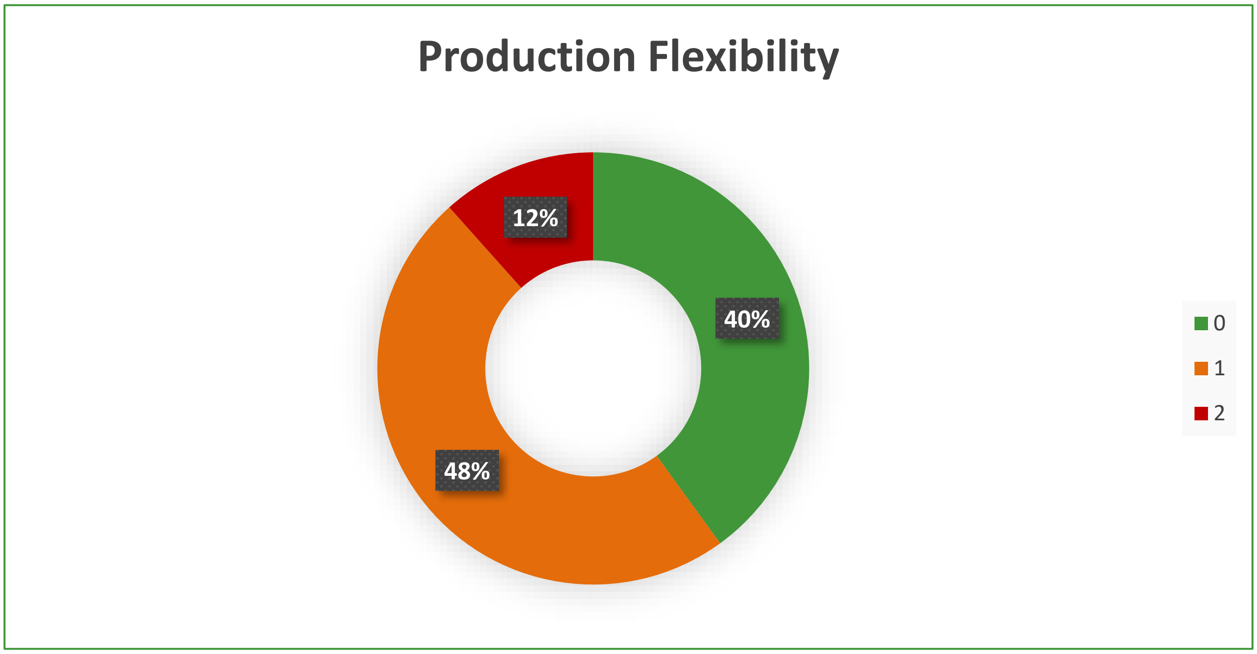

Figure 6.4. Distribution of production flexibility over 2017

6.3. Combined classification

In Section 5.1 we have created a classification based on revenues. In Section 5.2 we found a method to determine the degree of a SKUs production flexibility.

For our final safety stock model, we use the matrix displayed in Table 6.6 to determine the Cycle Service Level corresponding to a given classification and flexibility.

Class↓ | Flex.→	0	1	2
A	x+α-β	x+α	x+α+β
B	x-β	x	x+β
C	x-α-β	x-α	x-α+β
E	x-α-β	x-α	x-α+β
X	x+α-β	x+α	x+α+β

Table 6.6. CSL per class for ABC and SCC combined classification

As can be seen from Table 6.6, input consists of three factors namely x, α and β. X denotes the base CSL, α the change in classification and β the change in flexibility. Different values for x, α and β will be tested in the final model.

As we have shown in Section 2.2, seasonality tends to increase. As one can imagine, certain products are far more important in summer than in winter and the other way round. Due to this, as well as to prevent NPDs being unclassified for too long, we advise to update this new classification at least twice per year and preferable each quarter.

6.4. Conclusion

In this Chapter we have seen two ways of classifying products and eventually combined them into one method which we shall use. First, each product is given any of six classifications from the ABCDEX classification. This is purely based on revenues. Next, each SKU is scored either 0, 1 or 2, depending on how flexible this product is. A product which can easily be scaled up in production and/or be brought forward on the short term is given a score of 0 whereas a very inflexible product is scored 2. This method takes into account required materials, production line characteristics, batch (step) sizes and production frequency. Finally, the two methods are combined to provide a CSL as input for our safety stock model.

7. Model formulation

Now that we have formed a classification which accurately shows the importance of each SKU we have a solid basis for our safety stock model. In order to formulate this model, we make the following approach. First of all, in Section 7.1 we research requirements and constraints which our new model needs to meet in order to answer research question 3.1. Also, we see how we could improve the current way of working to answer research question 3.2. Knowing the requirements and constraints we then specify the safety stock model and illustrate its method in Section 7.2. Finally, we validate our model in Section 7.3. to answer research question 3.3.

7.1. Requirements, constraints and desires.

In order to create a safety stock model which can be used accurately as well as effectively, it has to meet certain requirements and constraints. After interviewing most people involved with current planning-decision making, a few things have come forward. First of all, the importance of seasonality should be incorporated within the model. As we have seen in Section 2.1, the gap between high and low season is increasing which means certain products are far more important in summer than in winter and the other way around. Our model should recognize the importance of SKUs in certain time periods and adjust safety stock accordingly. We shall address this requirement by advising to update the model at least twice a year and preferably each quarter.

Next, current users feel that there is a certain level of safety incorporated within the production process of some SKUs that is not taken into account when determining safety stock. There exists certain SKUs whose production can be changed last minute which means physical safety stock may be reduced. On the other hand, there are products and/or production lines for which intervening with production is very difficult or costly and therefore not desirable. These products may need a bit more safety stock. These requirements have been dealt with in Chapter 5.

Besides these requirements there are also a few hard constraints our model should meet. To prevent planning on obsoletes, the amount of safety stock should never be greater than the demand during the shelf life minus the average batch size. If it were to do this, a part of the safety stock would most likely become obsolete. In fact, if safety stock would equal the demand during the shelf life minus the average batch size, obsoletes will still occur half the time due to variation in the demand. To ensure our safety stock is consumed within the shelf life with 95% confidence, we subtract twice the standard deviation of demand during shelf life. Naturally, another confidence level can be chosen leading to a different number of standard deviations. Using 95% confidence, safety stock is bounded to a maximum by formula 7.1.

$$Max\ SS = \max(0, \mu_s - Q - 2\sigma_s) \quad (7.1)$$

μ_s: *Demand during the shelf life*

Q: *Average batch size*

σ_s: *Standard deviation of demand during the shelf life*

Finally, the tactical planning department argues for the use of the Root Mean Squared Error (RMSE) instead of a standard deviation of sales. This, because products that may be very whimsical in their sales might actually be better to forecast than products with steady sales. The RMSE measure has the benefit of being better linked to forecast accuracy.

7.2. Model specification

The safety stock model can best be illustrated by Figure 7.1

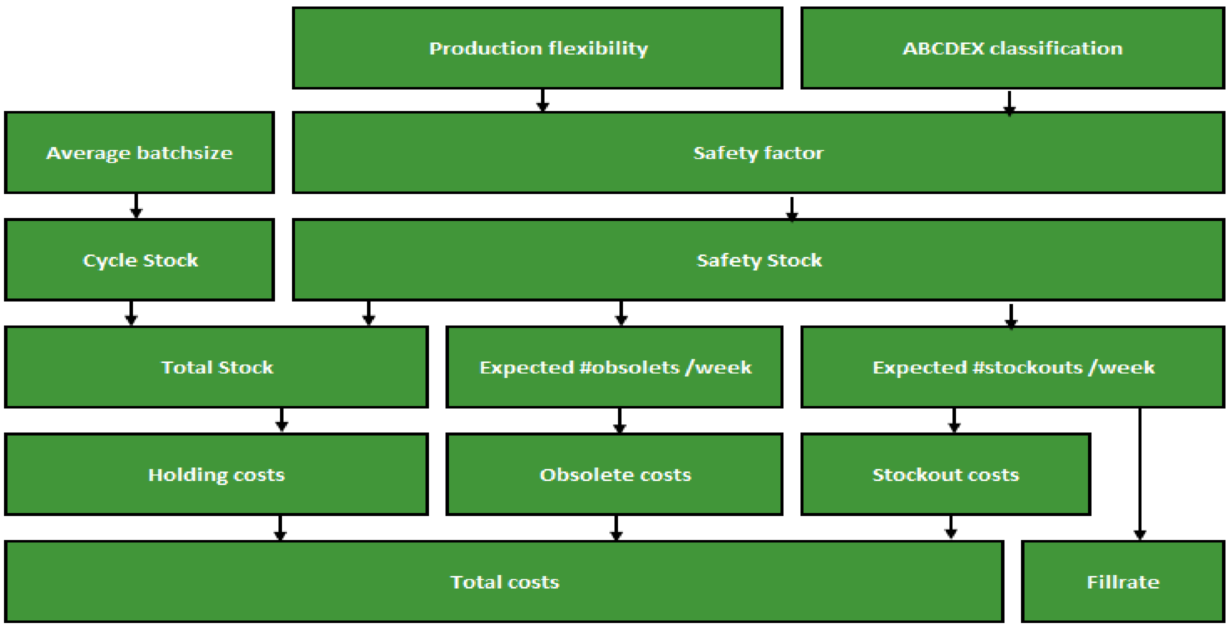

Figure 7.1. Safety stock model process

The process depicted in Figure 7.1. is performed for every SKU and works as follows:

1. SKU flexibility is determined as has been explained in Section 6.2.
2. An ABCDEX classification is determined as has been explained in Section 6.1.
3. Given the SKU flexibility and ABCDEX classification, a safety factor is determined as has been explained in Section 6.3.
4. Cycle stock is defined as half of the average batch size.
5. Safety stock is calculated using formula 3.3.
    a. The safety stock is bounded by formula 7.1. to ensure obsolete risk of safety stock is minimal.
6. The expected weekly stockouts are determined using formula 3.8.
7. The expected weekly obsoletes are determined using formula 3.13.
8. Total stock is the sum of cycle and safety stock.
9. Given the total stock, holding costs can be determined using formula 4.7.
10. Given the expected obsoletes, obsolete costs can be calculated using formula 4.8.
11. Given the expected shortages, stockout costs can be calculated using formula 4.9.
12. Given the expected shortages, a fillrate can be calculated using formula 3.7.
13. Given the holding, stockout and obsolete costs, total costs are determined.

7.3. Model validation

Before we can validate the results of our model, we first need to check if demand is normally distributed. To do so, we create a QQ plot and perform a Chi-square test. The QQ plot is displayed in Figure 7.2 and the results of the Chi-square test are displayed in Table 7.1

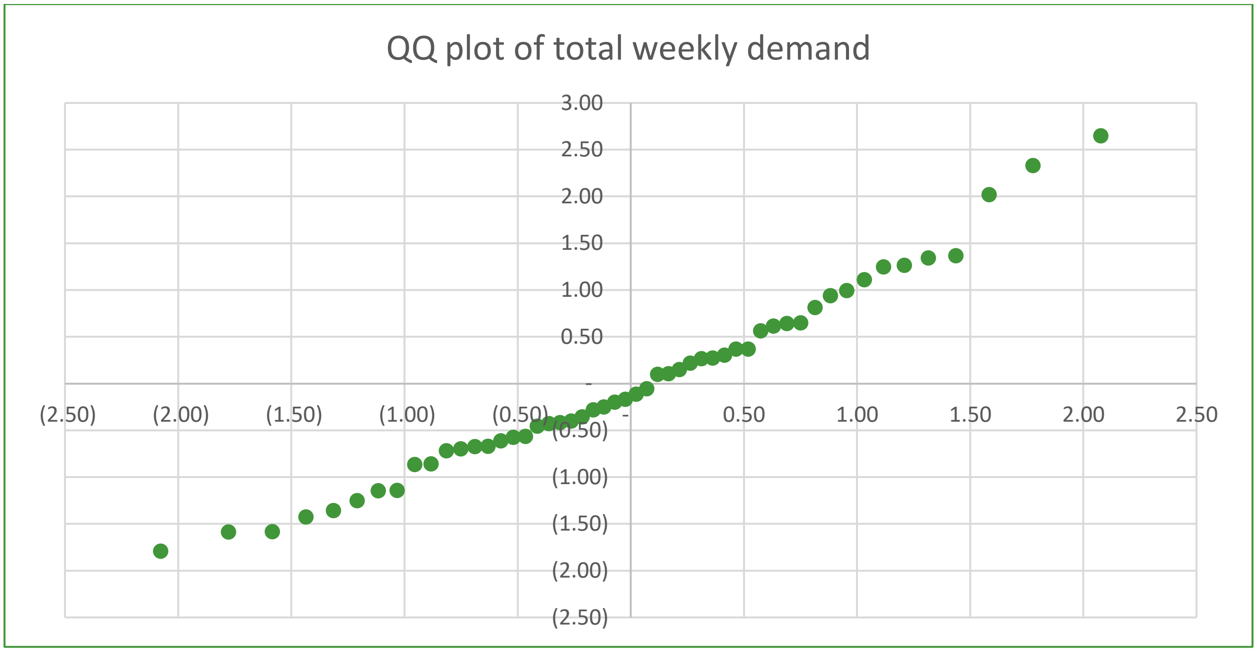

Figure 7.2. QQ plot of total weekly demand over all SKU's

Chi-square test	
df	16
Mean	7,734
st.dev.	1,782
Chi sq.	0.01
Confidence	99.0%
Critical value	5.81

Table 7.1. Chi-sqare test results

Our test statistic equals 0.01 which is smaller than the critical value of 5.81. We can therefore assume demand is normally distributed.

To ensure the validity of our model, we firstly use data of 2017 and compare it to the actual values. We only look at SKUs that are produced and sold by Grolsch and not take into account products that are repacked or imported. The total actual stock of the products that remain amounts to 17,826 pallets.

For the calculation of the fill rate we exclude all products that are produced fewer than 4 times a year. In addition, for the calculation of stockouts, obsoletes and fill rate, we do not take into account products for which the RMSE measure is unavailable or untrustworthy. To determine when a measurement is untrustworthy we have performed a statistical analysis on all our measurements of RMSE. We define extreme outliers to be more than 3 times the interquartile range less than the first quartile or more than 3 times the interquartile range higher than the third quartile. 90% of all extreme outliers have less than 20 measurements. We therefore denote untrustworthy to be less than 20 measurements of RMSE in the last two years. We note that a significant part of these excluded products is produced on a MTO basis and will therefore seldom lead to obsolete or stockout costs. Excluding them should therefore not have a significant effect on our outcomes.

We define cycle stock to be half of the average batch size and calculate safety stocks using formula 2.1. Results can be found in Table 7.2.

Measure	Model output	Actual value
Total Stock in pallets	17,925	17,826
Domestic stock availability (=fillrate)	99.2%	99.4%
#Pallets expected to exceed 30% due date	x	*Unknown*
Costs of products expected to exceed 30% due date	x	*Unknown*
#Expected stockouts in pallets	x	*Unknown*
Costs of expected stockouts	x	*Unknown*
Inventory costs	x	*Unknown*
Total costs	x	*Unknown*

Table 7.2. Model output and actual values for 2017

Stock availability deviates from the actual value by 0.2%. This difference can be attributed to the effect of the SCP department. They predicted stockouts and adjusted the production plan accordingly.
As can also be seen, our estimation of total stock deviates from the actual value with 99 pallets or 0.56%. To check whether this difference is statistically significant we perform a t-test on the differences per SKU. Our null hypothesis is that the mean of the differences equals zero. Our test statistic is determined by formula 7.3 and equals -0.11.

$$\mathrm{T} = \frac{\bar{X}}{S/\sqrt{df}} \qquad (7.3)$$

We test with a confidence of α=0.01. The critical value is 2.6. We do not reject our null hypothesis as -2.6 < -0.11 < 2.6.

7.4. Conclusion

In this chapter we have mapped all requirements and constraints which our model needs to meet. Next, we have explained the workings of our model and proved that we can use a normal distribution for our demand. Finally, we have validated our model using data of 2017 and concluded that the difference between our model and the actual values are not statistically significant.

8. Model evaluation

Now that we have our safety stock model it is time to compare its result with the old methods. This is done in Section 8.1 to answer research question 4.1. In Section 8.2 a sensitivity analysis is performed to answer research question 4.2.

8.1. Comparison

We run our model with data from 2017. Please recall from Section 6.5 that our input values consist of a value x, denoting the base CSL, a value α which denotes the change in classification and a value β which denotes the change in flexibility. Our input values for x, α and β are chosen in a manner such that total inventory is equal to 17,925 and the fill rate is equal to 99.2% which was outputted by the model using the old way of determining safety stock. Results can be found in Table 8.1.

Input	
x	91.2%
α	6.0%
β	2.2%
Output	
Average stock	17,925
Stock availability	99.2%
Exp. #pallets >30% THT	-34%
Exp. #pallets stockout	-29%
Total costs	-5%

Table 8.1. First model output using new method of safety stock determination

Even though total inventory as well as stock availability is similar to the old situation, we have decreased the expected number of pallets that exceed the shelf life as well as the expected number of stockouts. This is achieved by shifting safety stock from products that had a fill rate higher than 99.2% to products with a fill rate lower than 99.2%. This has resulted in yearly savings of 5%.

We now check whether we can decrease total costs even more by changing the base CSL as well as changing the difference between ABC classes (α value) and production flexibility classes (β value).

Using a small algorithm, we have tested all integer combinations off x, α and β. The best solution we have found is increasing *x* by 1% and decreasing both the α and β by 1% compared to the input of Table 8.1. Using these values, we can improve our solution while maintaining the same stock availability. This can be found in Table 8.2.

Input	
x	92.2%
α	5.0%
β	1.2%
Output	
Average stock	17,947
Stock availability	99.2%
Exp. #pallets >30% THT	-34%
Exp. #pallets stockout	-34%
Total costs	-7%

Table 8.1. Improved model output using new method of safety stock determination

In this new situation, total stock has increased slightly while the expected number of stockouts has dropped. Total savings using these settings amount to 7%

The complete matrix for these optimal values of *x*, α and β is shown in Table 8.3.

Class | Flex	0	1	2
A	96.0%	97.2%	98.4%
B	91.0%	92.2%	93.4%
C	86.0%	91.0%	88.4%
E	86.0%	91.0%	88.4%
X	96.0%	97.2%	98.4%
D	50.0%	50.0%	50.0%

Table 8.3. CSL matrix for optimal results

8.2. Sensitivity analysis

In this section we perform two sensitivity analyses. First of all, we are interested in a change in stock availability. We start with the results found in the previous section and change the value of *x* until stock availability has changed with 0.1% more and 0.1% less. Results with these settings are as follows:

Input	SA - 0.1%	Old	SA + 0.1%
x	91.0%	92.2%	93.6%
α	5.0%	5.0%	5.0%
β	1.2%	1.2%	1.2%
Average stock	-1.4%	17,947	+2.6%
Stock availability	99.1%	99.2%	99.3%
Exp. #pallets >30% THT	+0.0%		+0.5%
Exp. #pallets stockout	+12.5%		-13.3%
Total costs	+1.1%		+1.7%

Table 8.4. Model output where stock availability is improved by 0.1% and 0.2% respectively

Yearly costs increase with 1.1% with a 0.1% decrease in stock availability and 1.7% euros for a 0.1% increase. Stock decreases with 1.4% pallets at a lower stock availability and increases with 2.6% pallets for a higher stock availability.

Next, we perform an analysis to uncover the extra costs and decrease in fill rate if storage capacity would be lower and inventory would have to be reduced.

Input	Stock -1000 Pal	Old	Stock +1000 Pal
x	85.5%	92.2%	94.5%
α	5.0%	5.0%	5.0%
β	1.2%	1.2%	1.2%
Average stock	16,941	17,947	18,944
Stock availability	98.6%		99.4%
Exp. #pallets >30% THT	-1.1%		+0.9%
Exp. #pallets stockout	+79.5%		-20.8%
Total costs	+13.8%		+7.3%

Table 8.5. Model output where inventory is reduced by 1000 pallets and 2000 pallets respectively

We can see that yearly costs increase with 13.8% euros for a decrease of 1,000 pallets and 7.3% for an increase of 1,000 pallets. Stock availability decreases with 0.6% and increases with 0.2% respectively.

8.3. Conclusion

In this chapter we have shown that we can improve the old way of determining safety stock. With the same inventory and stock availability we can lower yearly total costs by more than 7%. We have also seen the costs of marginally changing stock availability as well as inventory. We conclude that current levels of inventory and stock availability are close to optimal however, total costs can still be reduced by shifting safety stock between products.

9. Qualitative recommendations

In the previous chapters we have analyzed Grolsch' current practices, researched what has caused Grolsch inventories to rise and looked into the effects of production planning decisions. We have done all this to eventually create a model that determines safety stock. Besides this tangible deliverable, we have noticed some other areas of potential improvement during our time at Grolsch. To finalize this research, we would therefore like to use this chapter to give some qualitative recommendations for improvement on the short, as well as the long term.

9.1. NPD

In Section 2.1. we have seen that NPDs have been added to the portfolio faster than old products have been delisted. When looking at market trends, this is not surprising. According to the Central Bureau of Statistics (CBS) in the Netherlands, the amount of breweries has quadrupled in ten years' time. It is especially microbreweries with one single employee that have grown the most as can be seen from Figure 9.1.

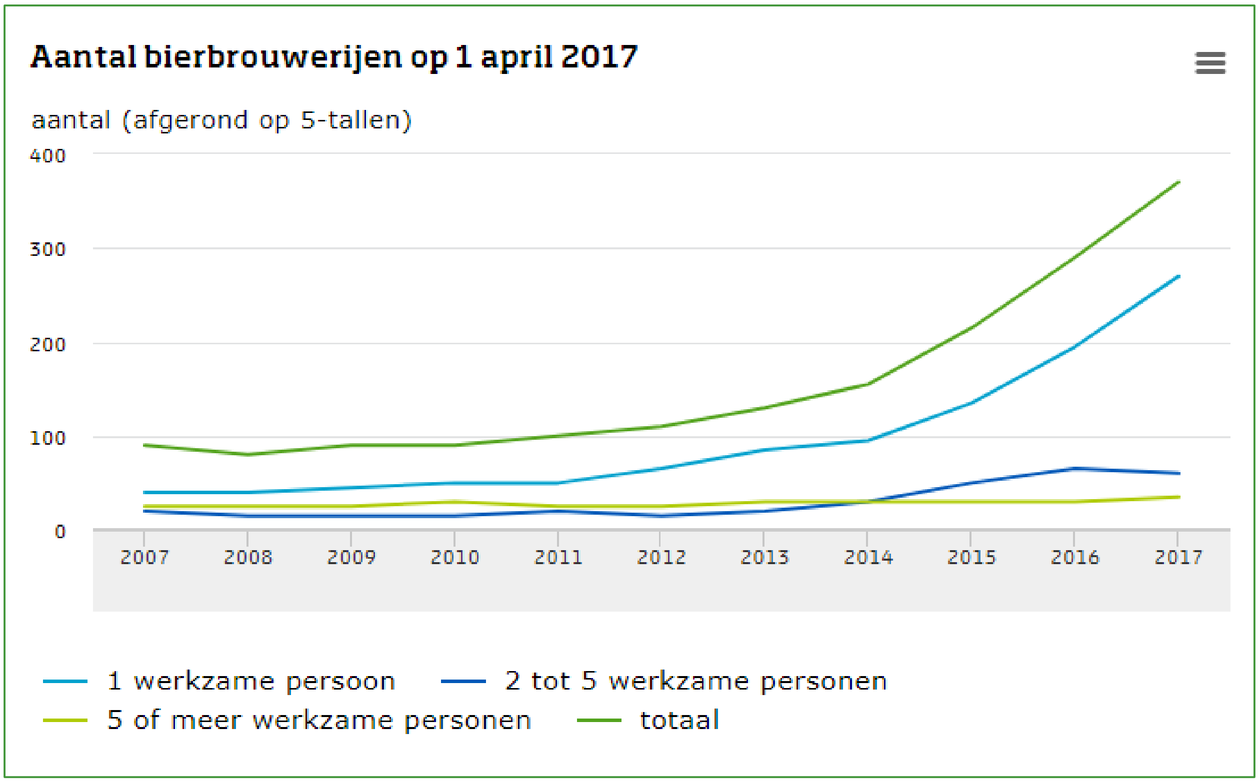

Figure 9.1 Growth of breweries in the Netherlands (CBS)

As one can imagine, these microbreweries mostly specialize in one type of beer which causes the market of beer to become highly diverse. In order to remain competitive, Grolsch cannot ignore this trend and needs to shift its focus to new types of beer too. They have begun to do so by introducing a new kind of beer every month in the last quarter of 2017.

We would like to stress the importance of continuously creating new, innovative beers. The next step is no less important which consists of checking the viability of these beers. A few months after the introduction of a NPD, its results in the market should be critically assessed and the decision should be made to either delist the product or scale it up. In fact, this assessment should be done for the whole portfolio in regular intervals to ensure Grolsch' portfolio does not grow beyond the capabilities of the warehouse. Already, the warehouse is coping with many different type of products and obsolete products do not occur seldom. If viability assessments are not done regularly, products with little demand remain in Grolsch' portfolio and production plan. This will increase the number of obsolete products.

9.2. RFID tracking

Interesting developments in the field of RFID tracking may prove to be very helpful to Grolsch. Due to new technologies, it has become relatively cheap to equip every pallet with a tracker creating the ability to locate every product in real-time. Implementing this technology has numerous advantages. The first obvious benefit is that pallets are no longer lost so we will decrease investments in purchasing new pallets. Second, it can easily be seen which pallets of a specific product have been in storage the longest so we can make sure they are dispatched first, decreasing the risk of obsoletes. Third, by visualizing the location of every pallet in the warehouse, free space is easily recognized. This causes time spend looking for a location when a pallet comes out of production to decrease. Moreover, implementing this technology will eliminate financial inventory losses due to counting errors and decrease communication between departments regarding the status of products. When taking it one step further, we could even leverage this new technology to create a competitive advantage. With this technology, it is possible to let customers track their orders in real-time. Not only is this a nice marketing aspect, it may even reduce our inventory. We could start tracking an order at production already and predict the time an order will be done. This can then be communicated to the customer who may be able to pick their order up as soon as it has come out of production. If this can be achieved, even for a small amount of products or customers, it will already cause a significant decrease in inventory.

9.3. Product postponement

Increasing the number of NPDs will lead to a greater portfolio which leads to a higher complexity. This complexity may be reduced if product postponement can be achieved. This postponement can be done at two locations. First of all, certain type of beers may come from the same brew. This is already the case as we have seen in Section 1.1. but for NPDs these possibilities should be researched further. Second, postponement may be achieved at packaging. At the moment there are certain products with identical beer that are produced for both the domestic as well as the export market. At the moment, these products are treated as two completely different SKUs. Perhaps it would be possible to create bilingual labels and straighten requirements for both markets more to combine these products.

9.4. Inter departmental cooperation

In our root cause analysis, we have seen that forecast bias is a cause for stock increase. We realize that most of Grolsch portfolio is produced on a forecast basis which will never be a 100% accurate. Yet, we would like to stress the importance of inter departmental cooperation. Regular and clear communication between the SCP and demand planning departments is critical for preventing stockouts as well as obsoletes. Especially due to the new trend of NPDs as we have seen in Section 9.1. forecasting is expected to become increasingly difficult.

9.5. Ship from harbour

As was explained in Section 1.5, as of right now, products are not dispatched from the harbour. Every truck that needs to pick up products from the harbour so they can be dispatched costs almost 100 euros for transport and handling. This transportation does not add any value and thus costs for this are a waste. During the length of this project, a small exploratory research has been carried out to calculate savings if products could be dispatched from the harbour. Results were very promising and we therefore advise to look into this further. We advise to make the necessary investments and adjustments to accommodate this in the first quarter of 2018 so dispatching from the harbour can be realised in the peak period of 2018 when inventory is at its highest.

9.6. Conclusions

In this Chapter we have given 5 qualitative recommendations. On the short term we advise Grolsch to look into the possibilities of dispatching from the harbour. Ideally, this is realized in the summer of 2018. For the medium term, we advise to create a business case for RFID tracking to investigate its feasibility. Also, we advise to research possibilities of product postponement to reduce production complexity. Finally, for the long term, we would like to stress the importance to keep up with the market trend towards new, innovative beers and the importance of inter departmental cooperation to reduce forecast bias.

10. Conclusion

This research was initiated because Grolsch' inventories have been rising and extra costs were made because of it. In order to research the causes of this and to try to improve Grolsch' inventory control, we have formulated the following research goal:

To analyze past and present production planning decisions and to develop a tool that will determine optimal amounts of safety stock while maintaining target service levels.

To achieve this goal, the following research questions have been used and answered as follows:

10.1. What has caused Grolsch' inventories to rise?

Grolsch inventories have risen mainly because of a shift in sales from low to peak season. We have concluded that these increased sales in peak season explain 37% of the increase in inventory. Next, there are three root causes with a similar influence on stock increase. 18% of stock increase can be traced back to a decrease in forecast bias, 19% can be traced back to a relative increase in the production error and 16% is caused by producing with increased batch sizes. Of the remaining 10%, we have concluded that 6% is caused by introducing NPDs faster than delisting products from the portfolio.

10.2. What does Grolsch' current ABC inventory classification look like?

Grolsch current ABC inventory classification is outdated and faulty. Roughly 2/3rds of products are not classified and of the products that are classified, the division is not in line with common theory. There are more products marked as A, most important, then classes B and C combined. On the other hand, an alternative classification exists which is more in line with theory. This classification however, is not used for determining safety stock.

10.3. What inventory control policies are used at Grolsch?

Grolsch inventory control policy can best be described as a (R,s,S) system however there are certain nuances that should be mentioned. First of all, the review period *R* equals 1 week in theory however is often shorter than 1 week in practice. This is because the production plan is often checked and updated throughout the week. Also the order-up-to level *S* is not very clear. Instead, it is chosen such that the DoC for the particular product is above a certain target but also not excessively large.

10.4. How are inventory control parameters determined at Grolsch?

Grolsch uses a Days of Cover (DoC) criterion to determine safety stock. This criterion is partly based on the ABC classification but heavily supplemented and changed by the insights and experience of employees.

10.5. How can inventory be classified?

The most common technique for classifying inventory comes from Pareto who describes that roughly 20 percent of products make up 80% of the annual dollar usage. These 20% of products should be given the classification A, most important. The next 30% is classified as B and the last half of the portfolio receives a C classification, least important. Most authors agree that the products with an A classification should receive the highest service level and thus relatively large amounts of safety stock. In literature, more extensive methods have been discussed that take into account factors such as revenues or profits (Silver, Pyke & Thomas, 2016), lead time and criticality (Chen, 2008), and availability and commonality (Flores & Whybark, 1987). Also, a number of authors argue for the use of multiple criteria and use methodologies such as Weighted Linear Programming (Ramanathan, 2006; Zhou & Fan, 2007), AHP (Flores, Olson & Dorai, 1992) and Fuzzy classification (Chu, Liang & Liao, 2008).

10.6. Which types of inventory control policies are described in literature

Literature distinguishes inventory control policies mostly on two factors; the type of review and the lot size. Reviewing inventory can be done periodically as well as continuously and the lot size can be either fixed or variable. This leads to four basic control policies which are:

A (R,s,Q) policy, meaning inventory is checked with frequency **R** and **Q** is ordered if inventory is below **s**.
A (s,Q) policy, meaning that **Q** is ordered as soon as inventory drops below **s**.
A (R,S) or (R,s,S) policy, meaning that with frequency **R**, inventory is raised to the level **S**. A (R,s,S) policy is similar to (R,S) except that inventory may be unchanged during **R** and therefore nothing is ordered.
A (s,S) policy means that as soon as inventory drops below **s**, inventory is raised to the level **S**.

For all inventory control policies, the idea of determining safety stock is the same. It is calculated by determining a safety factor and multiplying this by the standard deviation of demand during the lead time and the square root of the period of uncertainty.

10.7. What is the relation between safety stock and finance?

The relation between safety stock and finance can be described as the trade-off between stockout costs and obsolete costs. When having too little safety stock, chances of a stockout increases. When facing a stockout, Grolsch faces administration, transportation and lost sales costs. On the other hand, when safety stocks are too high, chances of the stock becoming obsolete increases. When products are not sold within 30% of their shelflife, they may have to be sold at a discount or in the worst case, destroyed.

10.8. What is the relation between safety stock and customer service?

Grolsch uses the term stock availability to measure customer service. We have proven that this equals the theoretical term Ready Rate which in our case equals the fill rate. The fill rate can be calculated by dividing the expected shortage at the end of a cycle by the expected demand during this cycle.

10.9. What requirements and constraints are there for a safety stock model?

The new safety stock model needs to take into account the effects of seasonality, should incorporate the production flexibility of a product and should never output a safety stock which has high chances of becoming obsolete. The first requirement is met by advising Grolsch to update the model at least twice a year and optimally each quarter. When the model is updated, classifications change because expected demand for seasonal products will change. Products such as Radlers which are very seasonal may receive a higher classification in peak season and will thus receive more safety stock. The second requirement is met by a Multi Critieria Analysis on the production flexibility of a product. Much like the traditional ABC classification, all products receive a classification ranging from 0, very flexible, to 2, inflexible. Products which are inflexible receive relatively more safety stock than flexible products. The safety stock model also limits the amount of safety stock based on the chances of it being consumed within the shelflife to address the third requirement. Finally, the RMSE measure is used instead of the standard deviation of demand to better incorporate the effects of forecast accuracy.

10.10. How can we improve the current inventory control methods?

The current inventory control methods are partly based on an outdated classification. The first step in improving the inventory control method therefore lies in updating this classification. This is easily done within the new safety stock model. Next, the effects of seasonality are not incorporated into the old inventory control methods as much as is desired. This is also improved into the new safety stock model. Finally, our safety stock model monetizes its outcomes and optimizes based on lowest costs. This makes it easier to defend a particular choice for safety stock. The debate on the trade-off between service and inventory is hereby quantified.

10.11. How do we ensure the validity of a new model?

We have validated our model with historic data. We have modelled levels of safety stock using the expected demand and RMSE for 2017 and concluded that difference between our model and the actual values were not statistically significant. The output for the stock availability in our model deviates from the actual value by 0.2%. This difference can be explained by the effect of the SCP department. Moreover, formulas to calculate safety stock and fill rate hold because we have proven that both inventory as well as demand are normally distributed.

10.12. What are costs and service levels associated with the new model and how does this score compared to the old methods?

In our new model we can achieve ssavings of approximately 6% simply by shifting safety stock between products. In addition, with slight changes to inventory and stock availability we can decrease yearly costs by 7%.

10.13. What is the effect of marginally increasing/decreasing target service levels?

Marginally decreasing the stock availability by 0.1% causes 1.4% less pallets but 1.1% more costs.
Marginally increasing the stock availability by 0.1% causes 2.6% more pallets and 1.7% more costs
Marginally decreasing inventory by 1,000 pallets causes a decrease of 0.6% in stock availability and 13.8% more costs.
Marginally increasing inventory by 1,000 pallets causes an increase of 0.2% in stock availability and 7.3% more costs.

11. Discussion & further research

In our final model, the number of obsoletes and stockouts and costs associated with it, plays a crucial role. Because it is not known how many pallets have passed the 30% shelf life or how many stockouts have occurred historically, it was impossible to check the outcome of our model thoroughly. We advise Grolsch to start collecting data on these occurrences. When this has been done for at least half a year, the approximation of 29% of the products value for obsolete costs and 35% of the products value for stockout costs can be validated.

Next, we have formulated a method to determine the production flexibility of a product. In our model however, this does not translate to an increase or decrease in the expected number of stockouts. A highly flexible product is expected to have fewer stockouts than an inflexible product with the same levels of safety stock. It may be interesting to look into ways of incorporating this production flexibility into the calculations for stockout and fillrate. Another way to tackle this challenge is to determine a CSL for every SKU instead of basing it on the classification of the product. Although this is very time consuming, we have experimented with running optimization algorithms. Such an algorithm selects a random SKU and changes its CSL marginally. If total costs decrease, it will accept the change and move on to the next SKU. After running several optimization loops, we were able to reduce total costs by almost 100,000 euros.

A third point of discussion concerns itself with Chapter 5 in which we have analysed the benefits and drawback of larger batch sizes. The benefits that are described in this analysis may not be fully attributed to the SCP department. Also in the Packaging department significant efforts have been made to produce more efficiently. Because the results of these two improvement projects are intertwined it is difficult, if not impossible, to determine which department is responsible for which part of the result. Moreover, the increased efficiency has also caused the production line to produce at a higher rate. The extra benefit of this increased speed has not been taken into account. After performing this research, we feel that much could still be researched in this area.

For the determination of external inventory costs, we have only looked at the transportation costs to and from the harbour. We have already determined that holding costs are equal however there is another cost factor which could be debated. When transporting goods to the harbour, extra handling and transportation takes place. The more often a product is handled and transported, the higher the risk of damage becomes. This increased risk of damage is not taken into account for the costs.

Staying on the subject of storing goods in the harbour, we would like to advice Grolsch to look further into the possibilities of harbour storage. In our research we have seen that inventory should not be reduced significantly. We therefore expect that harbour storage will be used regularly in the future. If Grolsch would be able to deliver customers straight from the harbour, costs of external inventory would be reduced by almost half.

12. Literature

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Appendix I. Expected external inventory costs

L $= Warehouse\ limit$
P $= \#pallets\ per\ truck$
H $= Handling\ time\ for\ one\ truck\ for\ both\ loading\ and\ unloading\ in\ hours$
W $= Hourly\ costs\ of\ handling\ in\ euro's$
T $= Transport\ costs\ for\ one\ return\ trip\ of\ one\ truck\ in\ euro's$
E $= Combination\ efficiency\ of\ a\ truck$
x_i $= Expected\ stock\ level\ in\ week\ i$
σ $= Historic\ absolute\ error\ of\ stock\ level$
p_i $= Expected\ \#pallets\ exceeding\ warehouse\ limit\ in\ week\ i$
t_i $= Expected\ \#trucks\ needed\ in\ week\ i$
CH_i $= Handling\ costs\ in\ week\ i$
CT_i $= Transport\ costs\ in\ week\ i$
TC $= Total\ costs$

$$z_i = \left(\frac{L - x_i}{\sigma}\right) = \left(\frac{19500 - x_i}{1495}\right) \qquad \forall i$$

$$P(x_i \leq L) = \Phi(z_i) \qquad \forall i$$

$$G(z_i) = \varphi(z_i) - z_i[1 - \Phi(z_i)] \qquad \forall i$$

$$p_i = \sigma * G(z_i) \qquad \forall i$$

$$t_i = \frac{p_i}{P} \qquad \forall i$$

$$CH_i = t_i * H * W \qquad \forall i$$

$$CT_i = t_i * T * (1 - E) \qquad \forall i$$

$$TC = \sum_{i=1}^{59} CH_i + CT_i$$

Appendix II. Analytical Hierarchical Process (AHP)

Procedure of the Analytical Hierarchical Process for determining the flexibility of a supplier:

1. Determining the criteria on which to score each alternative
   M1:Lead time in weeks
   M2:Distance to Grolsch in kilometres
   M3:Percentage delivered on time and in full ranging from 0 to 100%
   M4:Amount of inventory on stock, scored from 1 to 5 assessed by the materials manager.
2. Determining the weight of each criterion by making pairwise comparisons:
   1: The two criteria are of equal importance
   3: Criterion i is slightly more important than j
   5: Criterion i is highly more important than j
   7: Criterion i is very highly more important than j
   9: Criterion i is extremely more important than j

	M1	M2	M3	M4
M1	1.00	1.00	1.00	7.00
M2	1.00	1.00	1.00	7.00
M3	1.00	1.00	1.00	7.00
M4	0.14	0.14	0.14	1.00
Sum	3.14	3.14	3.14	22.00

	M1	M2	M3	M4	Total	Avg.	Cons.
M1	0.32	0.32	0.32	0.32	1.27	32%	4.00
M2	0.32	0.32	0.32	0.32	1.27	32%	4.00
M3	0.32	0.32	0.32	0.32	1.27	32%	4.00
M4	0.05	0.05	0.05	0.05	0.18	5%	4.00
	1.00	1.00	1.00	1.00		**CI**	0.00
						RI	0.90
						CR	0.00

The scores of the first table are divided by the sum of the column to obtain the scores in the second table. The weight of each criterion can be found in the column named "Avg" and is obtained by dividing the sum of the row by the number of criteria. Finally, a check is done to determine whether the pairwise comparisons are consistent.

3. Scoring each alternative and standardizing their score on a scale from 0 to 1.

Supplier	Scores				Standardized				Score
	C1	C2	C3	C4	C1	C2	C3	C4	
Supplier 1	2	175	99	4	0.06	0.07	0.00	0.50	0.06
Supplier 2	10	825	99	5	1.00	0.49	0.00	0.00	0.47
Supplier 3	5	450	99	3	0.41	0.25	0.00	1.00	0.25
Supplier 4	4	175	99	3	0.29	0.07	0.00	1.00	0.16
Supplier 5	1.5	325	99	3	0.00	0.16	0.00	1.00	0.10
Supplier 6	10	200	95	5	1.00	0.08	0.44	0.00	0.49
Supplier 7	1.5	75	94	3	0.00	0.00	0.56	1.00	0.22
Supplier 8	10	1075	95	5	1.00	0.66	0.44	0.00	0.67
Supplier 9	2.5	900	90	3	0.12	0.54	1.00	1.00	0.57
Supplier 10	4	1600	99	4	0.29	1.00	0.00	0.50	0.43

Each standardized score on the criteria is multiplied by the weight of the criteria and the sum of these outcomes is denoted by the final score.