MASTER THESIS

Feasibility of an Automated Offline Repacking Solution at Grolsch

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Management Summary

We conduct this research at the Grolsche Bierbrouwerij Nederland B.V. (Grolsch) for the study Industrial Engineering & Management. Grolsch is a Dutch beer brewery that was acquired by Asahi Breweries in 2016.

In this research we investigate the feasibility of an automated offline repacking machine. The brewery of Grolsch is completely designed for mass production. Originally, a very limited amount of packaging configurations were produced at Grolsch. The production lines are set up in such a way that the flow through the plant is made efficient for the mass production of these few configurations. However, nowadays Grolsch notices that customers request other packaging configurations. The production lines are unable to handle some of these configurations. Grolsch currently tackles this problem by producing these products as loose bottles on the production line and repacking these bottles in an offline manual setting. In this research, we look at the products that Grolsch currently produces on Production Lines 2, 4 and 7. These production lines produce bottles and Lines 2 and 4 have products that require manual repacking. To investigate the feasibility of an automated offline repacking machine, we design the following research goal:

To determine the feasibility of an automated offline repacking solution that will increase machine and factory efficiencies, increase flexibility of the production process, decrease stock levels and decrease repacking costs.

Design of alternatives
We start by looking at the technical and organizational requirements and wishes for an automated offline repacking machine at Grolsch. This gives us an overview of the capabilities that a machine must have and the limitations that the current situation at Grolsch has. Based on these requirements we come up with 5 alternatives:

1. A new production line that produces stock keeping units (SKUs) that originate from Production Line 2. These SKUs are now produced in their 24-loose bottle variant and are later repacked on the new production line. The speed of this new production line is 15,000 bottles per hour.
2. A production line that is equal to the line proposed in Alternative 1. The speed of this new production line is 30,000 bottles per hour.
3. A new production line that produces SKUs that originate from Production Lines 2 and 4. These SKUs are now produced in their 24-loose or 16-loose bottle variant and are later repacked on the new production line. The speed of this new production line is 15,000 bottles per hour.
4. A production line that is equal to the line proposed in Alternative 3. The speed of this new production line is 30,000 bottles per hour.
5. A new production line that produces SKUs that originate from Production Lines 2, 4 and 7. The SKUs from Lines 2 and 4 are now produced in their 24-loose or 16-loose bottle variant and are later repacked on the new production line. The SKUs from Line 7 are transported directly from Line 7 to the new line using a conveyor belt. As the new line is linked to Production Line 7, the speed of this new production line has to be equal to the speed of Line 7, hence the speed is 48,000 bottles per hour.

Evaluating alternatives
To determine the feasibility of the 5 alternatives, we evaluate them financially and logistically. To do so, we look at the benefits that an automated offline repacking machine has to offer. These benefits are improvements of the current situation of Grolsch. We look at the effect on the machine efficiency of the existing production lines, the effect of inventory aggregation on the stock levels and the reduction of operators due to the simplification of the current production lines. Besides, we find

a possibility to increase revenue by changing products that are currently packaged in a 3-pack to 4-packs. Finally, we find a possibility to lower the costs made by Grolsch on maintenance of the current production lines and manual repacking.

Besides the benefits, we look at 3 costs. First of all, the investment costs for the actual machine proposed in each alternative. Next, the increased handling costs by the warehouse due to the fact that products are now created on a production line, are then sent to the warehouse and are later transported to the automated offline repacking machine for the final production steps. This thus increases the required handling time of these products and thus the handling costs. Finally, we look at the expected production costs of the automated offline repacking machine for each alternative.

Results

After determining the benefits and costs, we calculate the present worth of the alternatives. We find that only Alternative 5 has a positive present worth, which means that this alternative is the only one that Grolsch should consider, since the other alternatives will cost Grolsch more. The payback period of Alternative 5 is 13 years. The results of the financial comparison between the alternatives is shown in Table M.1.

Table M.1: Financial comparison of the alternatives

Alternative	PW	Annual worth	Payback period
Alternative 1	-€ 5,998,565	- € 609,271	None
Alternative 2	-€ 6,106,080	- € 617,990	None
Alternative 3	-€ 4,650,712	- € 487,645	None
Alternative 4	-€ 1,456,328	- € 144,564	None
Alternative 5	€ 902,557	€ 100,160	13 years

Besides an automated offline repacking machine, we also look at a cratecover machine. Currently, manual workers put cratecovers over the crates. We find that a cratecover machine is a good investment in Alternatives 4 and 5. However, the best option for Grolsch is to add a cratecover machine directly to Production Line 2 instead of adding it to the new production line. This results in a payback period of 4 years.

Table M.2: PW and Payback period Cratecover machine

Option	Present Worth	Payback Period
Alternative 1	-€ 220,365	None
Alternative 2	-€ 29,105	None
Alternative 3	-€ 147,093	None
Alternative 4	€ 52,310	11 years
Alternative 5	€ 219,296	6 years
Production Line 2	€ 400,009	4 years

Recommendations

We recommend Grolsch to not invest in an automated offline repacking machine. Alternative 5 is the only option that has a payback period. However, this payback period is 14 years and the expected lifetime of the machine is 15 years.

Furthermore, we recommend Grolsch to invest in a cratecover machine and add this to Production Line 2. The benefits outweigh the costs for this investment and the payback period of this investment is 4 years.

Next, we recommend Grolsch to investigate buying simple, less expensive, packing machines to eliminate manual repacking for certain SKUs. For example, a machine that puts the carton on 3 or 4 bottles to create a 3-pack or 4-pack. These machines are less expensive than a complete automated offline repacking machine and could be interesting for Grolsch in both costs and production speed.

Finally, we recommend Grolsch to change the products that are currently in a 3-pack configuration to a 4-pack configuration. We expect Grolsch to increase the revenue of these products with €76,704 in 2020.

Acknowledgements

This thesis is the final result of my Master research performed at Grolsch for my study Industrial Engineering and Management. Over the course of five months I have investigated different opportunities of automated offline repacking solutions for the future situation of the brewery.

I want to thank Grolsch for the opportunity to conduct this interesting project. I immediately felt at home at Grolsch and especially at the Supply Chain Planning department. I would like to thank everyone that has helped me over the course of this project, either by answering every question I had or by guiding me in the right direction in brainstorm sessions. Without the input of all the people I have met and spoken with over this period, it would have been impossible to finish this thesis.

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Koen Bossink

Haaksbergen, December 2019

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Glossary

Word or abbreviation	Meaning
ATO	Assemble to Order
BB tank	Bright Beer tank
CODP	Customer Order Decoupling Point
DoC	Days of Cover: the number of days currently covered by the inventory on hand
FE	Factory efficiency
FTE	Full Time Equivalent
HL	Hectolitres = 100 litres
M&C	Maintenance & Cleaning
ME	Machine efficiency
MTF	Make to Forecast
MTO	Make to Order
NPD	New Product Development
SCP	Supply Chain Planning
SKU	Stock Keeping Unit
SS	Safety Stock

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1. Introduction

This research focusses on the feasibility of an automated offline repacking solution. Grolsch is a Dutch brewery that has been bought by Asahi Breweries in 2016. Besides the well-known brand Grolsch, they have other brands such as Kornuit, De Klok and Lech, which are all produced in Enschede. In 2018 67% of the produced beer was sold domestically, the remaining 33% is sold as export. Since the takeover by Asahi, Grolsch has increased both their revenues and net profit. We perform this research at the Supply Chain Planning department.

This first chapter introduces the project and outlines the project plan. Section 1.1 introduces the supply chain planning department. Section 1.2 gives an introduction to the production lines. Section 1.3 describes the reasons behind this research, Section 1.4 the research design, and Section 1.5 gives the final research deliverable.

1.1. Supply Chain Planning department

The Supply Chain Planning (SCP) department handles the tactical planning and scheduling of the production lines. Besides planning the production lines, the SCP department is also responsible for the material planning and the planning of all production activities outside the production lines, e.g. repacking of products into different packaging configurations, called the repack planning.

1.1.1. Tactical Planning

The often used hierarchical decomposition in manufacturing planning and control discerns strategic, tactical and operational levels of control (Anthony, 1965). The tactical level lies between the strategic level, where the organization's mission is defined, and the operational level, where short-term decisions are made regarding the execution of processes. At Grolsch, the tactical planning creates a production plan for the coming 78 weeks. This plan is verified and updated once a week. Besides this one-week check, the plan is also continuously updated when changes or uncertainties arise. The tactical plan considers the demand forecast, production capacity, (safety) stock levels, batch sizes and shelf lives. The output is a tactical plan that shows how much hectolitre (HL) per Stock Keeping Unit (SKU) should be produced each week.

1.1.2. Scheduling

The operational planning involves short-term decisions and has the lowest flexibility, as decisions on higher planning levels, respectively the strategic and tactical level, have demarcated the scope (Anthony, 1965). At Grolsch the tactical plan is used as the input for the scheduler. Based on the required HL per SKU that needs to be produced per week, the scheduler creates the operational plan for the next 12 weeks. The first 4 weeks of the plan are rather fixed, while the next 8 weeks are increasingly more rough as uncertainty increases. To create the operational plan, the scheduling department looks at the production capacity, setup- and changeover times, required (preventive) maintenance and any other restrictions or limitations. The scheduling department creates a detailed plan that shows precisely, down to the minute, what is done on the production lines during each day. The output of the scheduling department is needed for the brewing & filtration department and the material planning department.

1.1.3. Brewing & Filtration

Grolsch has two brewing installations where beer is brewed. The capacity of each of these two installations is 1700 HL per day. After brewing in one of the installations, the next step of the brewing process is to put the beer into fermenting and lager tanks. There are a total of 65 fermenting and lager tanks with a capacity of between 420 HL and 500 HL. The beer spends 3 weeks in these tanks. Afterwards, it is filtered in one of the three filtration lines. During this filtration process compounds can be added to create different kinds of beer, for example Radler beer. The filtration lines deliver the beer to one of the 20 bright beer (BB) tanks. From these tanks, the beer is filled at the production lines. The brewing & filtration department is responsible for getting the right beer on time in the right BB tank so that it can go to the production lines.

1.1.4. Material Planning

The final sub-department that the SCP department consists of is the material planning department. Grolsch offers a variety of different packaging formats. Beer is filled in kegs, bottles or cans. On a higher packaging level, the bottles or cans are packaged in plastic, carton or crates. The material planning department is responsible for the availability of all these materials and the timely delivery of these materials to the production lines. This department is also responsible for the returned goods, which at Grolsch are the bottles and crates that are sold domestically. The last responsibility of this department is to make the repack planning. This repack planning consists of a plan for all SKUs that are not produced as end products on the production lines, but instead require some manual repacking. For example, giftsets with different types of beer are repacked.

1.2. Production Lines

Grolsch currently has 8 production lines to produce the different SKUs. Each production line has a limited range of packaging formats that it can handle. Each line has different characteristics in terms of capacity, speed and packaging formats. Table 1.1 gives an overview of these production lines and their characteristics.

Table 1.1: Overview of Production line characteristics

Production Line	Packaging formats	Production schedule	Shift Hours per Week
Line 1	Kegs	Produces day and night	72 hours
Line 2	Specialty beers domestic 300ml	Produces day and night	120 hours
Line 3	Crates 24 bottles of 300ml	Produces day and night	120 hours
Line 4	450ml Swingtop bottles	Produces day and night	120 hours
Line 5	1.5L bottles	Produces when necessary	0 – 72 hours
Line 7	Non-returnable bottles	Produces day and night	120 hours
Line 8	300ml or 500ml cans	Produces day and night	144 hours
Line 20	1000L Tanks	Make to Order	0 – 40 hours
Proefbrouwerij	Kegs	Make to Order	0 – 40 hours

Production lines 2 and 4 share their personnel, Line 5 uses personnel of either Line 1, 4 or 7 when it is producing. The other lines are unable to share personnel and all have their own workforce.

The Proefbrouwerij is a small brewery within the brewery. Here, the brewers can produce small quantities of beer that are not possible using the other, larger brewing installations.

Grolsch currently does not have a Line 6. This is free, unused space near Line 5. Besides the production lines of Table 1.1, Grolsch identifies another “production line”, which is the manual repacking area. Here, workers perform all steps in the production process that Grolsch currently cannot perform on the automated production lines.

1.3. Reasons behind Research

From the goals set for the year 2019, Grolsch identified several projects that are relevant to investigate either on the short- or long-term. One of these projects is to investigate the feasibility of an automated offline repacking solution.

The brewery of Grolsch is completely designed for mass production. Originally, there was only a very limited amount of packaging configurations that were produced at Grolsch. The production lines are set up in such a way that the flow through the plant is made efficient for the mass production of these few configurations. However, nowadays Grolsch notices that customers require other packaging configurations. The production lines are unable to handle some of these configurations. Other configurations can be done on the current production lines, but the changeover times are so long and production rates so low that it is simply too inefficient to do so. Grolsch currently tackles this problem by producing these products as loose bottles on the production line and repacks these bottles in an offline manual setting.

Besides customer requirements, Grolsch is increasingly putting an effort in producing specialty beers. The addition of new specialty beers requires new packaging types and requires more changeovers. This is negatively impacting the efficiency of the production lines. The expansion of the production portfolio with these new specialty beers also requires an increasingly complex production planning.

The wish for an automated offline repacking solution has four reasons: (1) relatively low machine and factory efficiencies, (2) the capacity limitations of the warehouse, (3) costs of manual repacking and (4) flexibility in new developments. In the following sections, we elaborate on these four reasons.

Machine and Factory Efficiencies

Grolsch uses both machine and factory efficiencies to determine the performance of their production lines. Machine efficiency measures how the line performed relative to the expected required time period. This means that a machine efficiency of 80% means that 20% of the time is lost due to allowed stoppage time. Factory efficiency measures how effective the line performed based on external uncontrollable factors, such as quality issues with packaging material.

The current machine and factory efficiencies are insufficient for the growth that Grolsch is trying to achieve. The production lines are reaching their maximum capacity, as the weekly shift hours are almost at their maximum. The yearly volumes are also increasing. Grolsch could tackle this by adding an extra shift to the lines, however this is expensive and complex as the volumes are not high enough to require the extra shift throughout the year. Grolsch could also choose to have an extra shift for a certain period in the year. However, operators need to know this multiple weeks in advance and the actual required capacity is often not known weeks before. The best way to keep up with the growing volumes is to increase the efficiency of the production lines. In 2018, the overall factory efficiency of the production lines at Grolsch was XX%. The overall machine efficiency was XX% in 2018.

Figure 1.1 shows the tactical plan for Production Line 2 in 2019. Looking at this plan, Grolsch currently plans an average idle time of 7.4 hours per week. This is about 6% of the total available shift time. This is thus the available time for (unscheduled) breakdowns, stoppages or speed losses. There are four reasons why this will become insufficient in the future: (1) slack, (2) increase in production volumes, (3) increase in changeovers and (4) longer maintenance.

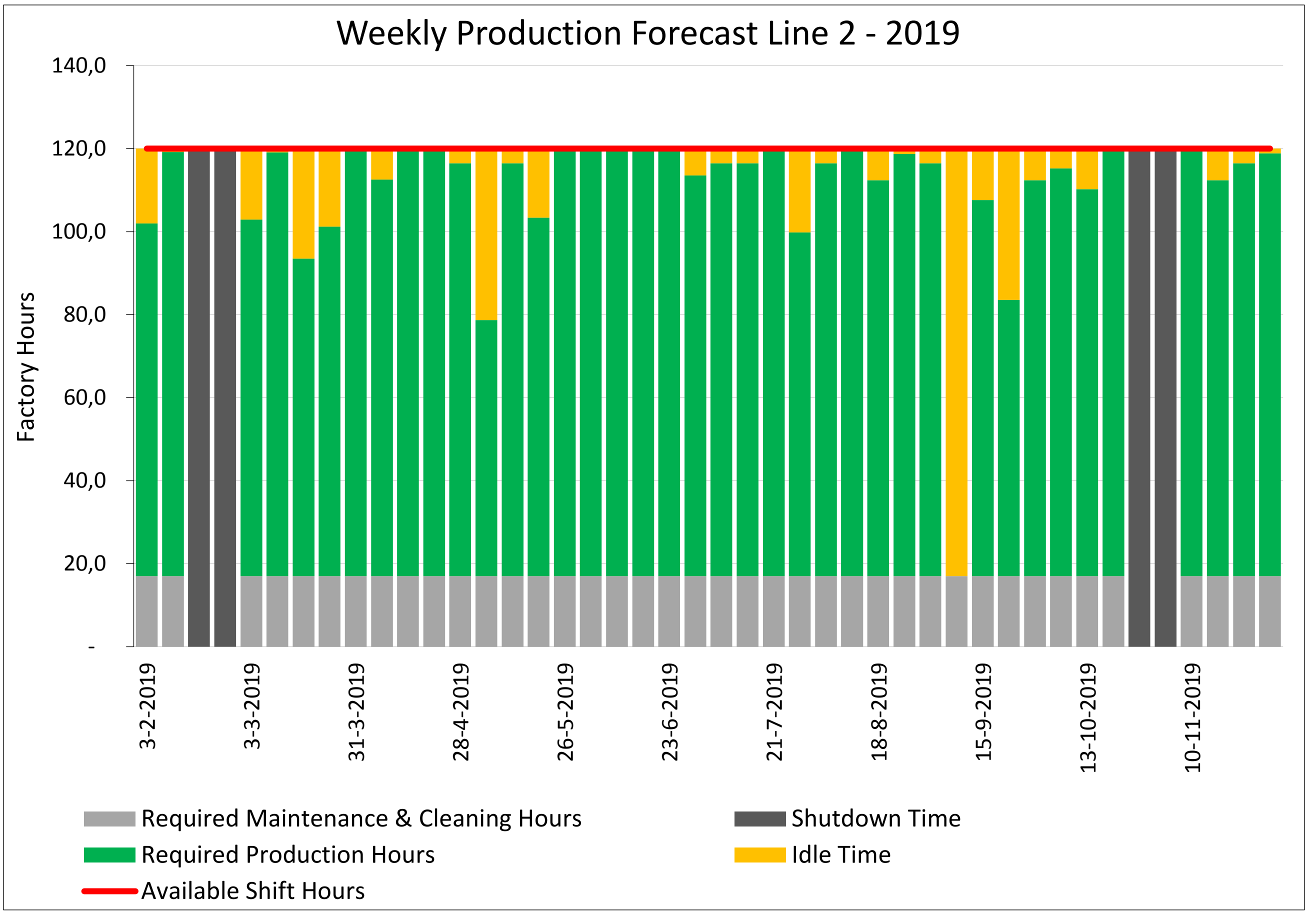

Figure 1.1: Weekly forecasted production hours Production Line 2 in 2019

First of all, we see in Figure 1.1 that although the average weekly idle time is 7.4 hours, this is actually influenced by a few weeks that contain a lot of idle time. The median weekly idle time is 3.5 hours and 14 weeks have an idle time of less than 1 hour. We see that there is not enough slack available to handle unexpected stops, speed losses or breakdowns. A breakdown that takes multiple hours or even days to fix, will thus potentially have a major impact on the production schedule, delaying future productions.

Second, the production volumes are expected to increase every year. Figure 1.2 displays the actual yearly volumes for years 2013 to 2018 and the forecasted production volume in 2019 to 2022. We see that production volumes are increasing. As the capacity is close to its maximum, Grolsch has to produce larger amounts with the same available machines and production time. Due to these higher production volumes, the average batch size is also increasing. This elongates the required production time per production, thus decreasing the idle time. Line 2 has produced for 46 weeks in 2018. The four weeks of shutdown in Figure 1.1 are required due to strategic periodic maintenance on the line. During this recurring periodic maintenance no production is possible. Of the 52 yearly available weeks, Grolsch can thus only use 48 weeks for production.

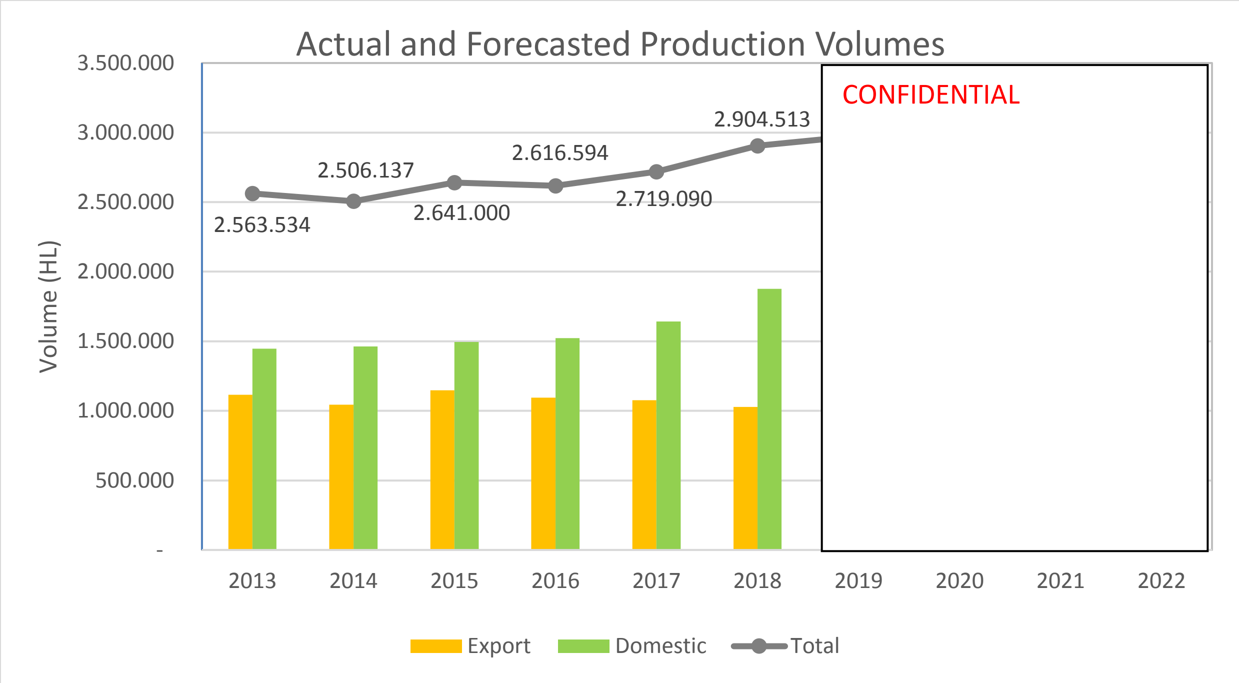

Figure 1.2: Actual and Forecasted Production Volumes

Third, changeover times have a big influence on the efficiencies of the machines. Every time production is done with a batch, some changeover time is required to go to the next batch. When this is the same SKU, and thus only a new beer tank has to be connected to the production line, it takes 15 minutes. However, changing the bottle used on the line can take up to 210 minutes. When the bottle remains the same, but the configuration changes from 24 loose bottles in a crate to four 6-packs in the same crate, the changeover time on Production Line 2 becomes 180 minutes. If the bottle, crate and configuration remain the same, and thus only the beer changes, this lowers to an average of 86 minutes. By lowering the required amount of changeovers and especially the long changeovers, the efficiency of the production lines will increase. Grolsch is also trying to produce more and different products. This means more SKUs and also more packaging configurations. This increases the total required amount of changeovers, thus lowering the efficiency of the production line and increasing the required production time.

Finally, the Maintenance and Cleaning (M&C) time required is planned by the SCP department as 17 hours per week for Line 2. This happens at the start-up in the week and at the end of the week. In 2018, however, the average actual M&C time was 18 hours. On average, thus, the actual available time for production was 1 hour shorter than planned. Besides M&C, Grolsch loses production time due to start-ups, shutdowns and other cleaning activities. Overall, one week of production on Line 2 requires 27.6 production hours of other activities. Because of the current machine efficiencies, Grolsch is required to produce almost every week. For example, Line 2 produced 46 weeks in 2018. This also means that Grolsch lost 27.6 hours per week for these 46 weeks due to these required activities. By increasing the efficiency of the line, Grolsch is able to produce the same amount of beer in a smaller period of time, thus reducing the required number of weeks. This consequently reduces the required time.

Stock levels

The warehouse at Grolsch has a theoretical limit of 20,000 pallets. It is possible to increase this limit to around 21,000 pallets when truly necessary. However, this is extremely undesirable as stock will be stored at different internal places than the end product warehouse, making it difficult to organize and inefficient to handle. Besides, this requires more internal replacements in the warehouse. After 18,500 pallets, the handling costs increase in the warehouse of Grolsch. This is the practical limit that

Grolsch is trying not to exceed if possible. This has resulted in Grolsch requiring external storage, which is currently done at the Harbour of Enschede. 4,000 pallets can be stored at the harbour.

The average weekly inventory level in 2018 was 17,455 pallets. Grolsch expects the average weekly inventory level in 2019 to rise to 20,587 pallets and to 24,772 pallets in 2020. During peak periods in 2019, inventory levels are expected to rise as high as 25,000 pallets. In 2020 inventories during peak periods can even be as high as 28,000 pallets. This leads to Grolsch needing even another external storage location and thus increased pressure on the process of the warehouse and the warehouse employees.

One of the reasons Grolsch has high stock levels, is that Grolsch holds safety stock for all make-to-forecast SKUs. This means that there are multiple plans done for the same type of beer, where the only differentiator is the packaging configuration. Stock is thus kept at the end-product level. This also means that the customer order decoupling point for all SKUs currently is placed after the production process. Products that follow the same production path up until the last differentiator, the packaging department, are currently split earlier in the process. Also the limiting capacity of the production lines and the seasonality of beer means that Grolsch has to build stock as much as possible during the weeks before the high season. For example, in 2018 there was an extraordinary long and hot summer. Sales increased to a point where production could not keep up with demand, thus requiring the safety stock to meet demand.

The processes at Grolsch make it impossible to divide one production into multiple smaller parts at the packaging process. With an average minimal batch size of 350HL for this process, it is currently undesirable to produce smaller quantities of slow-moving products, due to agreements for the sake of the efficiency of the production lines. This is especially difficult for new product developments (NPDs), as these often have uncertain and low demand. This creates a situation where every time a minimal batch size is made, part of this batch stays in the already full warehouse at Grolsch for multiple weeks. If the minimal batch sizes per SKU were lower, this lowers the required inventory levels. Lower minimal batch sizes would also decrease the chance of stock becoming obsolete.

Costs of Manual Repacking

Grolsch manually repacks a part of its SKUs. This happens due to the fact that not all configurations can be packed using the packaging machines available on the lines. These products are first produced as loose bottles on the production lines and are put in crates or boxes, which are transported to the repacking location. Here, workers take the bottles out of the crates or boxes, and repack the bottles to the desired configuration. Other activities of the repacking department consist of sorting returned bottles, transferring crates to the right pallets and creating gift packs.

The total forecasted volume of the repacked configurations in 2019 is 40,325 HL. In 2020 this increases further to 69,319 HL. Grolsch is developing more specialty beers that will first be sold in the configurations that currently require repacking. This is due to the fact that these are smaller configurations, e.g. 3-packs or 4-packs. This is done due to the nature of these products, as people tend to buy lower quantities of the same specialty beer at once.

Manual repacking is not as fast as a packaging machine. The speed at which products are repacked is only a fraction of the production line speed, which could limit Grolsch when the repack volumes would increase. Because of the lower speeds and the more labour-intensive production methods, manual repacking is also more costly. Looking at Production Line 2, crates of eight 3-packs are currently manually repacked. These bottles are first filled as 24 loose bottles in a crate. These crates are then transported to the repack area where workers take the bottles out, create 3-packs and put these back into the crates. 7 operators are working at Line 2. The nominal filling speed of this line is 180 HL per hour. 7 manual repack workers can only produce 13.3 HL per hour of these 3-packs.

An order of 500HL would only take 2.8 production hours to complete on Line 2. When this order needs repacking, this would add 37.6 hours to the required production time, totalling to 40.4 hours, assuming the number of manual workers is equal to the number of operators at Line 2. Obviously a lower amount of manual workers elongates the required repacking time.

Flexibility in new developments
The market is always changing, which means that different opportunities arise. Grolsch sees opportunities in creating new bottles in the future. This goes hand in hand with big investments on the production lines. The biggest part of this investment has to be done in the packaging part of the line, as additions to the machines are required. For example, a new bottle will mean that a new arm of the robot that puts bottles into crates or boxes has to be bought. This is a costly part to purchase. It is therefore interesting to look at a new packaging line that can process a larger range of different bottles and configurations to reduce future investment costs when new bottles are used.

1.4. Research Design

The problem stated in Section 1.3 is quite complex and large. Therefore, it is important to demarcate the problem. Section 1.4.1 describes the scope of this research. Next, Section 1.4.2 describes the research goal and questions, and the approach on how to answer the research questions. Finally, Section 1.4.3 describes the deliverable of this research to Grolsch.

1.4.1. Scope and Limitations

This research focusses on the feasibility of an automated repacking solution to increase machine and factory efficiencies at Grolsch. As there are 8 production lines that produce different product groups, it is important to demarcate the problem given the limited time available. We limit the scope of this research to production lines 2, 4 and 7. These production lines currently have SKUs that are manually repacked after being produced as loose bottles on the production lines or have many different configurations which increase the number of changeovers. These three lines also produce bottles. Kegs, cans and tanks are different and all have very different technical requirements compared to bottles and are therefore excluded from this research.

Grolsch keeps safety stock at the finished product level. In this research, we do not review the inventory policies and the formulas used to calculate safety stock at Grolsch. Yet, we are interested in the determination of safety stock levels due to the changed position of the customer order decoupling point, as part of the SKUs of Grolsch will be produced following an assemble-to-order production principle, and the effect of inventory aggregation on safety stock levels.

We limit this research to an investigation into a new offline automated repacking machine. We will not investigate possible modifications on the already available production lines. We investigate the economic feasibility of this offline solution.

1.4.2. Research Goal and Research Questions

The described problem leads to the following research goal:

The goal of this research is to determine the feasibility of an automated offline repacking solution that will increase machine and factory efficiencies, increase flexibility of the production process, decrease stock levels and decrease repacking costs.

To achieve this goal, we use multiple research questions. We present the research questions in the order of the chapters and describe how we answer them.

Chapter 2 – Current situation

1. *How does the current production and inventory planning perform and what is the current performance regarding the efficiencies, costs of production and warehousing and the planning of repacking at Grolsch?*
   Chapter 2 has the objective to get a detailed insight into the current situation at Grolsch. We first analyse the production process. Next we show the division of the SKUs over the production lines. This also gives an overview of all the packaging configurations that Grolsch uses and which are manually repacked. With this information, we analyse the costs that are related to the production and warehousing. Finally, to complete the analysis of the current situation, we look at the efficiencies of the production lines of Grolsch.

Chapter 3 – Literature

In Chapter 3, we position this research in the existing literature and investigate relevant research fields. The research goal can be split into three relevant topics: (1) postponement of manufacturing, as the final step of production will be delayed, (2) safety stock and the effect of risk aggregation on safety stock and (3) determining the payback period of a project. Because we look at the payback period, we also need to look at forecasting techniques, as we require production forecasts to determine benefits and costs. By performing a literature review, we find methods or techniques that help to achieve the research goal.

2.1. *What is available in literature on postponement of manufacturing?*
   The solutions that we investigate postpone parts of manufacturing for a selection of the SKUs of Grolsch. This also means that the Customer Order Decoupling Point (CODP) changes. We review existing literature on the CODP and the effects of changing it to an organization. Next, we research literature to find available methods about the postponement of manufacturing.

2.2. *What is available in literature on safety stock determination?*
   Postponement of parts of the manufacturing process means that stock will be kept at a different place in the supply chain. We research literature to determine methods to calculate safety stock levels at Grolsch for the new situation.

2.3. *How can the payback period of a project be calculated?*
   As the different solutions will be investigated for their feasibility, we need a method that compares solutions based on costs and savings. We review literature about methods to calculate the payback period and determine a valid method for this research.

2.4. *What are suitable forecasting models for the determination of future yearly production volumes?*
   As we look into the future to determine the payback period of the alternatives, we require a forecasting technique to determine the expected yearly production volumes.

Chapter 4 – Solution Design

3. *Which alternatives are suitable for an automated offline repacking machine at Grolsch?*
   In Chapter 4 we look at suitable alternatives for an automated offline repacking machine at Grolsch. We first consider the requirements and constraints that an alternative will have to comply with. Next, we propose alternatives based on these requirements and constraints.

Chapter 5 – Evaluating solutions

4. *Which alternative is the best option for Grolsch and how feasible is this alternative?*
   In Chapter 5 we analyse the proposed alternatives of Chapter 4. First of all, we look at the organization of the production process for each alternative. Next, we calculate associated costs, inventory levels and efficiencies based on the organization. Next, we calculate the payback period and the present worth of the alternatives based on the costs and benefits. Finally, we perform a sensitivity analysis to determine the robustness of the comparison.

Chapter 6 – Conclusion and Recommendations

In Chapter 6 we answer the main research question based on the results of the previous research questions. The conclusion describes the feasibility of an automated offline repacking solution and chooses which of the proposed alternatives is the best choice for Grolsch and whether this alternative is a feasible solution to the research problem. We also give recommendations about how Grolsch should implement this solution and what further research should be done in this area.

1.4.3. Deliverable

The final deliverable to Grolsch is an advice regarding the feasibility of an automated offline repacking solution. This research will provide a costs analysis of different alternatives. For these alternatives, we calculate both the benefits and costs. We use these to calculate the payback period. Besides, we perform a sensitivity analysis to determine the riskiness of the alternatives.

This research aims at identifying the optimal solution that provides the most benefits in the trade-off between on one hand the investment costs and payback time of the automated offline repacking solution and on the other hand the benefits in machine- and factory efficiency and holding cost savings due to a change in safety stock.

2. Current Situation

This chapter focusses on the first research question:
" What is the current situation at Grolsch regarding the efficiencies, the costs of production and warehousing and the planning of repacking? "

To answer this question, Section 2.1 shows an analysis of the SKUs that Grolsch has and how the overall production process of Grolsch looks. In Section 2.2 we research the costs related to production at Grolsch. In Section 2.3 we investigate the costs related to warehousing at Grolsch and finally in Section 2.4 we research the current machine and factory efficiencies at Grolsch.

2.1. Production Lines Analysis

Before going in depth into the costs that are associated with production and warehousing at Grolsch, we describe the current situation of the production process at Grolsch. In this section, we first show a flowchart of the production process of Grolsch. Next, we analyse the current set of SKUs that Grolsch has and the division of these SKUs over the productions lines. Finally, we elaborate on the manual repacking that Grolsch does.

2.1.1. Production Process

This section explains the production process in more detail. As Section 1.2 has shown, Grolsch has eight production lines that can be used. The production consists of four phases: the brewing phase, the filling phase, the packaging phase and the pelletizing phase. After the pelletizing phase, the storage process takes place. The packaging phase is either done online, where end-products are created directly on the line, or offline, where subassemblies are created on the line and these are later manually repacked to create end-products.

Figure 2.1 displays the flowchart of the production process at Grolsch. This represents the flow of products over the production lines 2, 4 and 7. We see that there are many steps in the production process. The process starts with either return bottles or new bottles. If there are return bottles, these need to be inspected and cleaned. As these are return bottles, it happens that the bottles in the crates are actually not used by Grolsch. These are sorted out along with the broken bottles. This sorting currently happens partly offline at the manual repacking department, before the bottles reach the production line. Another part is done automatically on the production line during the step 'check return packaging', along with the cleaning and inspection of these bottles.

The green part of Figure 2.1 shows the packaging area of the production line. When bottles go into crates, this area is fairly simple. The bottles are transported either to the machine that creates a 6-pack and then puts these into crates or the bottles go directly into the crates. When the bottles go into a carton, they either go directly into these cartons or they are put into packs. When this is the case, a machine first fills the boxes with empty packs and the bottles are then put into the empty packs inside the box. Finally the crates or boxes are stacked on a pallet and sent to the warehouse.

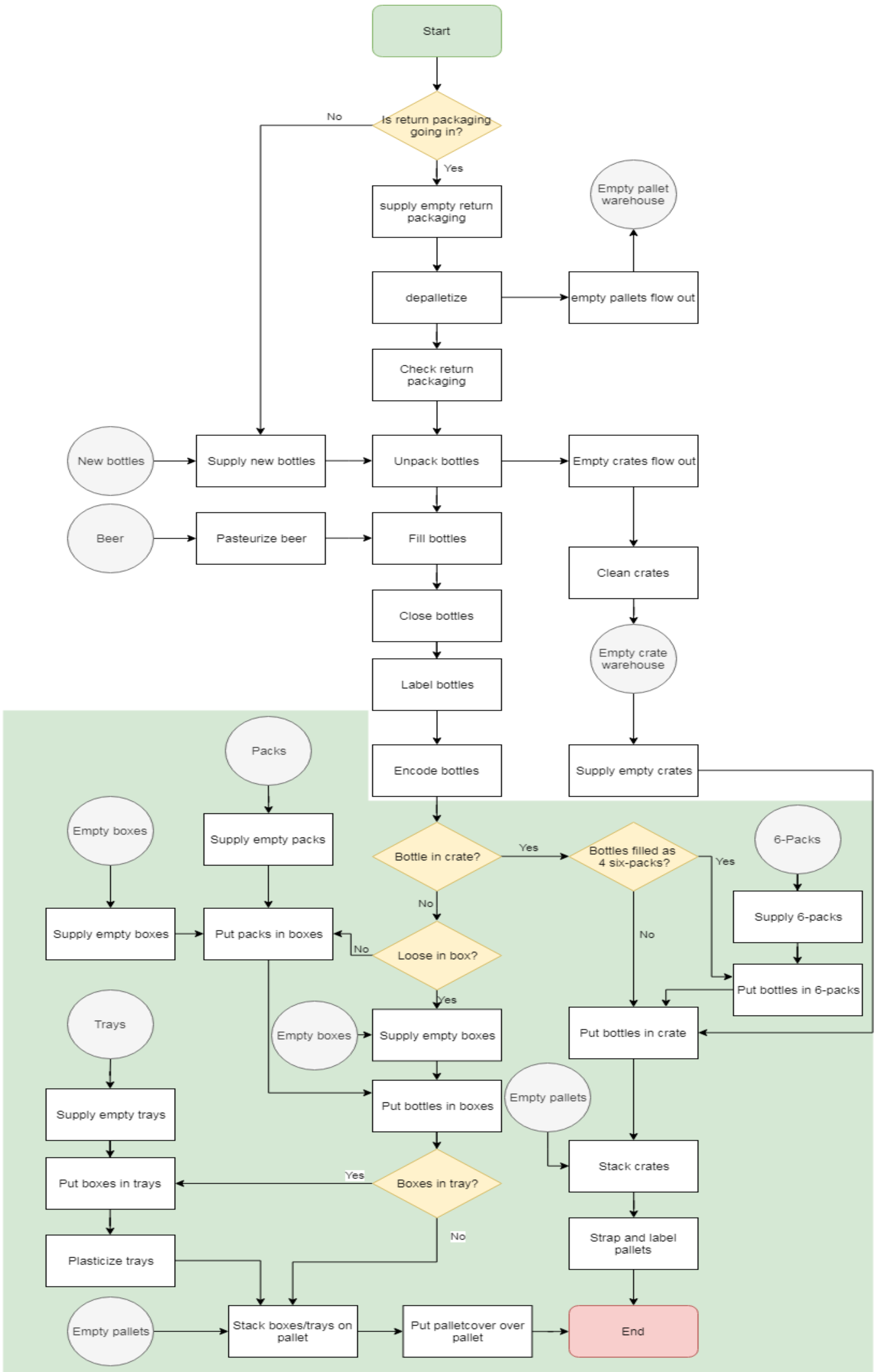

Figure 2.1: Flowchart production Grolsch

2.1.2. SKU Analysis

We mentioned in Chapter 1 that Grolsch currently has eight production lines. These production lines all have their own product groups that are produced. There is one other production location, where products are manually repacked. Table 2.1 shows the production lines at Grolsch, the number of SKUs produced on these lines and the forecasted volume produced on these lines in 2019.

Table 2.1: Current production line division

			Forecasted sales (in HL)				Average % of sales
Production Line	**# SKUs**		**2019**	**2020**	**2021**	**2022**	**2019-2022**
Line 1	24	(11.3%)					8.5%
Line 2	56	(26.4%)					10.2%
Line 3	2	(0.9%)					19.0%
Line 4	17	(8%)					7.0%
Line 5	3	(1.4%)					0.2%
Line 7	32	(15.1%)	Confidential				7.1%
Line 8	67	(31.6%)					42.2%
Line 20 (Tank filler)	7	(3.3%)					5.7%
Proefbrouwerij	4	(1.9%)					< 0.1%
Total	**212**						

From Table 2.1 we conclude that production lines 2, 4, 7 and manual repacking have a total of 105 SKUs, which is 49.5% of the total SKUs of Grolsch. The forecasted sales in 2019 of these 105 SKUs are XX HL, which is 24.3% of the total forecasted sales of Grolsch. We see in Table 2.1 that these volumes are increasing over the next three years.

Grolsch currently uses many packaging configurations. Table 2.2 gives an overview of the configurations that are done on production lines 2, 4 and 7. Online configurations relate to all the configurations that can be done on the production lines, offline configurations are all manually repacked configurations, which are first produced on the line in one of the other configurations, and then repacked. For example, eight 3-packs are first produced as 24 loose bottles in a crate on Line 2 and are then transported to the manual repacking area. Here the bottles are taken out of the crates, put into 3-packs and then put back into the crates.

Table 2.2: Packaging configurations division per production line current situation

Production Line	**Configurations online**			**Configurations repacked offline**		
Line 2	Crate 1x24	Crate 4x6		Crate 8x3	Crate 1x24[1]	Crate 6x4
Line 4	Crate 1x16	Carton 1x12		Carton 3x4	Carton 1x20	
	Carton 1x20	Carton 6x4				
Line 7	Carton 1x24	Carton 1x20	Carton 1x12	None		
	Carton 2x12	Carton 4x6				

In Table 2.2 we see that each production line has multiple configurations. A switch from one configuration to another requires changeover time, which lowers the utilization of the available machine capacity. In Section 2.2 we do a more in-depth analysis of the costs associated with these changeovers.

[1] These crates are repacked due to different crate stickers or special crate covers.

Besides different configurations, Grolsch has different bottles. Line 2 always produces 30cl bottles. However, there are 3 different types of 30cl bottles used. Line 4 has 2 different types of 45cl bottles. Line 7 uses 25cl, 33cl and 50cl bottles.

2.1.3. Repacking

In Section 1.3 we described that Grolsch is currently repacking a part of their SKUs. This is due to the fact that the current packaging machines are unable to comply with all the packaging configurations Grolsch has. The repacking department has two major responsibilities.

First of all, this department is responsible for the sorting bottles into the right crates. Bottles that are sold domestically are returnable in the Netherlands. This means that Grolsch has a return flow of bottles in crates. These bottles are often not put into the right crate by consumers or the bottles are not even used by Grolsch. Manual workers at the repacking department sort these returned crates to ensure only the correct bottles end up in the correct crates at the production lines.

The second responsibility of the repacking department is to perform the final packaging steps required before the product gets transported to the customer. Table 2.3 shows the activities that fall under this responsibility and the total expected sales volume per activity in the years 2019 to 2022.

Table 2.3: Repacking activities and their associated expected sales volumes

Activity	Exp. volume in 2019 (HL)	Exp. volume in 2020 (HL)	Exp. volume in 2021 (HL)	Exp. volume in 2022 (HL)
3-pack 30 CL bottle	10,316	4,723	5,150	5,615
4-pack 30cl bottle	1,200	1,000	1,090	1,188
Cratecover 24x30cl bottle	8,211	13,202	13,785	14,356
12-pack 45 CL bottle	1,200	5,000	5,465	5,974
4-pack 45CL bottle	5,242	3,199	3,347	3,502
20-pack 45CL bottle	1,072	903	1,489	2,118
Giftpack 5x30 CL bottle	439	484	532	584
6-pack 1.5L bottle	1,014	958	1,034	1,116
24-pack seal 33CL cans	3,707	0	0	0
Replacing pallets of crates	3,686	7,079	7,079	7,079
Replacing pallets of kegs	4,238	32,771	42,280	50,763
Total Line 2,4,7	**27,241**	**28,027**	**30,326**	**32,753**
Total	**40,325**	**69,319**	**81,251**	**92,295**

We see that the repacking volumes are increasing rapidly. The biggest cause of the increasing volumes is the replacing pallets of kegs activity. In Table 2.3 the activities that are coloured green are the activities done for SKUs of Production Lines 2, 4 and 7. When we look at only these activities, we see that in 2020 Grolsch expects a reduction in sales. However, in 2021 and 2022 this changes and the volumes increase.

2.2. Costs related to Production

Production costs are all costs incurred by a firm during the manufacturing of a product. These costs include a variety of expenses. We identify two relevant production costs for the current situation. First, we identify the hourly costs of running the production lines. Next, we look at the costs made due to manual repacking.

2.2.1. Hourly Production Costs

Costs are made once production lines are running. Table 2.4 shows the hourly costs made per line and the amount of operators that are required to run the line. We see that the costs are high, which is also a reason that Grolsch wants to reduce downtime of the production lines as much as possible.

Table 2.4: Hourly operating costs per production line

Production Line	Operating costs per hour	Number of operators
2	Confidential	7
4		7 or 8
7		5

Part of these operating costs are assigned to the operators working at the production lines. An operator has an hourly rate of €42.50.

Production Line 4
Production Line 4 has 7 or 8 operators. 7 of these operators are minimally required when the line is running. The 8th operator is only required when the SKU on the line is packaged in a carton instead of a crate.

The SKUs that are packaged in carton on Line 4 had a total production of 123,032 HL in 2018. With a nominal production speed of 135 HL/hour, we find that a total of **XXX** nominal operating hours were required for the extra operator. A production line almost never produces on their nominal speed. To determine the actual required hours for the SKUs that are packaged in carton on Line 4, Grolsch uses the Machine Efficiency (ME). This factors in a variety of different speed losses to determine the actual expected required production hours. It is calculated based on historical production data. We discuss the ME further in Section 2.4.

Looking at the ME of Production Line 4, which is currently set by Grolsch at **XX**% for 12-packs and 4-packs and **XX**% for 20-packs, we find that the total required machine hours are **X,XXX** hours in 2018. The cost of producing cartons on Production Line 4 for Grolsch in 2018 for the required 8th operator equals €66,366.

Table 2.5 shows the production costs associated with the carton products of Line 4 for the years 2019 to 2022. The required hours in Table 2.5 represent the time needed to produce the required volume based on the speed of Line 4 and the ME of the different configurations.

Table 2.5: Production Costs carton SKUs Line 4

Year	2019	2020	2021	2022
Required volume (in HL)	Confidential			
Required machine hours				
Expected costs	€ 57,192	€ 73,150	€ 74,410	€ 73,136

Production Line 7
Production Line 7 has 5 operators. Three of these operators are working at the filling part, which are always required. The other two operators are working at the packaging area of the line. Line 7 had a total production volume of 191,250 HL in 2018. With nominal production speeds per SKU ranging between 100 HL/hour and 150 HL/hour, we find that Grolsch required a total of **X,XXX** hours of production on Line 7 in 2018. 25cl products have a ME of **XX**%, 33cl products have a ME of **XX**% and 50cl products a ME of **XX**%. We find that the required machine hours were **X,XXX** hours. Grolsch paid a total of €173,292 for the two operators of the packaging area of Production Line 7 in 2018.

Table 2.6 shows the expected production costs associated with operating the carton machines of Line 7 for the years 2019 to 2022.

Table 2.6: Production costs carton SKUs Line 7

Year	2019	2020	2021	2022
Required volume (in HL)	Confidential			
Required machine hours				
Expected costs	€ 93,367	€ 112,921	€ 133,944	€ 164,774

Combining the production costs of the operators of Lines 4 and 7 that are required to produce the expected volumes of the years 2019 to 2022 gives us the total costs of producing the carton volumes in the current situation. Table 2.7 gives the total yearly expected production costs due to the extra operators that are required because carton is produced on Lines 4 and 7.

Table 2.7: Overview yearly expected production costs of extra operators Lines 4 and 7

Year	2019	2020	2021	2022
Expected costs Line 4	€ 57,192	€ 73,150	€ 74,410	€ 73,136
Expected costs Line 7	€ 93,367	€ 112,916	€ 133,944	€ 164,774
Total expected costs	**€ 150,559**	**€ 186,072**	**€ 208,353**	**€ 237,910**

2.2.2. Repacking

In Section 2.1.3 we described the activities that fall under the manual repacking department. Not all these activities fall within the scope of this research. For example, one of the activities is to replace kegs from a transportation pallet to a production pallet. We identify 6 activities that are currently processed on Lines 2, 4 or 7. After the bottles have been filled and put into crates, they are transported to the manual repack area where the final production process is carried out. Table 2.8 shows an analysis of these 6 repack activities. The cratecover activity is different compared to the other activities. Currently, manual workers put a cratecover on top of the crate. This is required for supermarkets so that it is clear whether the Radler beer in the crate is 0% or 2%. To do this activity automated, it requires a machine that is purchased solely for this purpose. We therefore exclude this activity from our solution design, but instead investigate the economic feasibility separately.

We see that the 6 activities are expected to take 9,674 man hours in 2019. The average cost of a manual repacking worker is €29.28 per hour. With this, we see that the extra costs of manual repacking, on top of the normal production costs, are equal to a total of €283,252. Excluding the cratecover activities we arrive at expected repacking costs of €254,631.

Table 2.8: Repacking activities and their associated expected volumes in 2019

Activity	Prod Line	Exp. volume in 2019 (HL)	Volume/worker /hour (HL)	Req. man hours in 2019	Exp. costs in 2019
Crate 8x3-pack 30cl	2	10,316	1.9	5429	€ 158,975
Carton 6x4-pack 30cl	2	1,200	1.9	632	€ 18,493
Cratecover	*2*	*8,211*	*8.4*	*978*	*€ 28,621*
Carton 1x20-pack 45cl	4	1,072	6.8	158	€ 4,616
Carton 1x12-pack 45cl	4	1,200	2.6	462	€ 13,514
Carton 3x4-pack 45cl	4	5,242	2.6	2016	€ 59,033
Total excluding cratecover		**19,030**		**8,697**	**€254,631**
Total		**27,241**		**9,674**	**€ 283.252**

Following the method of Table 2.8 and the yearly volumes of Table 2.3 we find the expected costs for the years 2020, 2021 and 2022. Table 2.9 gives an overview of the expected yearly repacking costs.

Table 2.9: Overview total yearly expected repacking costs 2019-2022

Year	2019	2020	2021	2022
Repack costs Line 2	€ 177,468	€ 134,213	€ 144,212	€ 154,879
Repack costs cratecover	€28,621	€ 46,018	€ 48,051	€ 50,041
Repack costs Line 4	€ 77,163	€ 96,222	€ 105,648	€ 115,834
Total Repack Costs	€ 283,252	€ 276,453	€ 297,911	€ 320,754

2.2.3. Changeovers

Due to the increasing number of SKUs, Grolsch is increasingly losing more time to changeovers. In Table 2.10 we see the expected changeover times for production lines 2, 4 and 7 in the years 2019 to 2022. We see that the yearly costs of changeovers are increasing as the expected required changeover time is also increasing.

Table 2.10: Overview changeover costs production lines 2, 4 and 7 in 2020-2022

Prod. Line	Hourly rate	Changeover time (hours)				Total costs changeovers			
		2019	2020	2021	2022	2019	2020	2021	2022
Line 2						€ 216,230	€ 232,244	€ 256,799	€ 280,101
Line 4	Confidential					€ 45,616	€ 47,180	€ 47,755	€ 47,313
Line 7						€ 216,189	€ 210,120	€ 226,328	€ 224,230
Total						**€ 478,035**	**€ 489,543**	**€ 530,882**	**€ 551,644**

The operating costs consist of all relevant fixed and variable costs, such as depreciation, hourly rate of operators, maintenance, energy and water use. The difference between these costs during normal operating hours and during changeovers is so small that we assume the operating costs during changeovers to be equal to the costs shown in Table 2.10.

2.3. Costs related to Warehousing

In this section the current costs related to warehousing are described. Grolsch keeps stock in order to ensure the availability of their products to the customers. There are costs involved with keeping stock. These costs can be divided in two: (1) holding costs and (2) obsolete costs.

2.3.1 Holding Costs

As we have seen in Section 1.3, the warehouse at Grolsch can store around 20,000 pallets. After 18,500 pallets, the handling costs increase in the warehouse of Grolsch. This is the practical limit that Grolsch is trying not to exceed if possible. Figure 2.2 shows the correlation between the inventory level and the required number of internal relocations. As the warehouse becomes fuller, it becomes harder to find a suitable location for a pallet. This results in extra internal relocations. To prevent these extra internal relocations from happening and because the required stock levels are too high to handle in the warehouse, Grolsch requires external storage. This is currently done at the Harbour of Enschede.

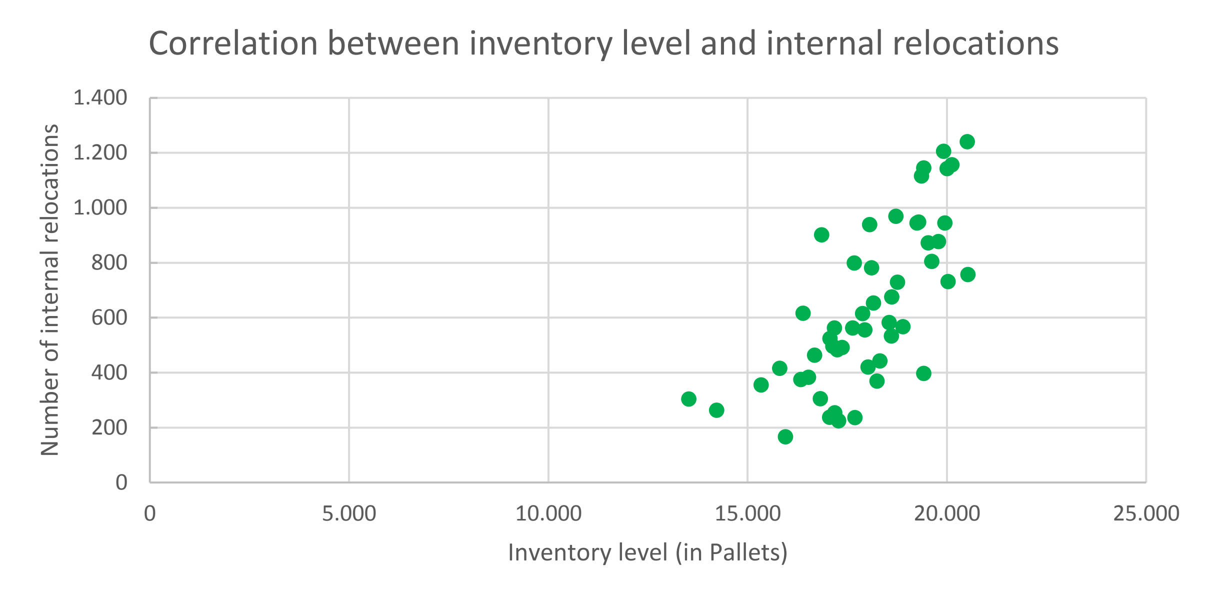

Figure 2.2: Correlation between inventory level and number of internal relocations

Figure 2.3 displays the actual weekly inventory levels in 2018. The average weekly inventory level in 2018 was 17,455 pallets. This is just 6% below the practical limit. The red line indicates the total available internal capacity, which is 20,000 pallets. The green line indicates the actual inventory levels at the internal warehouse. Without the external storage locations, Grolsch would have too much inventory in stock to handle during the last weeks of 2018. This results in storing pallets at other places than the warehouse locations. This is very undesirable and Grolsch tries to avoid this.

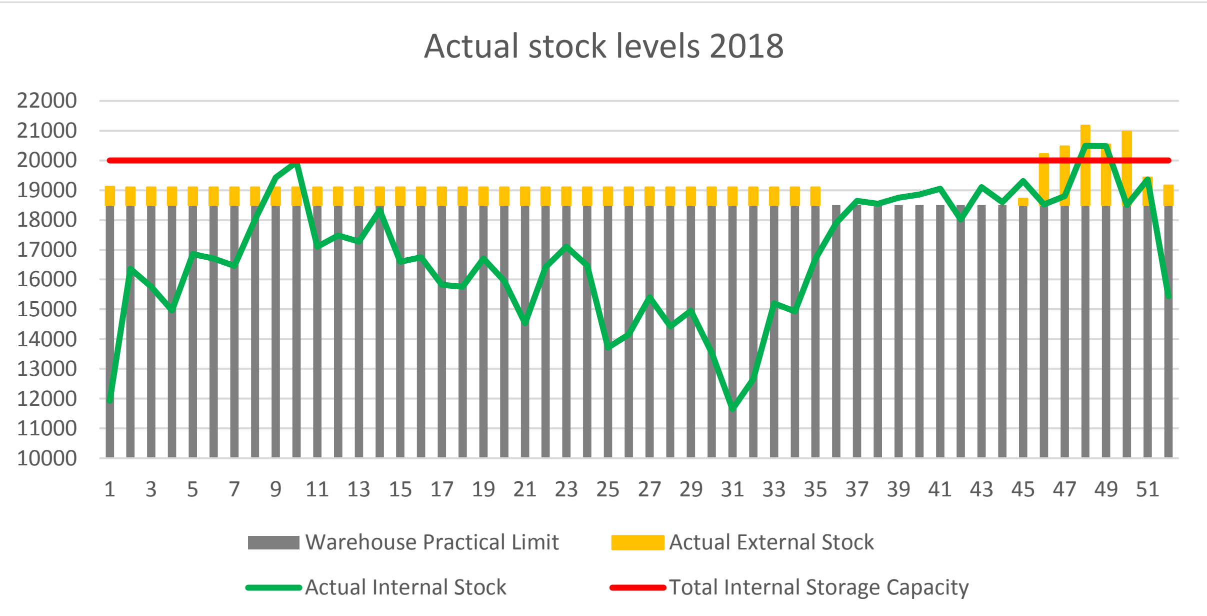

Figure 2.3: Actual Inventory levels 2018

Figure 2.3 shows a drop in the stock levels in the middle of the year. This is because beer sales have seasonality. The high season consists of the second and third quarter of the year and there is also a small peak in December. We see that the stock levels are increased just before the start of the high season. During the season, the stock levels decrease as demand increases.

For the year 2019 another external warehouse will also become necessary, as the storage limit of 4,000 pallets at the harbour is expected to be insufficient to store all the required stock. This new external warehouse has a storage limit of 3,000 pallets, making the total storage capacity for Grolsch around 27,000 pallets. Figure 2.4 displays the stock predictions for 2019. We see that Grolsch has to increase the external stock levels in order to keep the internal warehouse from overflowing. In fact, the harbour will be completely filled for almost the entire year.

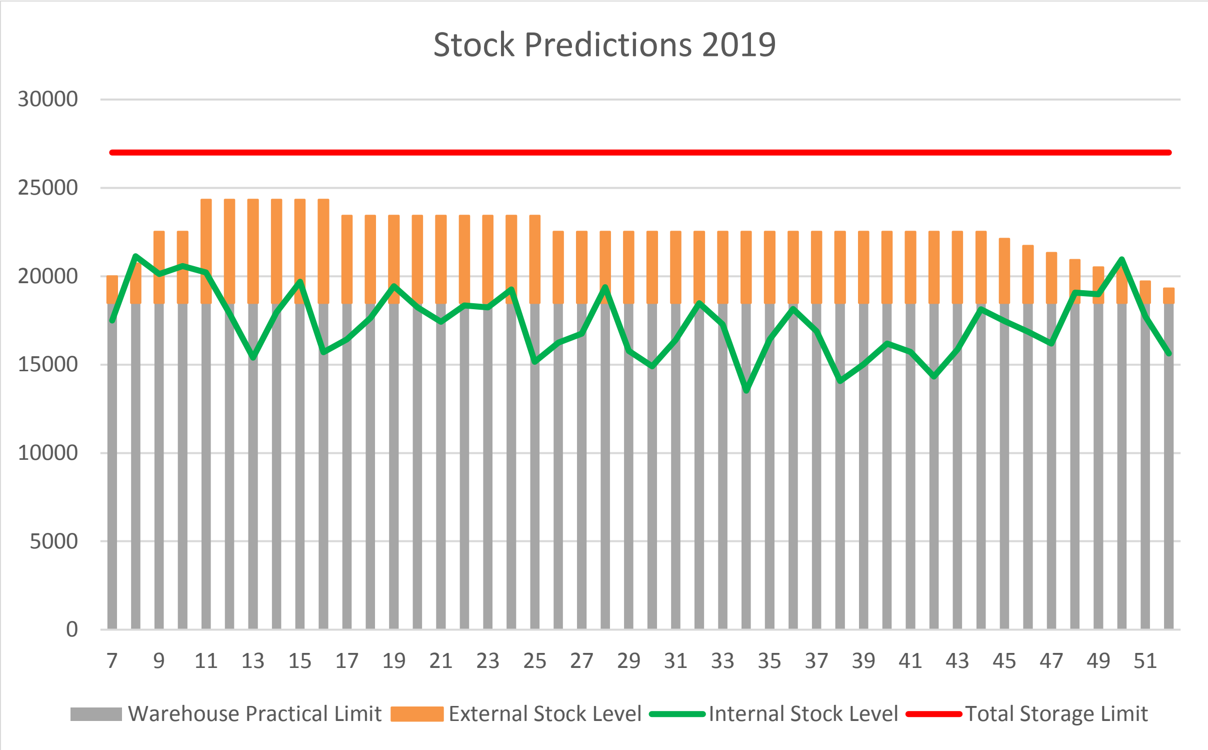

Figure 2.4: Stock predictions 2019

Figure 2.4 shows that Grolsch expects to reach the practical limit of its warehouse for most of the weeks, while having one of the external storage locations also completely filled. We see that in order to keep the stock levels beneath the practical limit, Grolsch has to increase the transportations to the external storage locations. Previously, Grolsch was able to fill the external warehouses with stock that could be transported directly from these warehouses, for example because the pallets are transported using ships directly at the harbour. However, due to the increased stock levels it is not possible to send only these products to the external warehouses. This results in Grolsch having to return these products to the brewery and shipping from the brewery, which is costly.

Finally, Figure 2.5 shows the stock predictions for 2020. We see that the external storage locations are filled up to keep the internal inventory levels below the practical limit.

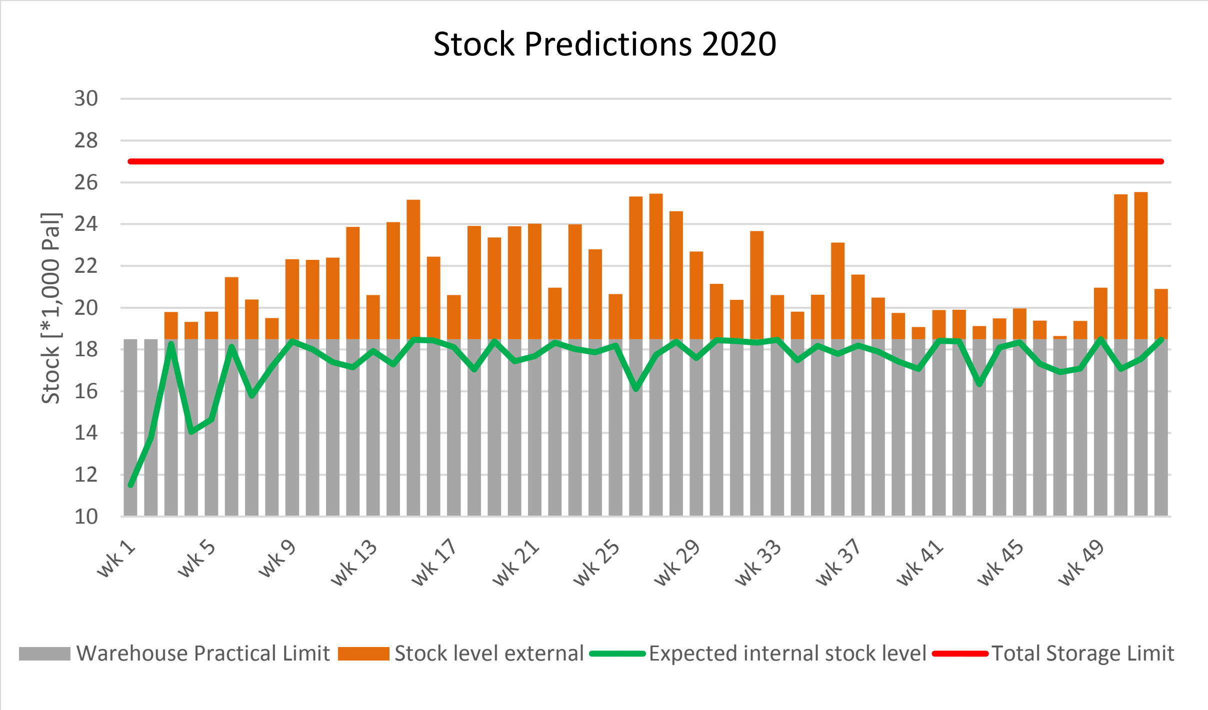

Figure 2.5: Stock predictions 2020

The total investments made in inventory can be extremely high, which creates a situation where capital is tied up in raw materials, half-fabricates and finished goods (Axsäter, 2015). For Grolsch this is not different. Obviously, there are some extra costs involved in storing inventory at the external locations. This is due to the extra transportation and handling costs. We assume there are no extra storage costs involved with these external warehouses due to the fact that the harbour is also property of Grolsch. In the future it will remain property of Grolsch due to the fact that other activities are done there as well.

Based on the stock predictions shown in Figure 2.4, the average weekly stock level in 2019 for both internal and external storage locations combined at Grolsch is expected to be 20,739 pallets. Using Equation 2.1, we calculate the weekly holding costs associated with this stock level.

$$Weekly\ holding\ costs = CC_W * CP * I \tag{2.1}$$

Here, CC_W = Weekly WACC rate;
CP = Average cost price per pallet;
I = Weekly inventory level in pallets.

The Weighted Average Cost of Capital (WACC) is a calculation of a firm's cost of capital (Sullivan, Wicks, & Luxhoj, 2006). At Grolsch, a yearly rate of 5.1%, or a weekly rate of 0.10% is used.

To determine the cost per pallet, we investigate the actual inventory levels and the corresponding value of the inventory over the year 2018. Figure 2.6 displays the relation between inventory levels and the value of this inventory. Looking at the trend line equation, we find the average cost per pallet to be €270.44. This can be used as the average cost price per pallet in Equation 2.1.

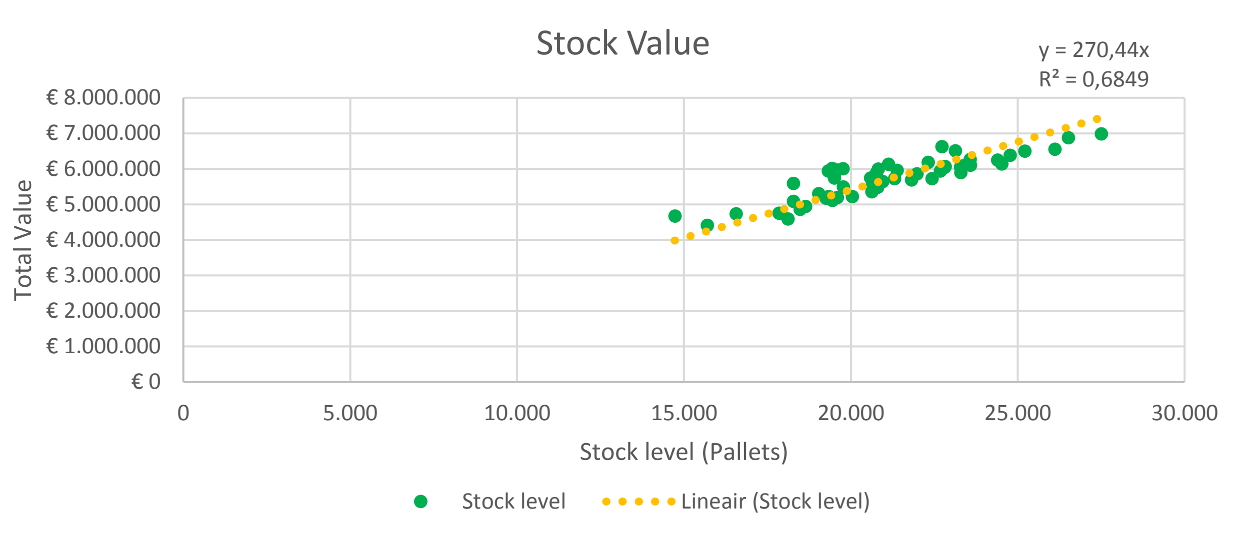

Figure 2.6: Stock Value Grolsch 2018

Using Equation 2.1, we calculate the average expected weekly holding costs in 2019 to be €5,609 (20,739 * 270.44 * 0.10%). Over the year, this sums up to yearly expected holding costs of €286,041. Compared to 2018, where holding costs were €240,747, this is an expected increase of €43,198 or 17%. We use Equation 2.1 to determine the expected holding costs for the year 2020 to 2022. Table 2.11 gives an overview of the expected holding costs for the years 2019 to 2022.

Table 2.11: Overview holding costs 2019-2022

Year	2019	2020	2021	2022
Expected average weekly stock level	20,739	21,075	22,104	23,228
Expected holding costs	€ 286,041	€ 290,676	€ 304,862	€ 320,377

Another important variable cost factor is the external inventory costs. As the warehouse of Grolsch does not have enough capacity to store all the required stock, Grolsch keeps stock at two other external storage locations. The formula to calculate these costs per pallet is shown in Equation 2.2.

$$\text{External Inventory costs per pallet} = \frac{T_t * R + C_O + (1-E) * C_O}{P_t} \tag{2.2}$$

Here, T_t = Required time for a return trip to the harbour;
R = Hourly rate of personnel;
C_O = Costs of a one-way trip;
E = Efficiency of transport;
P_t = Number of pallets per truck.

One trip to the harbour costs €60. It takes 30 minutes to both load and unload the trucks at the brewery and the harbour. When these pallets need to be transported back to the brewery, it costs €60 for the trip and the loading and unloading takes respectively 30 and 40 minutes. Obviously, Grolsch tries to combine these trips to reduce the amount of empty runs. We assume that an efficiency of 30% is possible for filling the return trip of a truck. The average hourly rate of personnel at Grolsch is €31. A trip to the new storage location of Grolsch takes approximately the same time, therefore we assume that the costs of storage at this location are equal to the costs at the harbour. Using Equation 2.2 we arrive at the following costs per pallet:

$$\text{External Inventory costs per pallet} = \frac{2.17 * 31 + 60 + (1 - 0.3) * 60}{26} = 6.51$$

Uncertainties in supply and demand combined with lead times in production and transportation create the need for safety stocks (Axsäter, 2015). Grolsch produces using the Make To Order (MTO) and the Make To Forecast (MTF) principles. For MTO products, no safety stock is needed since the demand for these products is known and fixed. For MTF products, Grolsch does keep safety stock. Grolsch keeps this based on a Days of Cover (DoC) principle. The parameter DoC indicates how many days the current on-hand stock is sufficient to cover demand based on the forecast. For each SKU, the minimum and maximum DoC are determined. The minimal DoC is thus the safety stock. The maximum DoC is necessary as beer is a perishable product. This is determined as 30% of the time until the expiration date. By producing stock for a maximum expected number of days, the chance of unsaleable stock due to expiration dates is minimised.

To calculate the average safety stock level using the DoC principle, Grolsch uses Equation 2.3.

$$\text{Safety Stock (SS)} = \frac{\text{DoC}}{7} * \mu \tag{2.3}$$

Here, DoC = Minimal Days of Cover (in number of calendar days);
μ = Mean weekly demand.

To give an example, if a SKU has a minimal DoC of 14 days and the mean weekly demand is 200, the safety stock is 400 units. Grolsch uses the real-time sales and sales forecasts of the next weeks to determine safety stock levels continuously. This way, safety stock levels are lower during low seasons. Safety stock is then also increased during peak periods. A big advantage of this method is that during the low season, stock levels are also lower and costs simultaneously. During the high season, stock is increased to ensure stock availability.

Applying Equation 2.3 to the SKUs of Grolsch gives a total average safety stock level of 6,684 pallets in 2018. This thus means that safety stock accounts for 36.8% of the total average stock level at Grolsch. Applying **Fout! Verwijzingsbron niet gevonden.** to the forecast of 2019 we find a total expected average safety stock level of 6,625 pallets.

As we have seen in Section 2.1.2, Grolsch has many different configurations. Most of the beers at Grolsch are used in multiple configurations. Table 2.12 shows the beers that go into different configurations on Production Line 2. We see that these SKUs combined have an average safety stock of 2,499 pallets and a total average stock of 5,346 pallets in 2018.

Table 2.12: Overview SKUs per beer ID

Beer ID	Container	Number of different SKUs	Sum of Safety Stock	Sum of Average Stock
242362	Bottle 300ml	3	157	806
242369	Bottle 300ml	3	1208	2490
242376	Bottle 300ml	3	64	215
242385	Bottle 300ml	7	175	414
242387	Bottle 300ml	3	104	28
256839	Bottle 300ml	2	10	102
262255	Bottle 300ml	2	5	183
262466	Bottle 300ml	2	4	86
262738	Bottle 300ml	3	363	469
262739	Bottle 300ml	5	389	509
262942	Bottle 300ml	2	17	5
263062	Bottle 300ml	2	3	39

Table 2.13 shows the breakdown of one of the beers from Table 2.12, beer ID 262738. We see that there is one SKU that contains a crate with four 6-packs, one SKU that contains a crate with 24 loose bottles and one SKU that has a cratecover, which is a requirement from the Dutch supermarkets.

Table 2.13: Breakdown of stock division for Beer ID 262738 – 300ml Bottle

SKU ID	Package	Configuration	Safety Stock	Average Stock
92122	Bot 300ml	Crate 4 x 6-pack	260	290
92133	Bot 300ml	Crate 24 loose	61	118
92284	Bot 300ml	Crate 24 loose cratecover	42	27
Beer ID 262738		**Total**	**363**	**469**

2.3.2. Obsolete Costs

As mentioned in Section 1.3, Grolsch has to produce minimal batch sizes due to several reasons. The most important reason is filtration, where a minimal batch size of 350HL is required for most products. Another cause for the minimal batch sizes is the three hour production rule. This means that Grolsch requires a batch size to be large enough to require production for at least three hours. Grolsch dedicates its productions to SKUs. This means that for Grolsch it is not possible to produce, for example, 100HL of a beer. In this case, it would be necessary to produce at least 350HL of this beer. This results in a situation where Grolsch needs to produce more of the same beer, while based on the forecast this may not have been necessary. Besides higher inventory costs, this increases the chance of stock becoming obsolete.

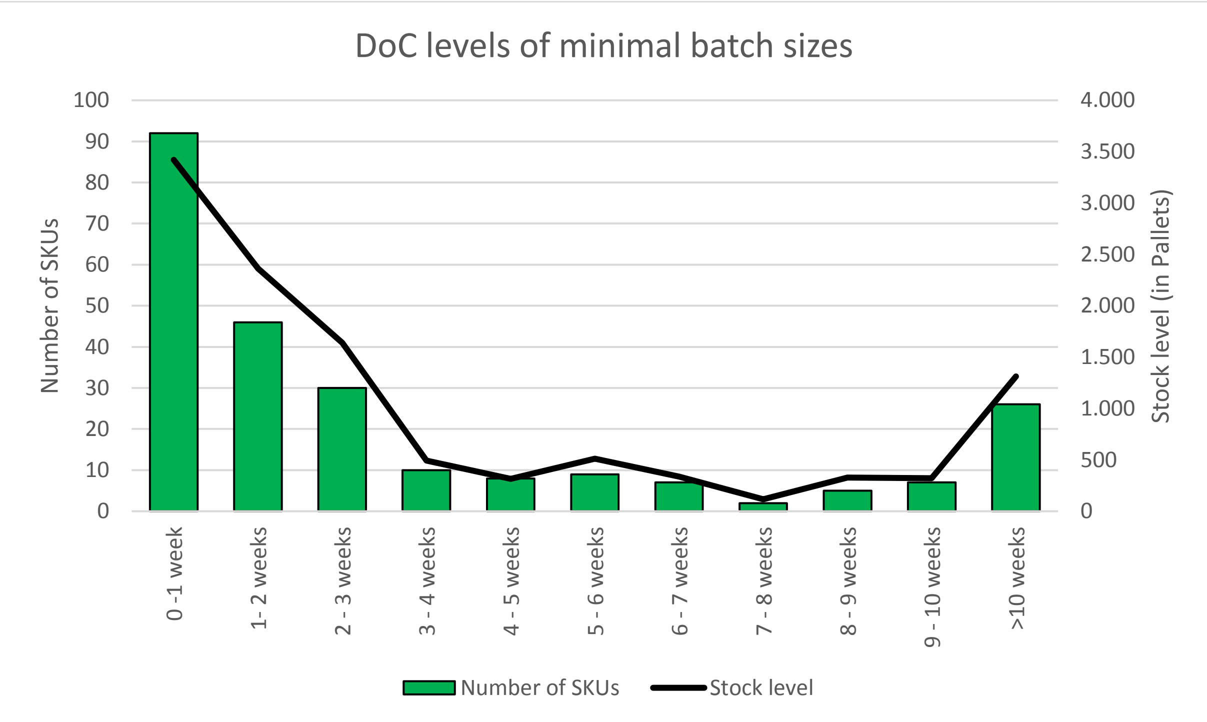

Figure 2.7: DoC levels of minimal batch sizes

Figure 2.7 shows the DoC levels that occur when a minimal batch size is made of a SKU based on the average sales in 2018. We see that for most of the SKUs, the minimal batch size will on average create stock that lasts at most three weeks. The SKUs with DoC levels higher than 10 weeks are mostly new product developments (NPDs) made in 2018, which makes sense as these are new and demand is still low. We see in Figure 2.7 that 47 SKUs have stock that is expected to last at least 6 weeks. The total stock created by minimal batch sizes of these SKUs is 2,419 pallets, from which 1,211 pallets are expected to last more than 6 weeks.

As beer is perishable, there is a maximum age at which Grolsch sells it. When products hit their shelf life (maximum age), this does not necessarily mean that they are destroyed. Grolsch keeps the shelf life as 30% of the due date of a product. This is a rule that Grolsch has created and one that customers are used to. Customers therefore may not accept products older than 30% of their due date. Grolsch makes a distinction between the groups of products with 30%-60% of the due date and products that exceed 60% of their due date. For the first group, Grolsch either sells the products for the regular price or sells it with a discount. The second group is either sold for the cost price of Grolsch or destroyed. The costs of destroying one pallet with obsoletes costs Grolsch €45. These costs come on top of the costs already made due to the production of the products.

Looking at the shelf life of the products, there are 22 SKUs that are expected to not be completely sold when they reach their maximum shelf life. These 22 SKUs have a total stock of 1,181 pallets when the minimal batch sizes are made. 346 pallets are expected to not be sold within their shelf life, based on the average weekly sales in 2018.

In 2018, Grolsch had a total of €**XXXX** in costs related to obsoletes. 24% of these costs were made due to obsoletes, products that were not sold before their due date and had to be destroyed. The other 76% of the obsolete costs are due to discounts for products that passed their shelf life.

In 2019, Grolsch expects the obsolete costs to increase. One reason for this is that Grolsch is increasing their product portfolio. The forecast of New Product Developments are highly uncertain as there is no known historical sales data. This causes the chance of obsoletes to be higher. Also, given the minimal batch sizes that Grolsch uses, it can simply be inevitable for some slow-movers to become obsolete.

2.4. Current Machine and Factory Efficiencies

In Section 1.3 we showed that the machine and factory efficiencies are not reaching their target levels. In this section, we look closer at the ME and FE of the production lines at Grolsch. We look at how Grolsch determines the ME and FE and analyse the ME and FE values of the production lines.

To analyse the efficiency of the production lines, Grolsch uses two different efficiency rates: factory and machine efficiency. Actual production output is dependent on many variables. Figure 2.8 shows the build-up of production capacity at Grolsch. Grolsch identifies five production capacity losses. The first four, respectively idle time, adjustments, Maintenance and Cleaning (M&C) and allowed stops, are all losses that are "planned" by the SCP department.

Idle time and adjustments are decided at the SCP department, based on the required productions for a certain week. Adjustments are all "allowed" time losses, such as planned shutdowns. The M&C are the hours that are spent during maintenance and cleaning periods. Allowed stops are all downtime periods related to changing between brands, packs, shifts or others. The service stops relate to time lost on a line due to factors that are outside of the production control, but within the plant management's control. Examples are shortages of materials, quality issues or breakdowns.

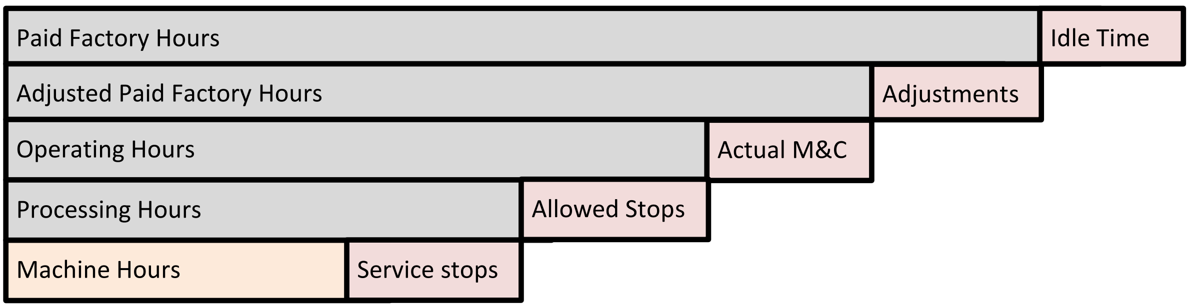

Figure 2.8: Build-up of Production Capacity

Machine efficiency (ME) is a variable that measures how effective the line has performed relative to the time period available once adjustments for actual M&C time and actual allowed stoppage time have been made. This is thus the efficiency of the production compared to the planned available processing time. ME is used as an input for the SCP department. Based on the speed of the line, ME adjusts the expected time needed to fulfil a production order. The ME is updated every three months based on the actual ME outputs. This way, the planned production schedule becomes more reliable when production lines perform significantly better or worse than expected. The ME is calculated as:

*Machine Efficiency [%] = Expected Factory Hours / Machine Hours * 100%* (2.4)

Expected Factory Hours are the expected hours required for production. This is based on the saleable volume produced divided by the rated speed of the production line. For example, a line rated at 100HL per hour is expected to take 10 hours to complete an order of 1000HL.

Factory efficiency (FE) is a measure of how effectively the line has performed relative to the time period available that is within the direct “control” of the plant. It thus measures what the impact of external uncontrollable factors has been. FE is calculated at Grolsch as:

*Factory Efficiency [%] = Expected Factory Hours / Paid Factory Hours * 100%* (2.5)

Example of ME and FE calculation:
Suppose a machine runs at 300HL/hour. It produces 23,000HL in a total period of 120 hours where no idle time was planned. During these 120 paid factory hours, M&C was 10 hours, there were 10 changeovers of 20 minutes each. There was a 30 minutes stoppage due to a steam supply failure.

Expected Factory hours = 23,000 / 300 = 76.67 hours
Machine hours = 120 – (10 + 10*0.33 + 0.5) = 106.17 hours

ME = 76.67 / 106.17 * 100% = 72.2%
FE = 76.67 / 120 * 100% = 63.7%

Using these two formulas, we calculate the FE and ME for 2018 at Grolsch. Table 2.14 shows both the FE and ME of Grolsch in 2018. Table 2.14 shows these efficiencies per production line and also target efficiencies determined at the start of 2018 by Grolsch. Efficiencies of Line 5 and Line 20 are not calculated, these lines produce in an irregular schedule as the demand of the SKUs produced on these lines is too low. The targets are set based on historical data of the performance of each of the production lines and the expected improvements that Grolsch wishes to achieve for the year for the production lines.

Table 2.14: Actual and Target Efficiencies Production Lines 2018

Production Line	Actual FE	FE Target	Actual ME	ME Target
Line 1				
Line 2				
Line 3				
Line 4		Confidential		
Line 7				
Line 8				
Overall production				

Looking at the actual FE and ME values of 2018, we conclude that none of the lines has reached its target efficiency. We also conclude that especially Line 2, 4 and 7 perform poorly. The other lines performed closer to their targets, although not reaching their targets.

There is a big difference between the FE and the ME of a line. This is called the 'FE-ME Gap' at Grolsch. This gap consists of all losses that Figure 2.8 displays. This gap is thus an indication of the portion of the total available time that the production lines are allowed to lose. Table 2.14 shows that the overall production FE-ME gap in 2018 was **XX**%. So, on average Grolsch lost **XX**% of its' available production time in 2018 to the described losses.

As we have seen in Section 1.3, Grolsch expects growth in their yearly sales volumes. As the current capacity of the machines is almost reached, Grolsch has two options. The first option is to add extra shifts to the production lines. This is costly and complex, because an extra shift would be expensive and the volumes are not growing hard enough to maintain this extra shift in every week of the year. The other option is to increase the efficiency of the production lines. This way, Grolsch is able to create more output with the same operating hours.

2.5. Conclusion

In this chapter we have investigated the current situation at Grolsch by answering the first research question:
" What is the current situation at Grolsch regarding the efficiencies and costs of the production and warehousing and the planning of repacking? "

We conclude that the current situation is not sustainable for the volume growth that Grolsch expects. We see that with the increasing volumes, the available slack is shrinking. Due to new product developments and the increasing volumes Grolsch has more changeovers.

In Section 2.3 we have seen that the warehouse is full at Grolsch. One of the reasons that we found for this problem is the fact that Grolsch keeps safety stock for each SKU. The seasonality of beer sales and the required build-up of stock to meet demand during peak season is also a reason for the higher inventory levels. Next, we have seen that obsolete costs in 2018 were €**XXXX**. In 2019 we expect these costs to increase. We have seen that creating minimal batch sizes of products creates a situation where for multiple SKUs we expect stock not to be sold before it becomes obsolete.

Finally, we conclude that the current efficiencies are below target. The overall machine efficiency in 2018 was X%, while the target was set at X+5%. The factory efficiency in 2018 was Y%, while the target was Y+4%. In order to keep up with the expected growth in sales of Grolsch, increasing the efficiency of the production lines is required. It is also a potential great way to reduce costs, as an increase in efficiency would lower the required time to produce the same volume.

3. Literature Review

This chapter gives an overview of relevant literature for this thesis. Section 3.1 gives an insight in the customer order decoupling point and the determination of this point. In Section 3.2, we address techniques to postpone relevant parts of manufacturing. Section 3.3 addresses techniques on the calculation of safety stock of subassemblies. Then, Section 3.4 provides techniques to calculate the payback period of projects. Next, Section 3.5 presents different forecasting techniques. Section 3.6 gives an insight in sensitivity analysis tools and finally, Section 3.7 provides a conclusion.

3.1. The Customer Order Decoupling Point

A typical production company produces its products based on (at least) one of four principles: engineer-to-order (ETO), make-to-order (MTO), assemble-to-order (ATO and make-to-stock (MTS) (Wikner & Rudberg, 2001). MTS is also known as make-to-forecast (MTF).

ETO represents a production process where the degree of variety or customization is high, often only raw materials are kept in stock at the firm. MTO offers slight less variety, but has the benefit of a lowered lead time, as partly finished products or components are kept is stock. ATO offers even less variety, as semi-finished products are kept in storage. The key to the success of ATO is that product differentiation is limited and the firm can keep semi-finished products in stock. Finally, firms that adopt the MTS principle keep the finished products in stock. The success of MTS is instantaneous delivery (Akinc & Meredith, 2015).

Figure 3.1 illustrates these four principles. We see that at ETO, the customer order enters the supply chain at the start of the process. On the other hand, at MTS, the customer order enters the supply chain at the finished goods level. The entire supply chain is thus carried out under uncertain demand, while at ETO the entire supply chain is carried out under certain demand (Wikner & Rudberg, 2001).

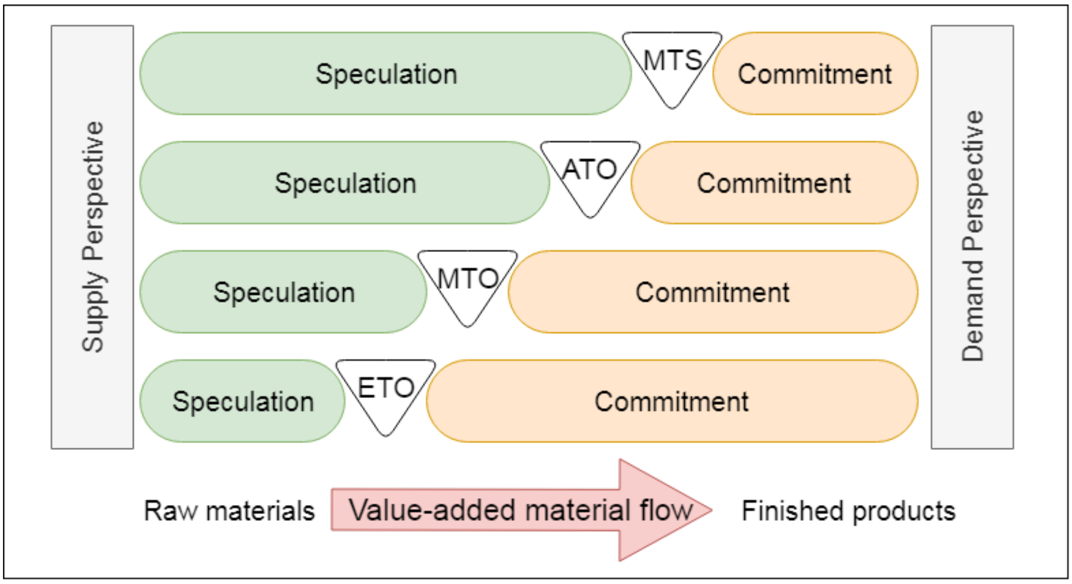

Figure 3.1: Customer Order Decoupling Point (Rudberg & Wikner, 2004)

These four principles relate to the point in the supply chain where customer demand is certain and a firm begins to produce based on certainty. This point is also called the Customer Order Decoupling Point (CODP) (Rudberg & Wikner, 2004). The further downstream the CODP is positioned, the more value-adding activities are carried out under uncertainty, and the further upstream the CODP is positioned the more activities are based on actual customer orders (Wikner & Rudberg, 2001).

The CODP is thus also the furthest downstream place where stock is kept at a firm (Akinc & Meredith, 2015). For a firm that wishes to differentiate the last step of the production step at the latest possible moment, ATO is thus the best suited principle.

An ATO manufacturing system is one where semi-finished products are assembled in different configurations, to produce a range of end products. This is common for supply chains where production lead times are significantly longer than the required assembly time of the end products (Elhalfsi, et al.,2015).

3.2. Manufacturing Postponement Techniques

Postponement is the capability of a supply chain to delay product differentiation closer to the time where actual demand for the product is known (Graman, 2010). The main benefits of postponement are: (1) keeping inventory upstream where inventory costs are lower, (2) improvements in customer service levels through reduced lead times and broad product offerings and (3) delay further investments into the product to until the latest moment possible (Graman, 2010).

Customers nowadays want a product that fits their specific needs and are no longer willing to pay high premiums for customised products (Rudberg & Wikner, 2004). Postponement applications have been growing in recent years as firms increasingly develop global products that are customised for local markets. Waiting until the last minute to apply the last step(s) of production, such as packaging, can have substantial benefits (Twede, Clarke, & Tait, 2000).

Twede et al. (2000) identify different postponement strategies. First, they identify full speculation, which is the traditional mass production model where products are manufactured at a central location and shipped to several warehouses. This strategy uses the MTS principle described in Section 3.1. Logistics postponement keeps the manufactured end products at a central location in contrast to full speculation. This strategy also uses the MTS principle.

A strategy with actual postponement is identified by Twede et al. (2000) as the packaging postponement strategy. In this strategy, semi-finished products are kept at a point near the market. The last production process, i.e. the final assembly packaging and/or labelling, is performed only when customer orders arrive. Twede et al. (2000) call this strategy full postponement when this last production process is done at a central point instead of at a place close to customers, and thus logistics are also postponed. This is also called manufacturing postponement (Gattorna, 1998). Manufacturing postponement focuses on designing the products, so that they are kept undifferentiated for as long as possible. This decreases inventory since components can be used for multiple products and thus the safety stock can be lower (Gattorna, 1998).

One of the most important factors for selection a postponement strategy is the needs of the final customers. When demand is unpredictable, the risk of following the MTS principle is high. Packaging postponement can reduce the risk of having products in obsolete packages. The rate of obsolescence is an important product characteristic (Twede, Clarke, & Tait, 2000). Graman (2010) also notes that products that face high uncertainty in demand would benefit from using a postponement strategy. He also notices that postponement is often more costly, due to extra setups, smaller lot sizes and additional operations such as handling, storage, and retrieval. Graman (2010) combines this to a hybrid view where both the MTS and the ATO principle is integrated, based on the uncertainty of demand and the trade-off between benefits and costs. Chopra and Meindl (2016) call this partial, or tailored, postponement. They describe tailored postponement as a strategy where an organization produces only the portion of demand that is unknown using postponement. The portion of demand that is known is produced following the MTS principle.

To implement full postponement, or manufacturing postponement, the manufacturing process is re-designed to allow processes that do not differentiate the product until the CODP. Products are manufactured based on forecasts up until the CODP. The processes that differentiate the products, which are placed after the CODP, are initiated only when customer orders arrive (Gattorna, 1998).

3.3. Safety Stock Calculations

Stockouts can occur only when the inventory on hand is low (Silver, Pyke, & Thomas, 2016). In order to prevent stockouts, the inventory on hand should be high enough to fulfil the expected demand during the lead time of a new production. Lead time is defined as the time between the placement of an order and the time the production of the order is done (Silver, Pyke, & Thomas, 2016). Demand is often uncertain, meaning that the expected demand during lead time is not necessarily the actual demand that will occur. To deal with the uncertainty of both production and demand companies hold safety stock (King, 2011). Safety stock is defined as the average inventory level just before a replenishment order arrives.

Figure 3.2 shows how safety stock works. We see that the red line indicates the safety stock level. Ideally, the safety stock will always be the minimal stock level that is reached. When demand during an order cycle (or lead time) is higher than expected, the safety stock ensures that this is still covered and no stockout occurs.

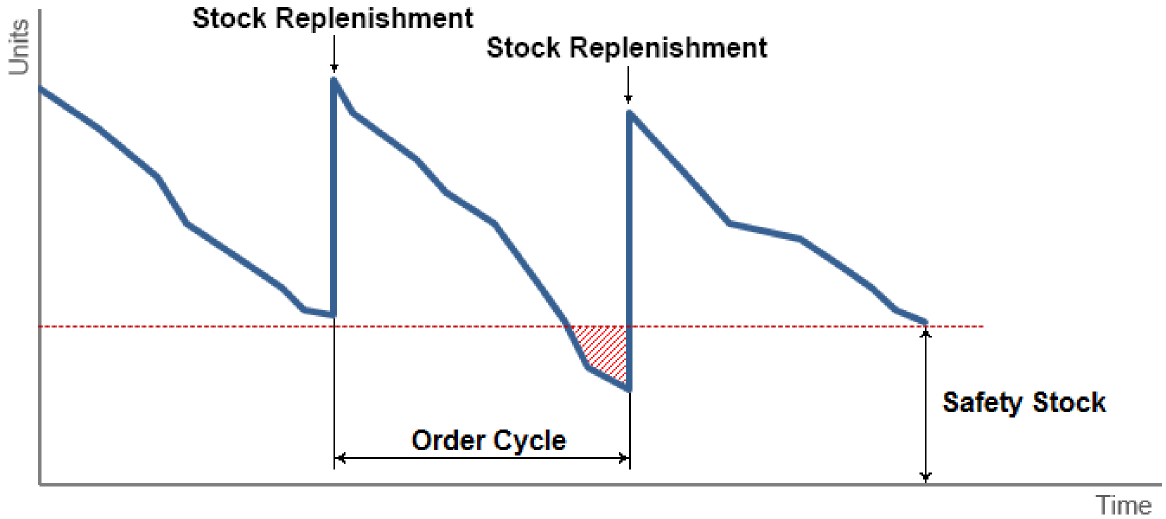

Figure 3.2: Safety Stock level and replenishment cycles (Smirnov, 2018)

Safety stock is determined by using a desired level of product availability. This is also called the safety factor. This represents the risk of stockouts a company takes (Chopra & Meindl, 2016). Equation 3.1 shows that standard safety stock calculation. Here the CSL refers to the fraction of replenishment cycles where actual demand is lower or equal to the average expected demand during lead time plus the safety stock, i.e. the fraction where no stockouts occur.

$$SS = F_S^{-1}(CSL) * \sigma_D * \sqrt{L} \tag{3.1}$$

Here, SS = Safety Stock;
CSL = customer service level;
σ_D = standard deviation of demand;
L = average lead time.

Equation 3.1 determines the safety stock for one end product, which assumes independence in its demand (Hernandez-Ruiz, Olivares-Benitez, Martinez-Flores, & Caballero-Morales, 2016). However, organizations adopt different strategies to reduce safety stock levels, while maintaining the same CSL. One of the ways organizations accomplish this, is through aggregation. This consists of, for example, centralizing inventories in a single warehouse, instead of having different storage points (Hernandez-Ruiz et al., 2016).

An organization that offers a wide variety of modular products as customized products must maintain aggregation in inventories. When an organization wants to reduce safety stock levels in addition to this aggregation, it has to consider the application of component commonality (Hernandez-Ruiz et al., 2016). Equation 3.1 can be adjusted considering the distribution of the aggregated inventory, if there is component commonality between the products (Hernandez-Ruiz et al., 2016). Equation 3.2 shows how the demand and standard deviation are expressed when aggregated inventory distribution is considered.

$$\begin{aligned} d' &= \sum_{l=1}^{m} d_l \\ \mathrm{var}[d'] &= \textstyle\sum_{l=1}^{m} \sigma_l^2 + 2\sum_{l<z} \mathrm{cov}_{lz} = \sum_{l=1}^{m} \sigma_l^2 + 2\sum_{l<z} \rho_{lz}\sigma_l\sigma_z \\ \sigma' &= \sqrt{\mathrm{var}[d']} = \sqrt{\sum_{l=1}^{m} \sigma_l^2 + 2\sum_{l<z} \rho_{lz}\sigma_l\sigma_z} \end{aligned} \tag{3.2}$$

Here, d' = aggregate demand;
d_l = demand during lead time of product l;
var[d'] = variance of aggregate demand;
σ' = standard deviation of aggregate demand;
σ_l = standard deviation demand during lead time of product l;
ρ_{lz} = Pearson correlation coefficient between products l and z.

Combining Equation 3.1 and Equation 3.2 gives us the safety stock level for each product l into an aggregate inventory of products with component commonality. Equation 3.3 shows the combination of these two other equations.

$$SS_l = F_S^{-1}(CSL)\sigma'\sqrt{L_l} = F_S^{-1}(CSL)\sqrt{\textstyle\sum_{l=1}^{m} \sigma_l^2 + 2\sum_{l<z} \rho_{lz}\sigma_l\sigma_z}\,\sqrt{L_l} \tag{3.3}$$

Equation 3.1 considers a situation where the demands are not independent. This is not always the case. When the demands are independent, i.e. $\rho_{lz} = 0$, Equation 3.3 can be simplified. This simplification leads to Equation 3.4 (Hernandez-Ruiz et al., 2016).

$$SS_l = F_S^{-1}(CSL)\sqrt{\textstyle\sum_{l=1}^{m} \sigma_l^2}\,\sqrt{L_l} \tag{3.4}$$

3.4. The Payback Period

Most engineering projects have different feasible design alternatives that can be used to reach the goal. When the selection of one of these alternatives excludes the choice of any of the others, the alternatives are called mutually exclusive. Mutually exclusive alternatives typically require different investments, have varying annual revenues and costs and sometimes even have different useful lives (Sullivan, Wicks, & Koelling, 2014).

Comparing mutually exclusive alternatives comes down to making an economic comparison between these alternatives. In this comparison, it is determined whether the added benefits from a more-expensive alternative outweigh the added costs and thus bring a positive return (Sullivan, Wicks, & Koelling, 2014).

To determine whether an investment and its associated costs can be recovered by revenue over time, the Present Worth (PW) method can be used, also called the Net Present Value. The PW method is based on the equivalent worth of all incoming and outgoing cash flows relative to a beginning point in time. This means that all cash flows are discounted to a beginning point, which is usually the present or start of the project, at an interest rate which is generally the Minimum Attractive Rate of Return (MARR). The MARR is the return rate that a project needs to achieve in order to be a viable investment for a firm. This is often a return rate that top management of an organization decides (Sullivan, Wicks, & Koelling, 2014).

$$\mathrm{PW}(\mathrm{i}\%) = \sum_{\mathrm{k}=0}^{\mathrm{N}} \mathrm{F}_{\mathrm{k}} * (1+\mathrm{i})^{-\mathrm{k}} \tag{3.5}$$

Here, i = effective interest rate, or MARR, per compounding period;
k = index for each compounding period;
F_k = future cash flow at the end of period k;
N = number of compounding periods in the planning horizon.

Equation 3.5 is used to calculate the PW of a project. We see that future cash flows are progressively being discounted. Cash flows are discounted due to the time value of money. This means that we assume that a dollar today is worth more than a dollar tomorrow. When applying the PW method, there is one general decision rule to determine the feasibility of a project. If the PW(i = MARR) ≥ 0, the project is economically justified (Sullivan, Wicks, & Koelling, 2014).

When comparing alternatives, there are several differences that may occur between alternatives. For example, one alternative can have better operational performance compared to the other. It is imperative to incorporate these differences in the comparison (Sullivan, Wicks, & Koelling, 2014).

The study period is the selected time period over which mutually exclusive alternatives are compared. The determination of this period is influenced by several factors, for example the useful life of alternatives. Looking at the useful lives of alternatives being compared, two situations can occur:

1. Useful lives are the same for all alternatives;
2. Useful lives are unequal among the alternatives and at least one is unequal to the study period.

When situation 1 occurs, the PW method is sufficient for the comparison. The study period is equal to the useful life of all alternatives and thus puts the alternatives on a common and comparable basis. It is therefore possible to compare the PW of the alternatives. The alternative with the highest PW at i = MARR is the alternative that should be selected (Sullivan, Wicks, & Koelling, 2014).

For situation 2, it is not sufficient to apply the PW method. If an alternative has a useful life shorter than the study period, the remaining period has to be compensated in some way as each alternative has to provide the same level of service over the study period. If the study period is 10 years and the alternative has a useful life of 7 years, 3 years remain of the study period. This period has to be bridged, for example by investing again. This would then make the alternative have 4 years left after the study period. When this is the case, an estimated market value is normally used as a representation of the cash flows that occur after the study period terminates (Sullivan, Wicks, & Koelling, 2014).

When alternatives have unequal useful lives, one way to compare the alternatives is on the basis of Annual Worth (AW). When comparing alternatives using the AW method, it does not matter that alternatives have unequal lives, as the AW of a project is an equal annual series of dollar amounts that is equivalent to the cash inflows and outflows at an interest rate which is generally the MARR. The annual worth method is also often used to determine whether the ranking of alternatives using other methods is done fair (Sullivan, Wicks, & Koelling, 2014).

$$AW(i\%) = R - E - I * \left(\frac{i(1+i)^N}{(1+i)^N - 1}\right) + S * \left(\frac{i}{(1+i)^N - 1}\right) \tag{3.6}$$

Here, R = annual revenues of the project;
E = annual expenses of the project;
I = initial investment for the project;
i = effective interest rate, or MARR;
S = salvage (market) value at the end of the study period;
N = project study period.

Equation 3.6 is used to calculate the annual worth of a project. We see that the investment which is done at the start of the project is equally divided over all the years, as if it were an annuity. The same goes for the market value at the end of the study period. By doing so, the AW is found which is the equivalent uniform annual worth of all cash inflows and outflows. For the AW method, the same decision rule applied as the decision rule of the PW method, namely if the AW(i = MARR) ≥ 0, the project is economically justified (Sullivan, Wicks, & Koelling, 2014).

Another important method to determine the economic justification of a project is the payback period method. The other methods reflect the profitability of a proposed alternative for a study period. The payback method, however, indicates a project's liquidity. This is also used as a measure of a project's riskiness, since liquidity shows how fast an investment can be recovered (Sullivan, Wicks, & Koelling, 2014).

We distinguish between the simple and the discounted payback period. The simple payback period does not take the time value of money into account. This method simply looks at when the sum of cash inflows exceeds the initial investment. This can lead to misleading results, which is why it is recommended to use this method as supplemental information in conjunction with other methods (Sullivan, Wicks, & Koelling, 2014).

The discounted payback period is calculated considering the time value of money. This method produces the breakeven life of a project. Both payback period methods do not include cash flows occurring after the breakeven point. This is why a method can be misleading, as a longer payback period can yield higher overall returns than a project with a smaller payback period (Sullivan, Wicks, & Koelling, 2014). Equation 3.7 shows the discounted payback period method.

$$\sum_{k=1}^{\theta}(R_k - E_k) * \frac{1}{(1+i)^k} - I \geq 0 \tag{3.7}$$

Here, R_k = revenue earned in period k;
E_k = expenses in period k;
I = initial investment of the project;
i = effective interest rate, or MARR;
k = number of the period;
θ = smallest value of periods that satisfies Equation 3.7.

3.5. Forecasting Techniques

There are many different techniques available to forecast demand in a supply chain. These techniques can be categorized in four types (Chopra & Meindl, 2016):

1. Qualitative: Qualitative methods are primarily subjective and rely on human judgement.
2. Time series: Using historical demand to make forecasts.
3. Causal: Forecasting using correlation with certain factors in the environment.
4. Simulation: imitating the consumer choice that gives rise to demand to forecast.

For this research, the best fit for the annual demand data of the SKUs of Grolsch is the time series forecasting technique, since there is historical data available and no external influences that can be taken into account.

To create a forecast, we require a level, trend and a seasonal factor. Level measures the expected value of deseasonalized demand. Trend is the rate of growth or decline in demand for the next period, and seasonality covers the predictable seasonal fluctuations in the demand. Time series forecasts can be divided into static and adaptive forecasting methods. A static method assumes that the estimates of level, trend, and seasonality do not vary as new demand is observed. In adaptive forecasting, the estimates of level, trend, and seasonality are updated after every demand observation (Chopra & Meindl, 2016).

In this research, we have access to both historical data and forecasts made by Grolsch. We therefore conclude that adaptive forecasting methods are the best choice since these can be updated to match with the forecasts of Grolsch, thus allowing for a better fit. Adaptive forecasting methods are not always better. For example, if the demand forecast is created by the estimates of customers, it might be that customers tend to overestimate their expected demand. Static forecasting methods can then be a good solution to the overestimation of demand by customers.

We discuss 3 adaptive forecasting methods: (1) moving average, (2) simple exponential smoothing, (3) Holt's model.

Moving average
The moving average method is used when demand has no observable trend or seasonality (Chopra & Meindl, 2016).

In this method, the level in a period is estimated as the average demand over the most recent N periods. This represents an N-period moving average (Chopra & Meindl, 2016).

Simple exponential smoothing
The simple exponential smoothing method is also used when the demand has no observable trend or seasonality (Chopra & Meindl, 2016).

In this method, the initial estimate of level is taken to be the average of all historical data because demand is assumed to have no trend or seasonality (Chopra & Meindl, 2016). This level is thus the forecast for all future periods. After observing the demand in the next period, a smoothing factor is used to revise the estimate of the level based on the actual demand in the period (Chopra & Meindl, 2016). Equation 3.8 is used to determine the initial level.

$$L_0 = \frac{1}{n}\sum_{i=1}^{n} D_i \qquad (3.8)$$

Here, L_0 = initial estimate of level;
D_i = demand of period i;

n = number of periods.

After observing the demand of the next period, we revise the estimate of the level using Equation 3.9. The revised level is the weighted average of the observed demand and the old estimate of the level, based on the smoothing factor (Chopra & Meindl, 2016).

$$L_{t+1} = \alpha D_{t+1} + (1 - \alpha) L_t \tag{3.9}$$

Here, L_t = current estimation of level;
L_{t+1} = revised estimate of level for period t+1;
D_{t+1} = demand of period t+1;
α = smoothing factor.

Holt's model
Holt's model is appropriate when demand is assumed to have a level and a trend, but no seasonality. We obtain an initial estimate of level and trend by running a linear regression between demand and time. The slope measures the rate of change and is the initial estimate of the trend. The constant measures the estimate of demand at period t=0 and is the initial estimate of the level. The forecast for period t=1 is then the initial level plus the initial trend (Chopra & Meindl, 2016).

After observing demand for period t, we revise the estimate for level using Equation 3.10.

$$L_{t+1} = \alpha D_{t+1} + (1 - \alpha)(L_t + T_t) \tag{3.10}$$

Here, L_t = current estimation of level;
L_{t+1} = revised estimate of level for period t+1;
D_{t+1} = demand of period t+1;
T_t = current estimation of trend;
α = smoothing factor.

After using Equation 3.10 to determine the revised estimate of the level for period t+1, we use Equation 3.11 to determine the revised trend.

$$T_{t+1} = \beta(L_{t+1} - L_t) + (1 - \beta) T_t \tag{3.11}$$

Here, T_{t+1} = revised estimate of trend for period t+1;
L_t = current estimation of level;
L_{t+1} = revised estimate of level for period t+1;
T_t = current estimation of trend;
β = smoothing factor.

α is the smoothing factor for level and β is the smoothing factor for trend (Chopra & Meindl, 2016). We find that Holt's model is the most suitable model for Grolsch. This is due to the fact that Grolsch does have a trend in their sales/production volume, as we have seen in Section 1.3. Demand of beer has seasonality, because there is more demand during the summer period. As we look at annual demand in this research, we decide that there is no seasonality to take into account.

Forecasting error
A forecasting error is the difference between the actual value and the forecasted value. Mean Absolute Deviation (MAD) is widely used to determine the accuracy of forecasts. This is the average of the absolute deviation over all periods (Chopra & Meindl, 2016). Equation 3.12 shows how the MAD is calculated.

$$MAD_n = \frac{1}{n}\sum_{t=1}^{n}(|F_t - D_t|) \qquad (3.12)$$

Here, F_t = Forecasted value of period t;
D_t = observed demand of period t;
N = number of periods t.

When the forecasting method stops reflecting the underlying demand pattern, the forecasting error is unlikely to be randomly distributed around 0. To track and control the forecasting method, one approach is to use the sum of forecasting errors to evaluate the bias. Equation 3.13 shows how the bias is calculated. If the bias fluctuates around 0, the error is truly random and not biased.

$$bias_n = \sum_{t=1}^{n} F_t - D_t \qquad (3.12)$$

Here, F_t = Forecasted value of period t;
D_t = observed demand of period t;
N = number of periods t.

3.6. Sensitivity Analysis

Sensitivity analysis is used to explore what happens to a project's profitability when estimated values in the study are changed (Sullivan, Wicks, & Koelling, 2014). A sensitivity analysis is basically changing factors within a model and observe the new behaviour of the model. Sullivan et al. (2014) describe two possible ways for changing and observing the model.

The first sensitivity analysis is the decision reversal. This is used to determine what percentage of change is required to reverse the decision about the economic acceptability of a project. For example, we have a project that currently has a negative present worth. Decision reversal determines the required percentual increase in the revenues to breakeven (Sullivan, Wicks, & Koelling, 2014).

The second sensitivity analysis is the spiderplot. This approach explicitly shows the impact of variability in the estimate of a factor. For example, we determined the annual savings of a project. The spiderplot creates multiple percentual changes (for example -10%, -5%, +5% and +10%) to this factor to determine the present worth given the change (Sullivan, Wicks, & Koelling, 2014).

Since Grolsch is interested in knowing what is required to make a infeasible alternative feasible, we determine that the decision reversal is the appropriate form of sensitivity analysis in our study. Using this form, we determine what changes to the estimated values are required to make an alternative feasible.

3.7. Conclusion

In this chapter we reviewed literature to answer research questions 2.1 to 2.3.

2.1. What is available in literature on postponement of manufacturing?

Section 3.1 has shown what the CODP is and how this point is decided. In addition, it has illustrated which CODP fits the different production principles that an organization can use. From Section 3.2 we conclude that there are two postponement strategies. The first postponement strategy is packaging postponement, which keeps semi-finished products in store and finishes these once orders arise. The second strategy is manufacturing postponement in which products are designed in such a way that manufacturing can take place later in the process.

For Grolsch it seems that packaging postponement is the best option since this is basically what currently happens at the repacking department. It is also possible to implement this since we have semi-finished products in the form of crates with loose bottles. Besides, for manufacturing postponement we would have to re-design products which seems both impractical and ineffective since the product design is fairly simple and Grolsch is already producing directly for the market.

2.2. What is available in literature on safety stock determination?

In Section 3.3 we have looked at the available literature on safety stock determination, thus answering RQ 2.2. We first found a standard safety stock calculation method that can be used for most SKUs that contain no aggregation with other SKUs and have independent demand. Next, we found a method that does include aggregation amongst different SKUs and (in)dependent demand. Hernandez-Ruiz et al. (2016) have developed an advanced version of the standard safety stock calculation method that can be used to determine the safety stock of components that are part of different SKUs.

We conclude that the aggregation method for safety stock calculations can be useful for Grolsch. We have seen that Grolsch has several products that have both a crate with loose bottles and other packaging configurations. Aggregating the safety stock on the crates could lower the inventory levels of Grolsch.

2.3. How can the payback period of a project be calculated?

For RQ 2.3 we reviewed methods to calculate the payback period of a project. First we investigated the present worth method, which is used to see whether a project is economically feasible. Next, we described the annual worth method, which is used to compare mutually exclusive project with different useful life times. Finally, we described the payback period.

We conclude that each of these three methods fits the situation at Grolsch. Grolsch is more interested in the payback period, which is derived from the PW method. The annual worth method is a good method to compare the outcomes of the PW method, in order to determine if the ranking is fair.

Finally, we conclude that the decision reversal is an appropriate tool to perform a sensitivity analysis on the variables used to calculate the payback period of the alternatives.

2.4. What are suitable forecasting models for the determination of future yearly production volumes?

Section 3.5 has shown three methods to forecast using time series. We found that time series was the most useful type of forecasting methods for Grolsch, since historical data is available. From the three methods, we conclude that Holt's model is the most useful for Grolsch. This model assumes there is a trend in the data, which we also found to be the case for Grolsch. It assumes that there is no seasonality in the data, which is the case for Grolsch given that we look at yearly production volumes.

4. Solution Design

In this chapter, we focus on our third research question. To answer this question, we start in Section 4.1 where we investigate the requirements and wishes that an alternative should meet. In Section 4.2 we elaborate on the design of the proposed alternatives. Then, Section 4.3 provides a conclusion.

4.1. Requirements & Wishes for an automated offline repacking machine

The alternatives that we investigate at Grolsch have to meet certain requirements and wishes. Without these, the alternatives will not be applicable to the situation of Grolsch. We divide the requirements and wishes in technical and organizational. Technical requirements are the technical aspects that must be considered to successfully implement an automated offline repacking machine. An example of a technical requirement is which inputs and outputs the production line should be able to handle. Next, we have organizational requirements. These are all the requirements that Grolsch has for the alternatives, for example which activities should the production line be able to handle. Finally, we have organizational wishes. These wishes are additional machines that may be added to the production line if the benefits outweigh the costs or additional options that an alternative provides.

4.1.1 Technical Requirements

An alternative consists of a production line that repacks packaging configurations in an automated offline setting. For this line to be a useful solution for the situation at Grolsch, we determine 7 technical requirements:

1. Bottle size range
2. Packaging configuration range
3. Input handling
4. Output handling
5. Input and output location
6. Forklift lane
7. Link with existing information systems

Technical Requirement 1 – Bottle size range

The production line has to be able to handle a large range of bottles, depending on which of the current production lines are included. For example, Line 2 only handles 30cl bottles. An alternative that only involves products that originate from Line 2 will thus only require 30cl bottles. We find that the current range of bottles of Grolsch lays between 25 CL and 45 CL on Lines 2, 4 and 7. Based on these two bottles, we determine the minimum and maximum height and width of bottles that the new line should be able to handle. Table 4.1 gives the range of bottle sizes that the new machine should be able to handle, if bottles from all production lines are included. When bottles from only part of the production lines are included, the required range becomes smaller. However, the size of the bottles is within the normal range of most machines and including/excluding bottles from Lines 2, 4 or 7 should not make a big difference on the required machine.

Table 4.1: Range of bottle sizes

	Bottle 25 CL	**Bottle 45 CL**
Height	198 mm	257.4 mm
Width	54.7 mm	69.4 mm

Technical Requirement 2 – Packaging configuration range
The machine should be able to handle the different range of packaging configurations that Grolsch currently uses for their bottles. Table 4.2 shows the packaging configurations that Grolsch currently used, specified per bottle.

Table 4.2: Packaging configuration requirements

Bottle	Configurations			
25 cl	6-pack	24-pack		
30 cl	2-pack	3-pack	4-pack	6-pack
33 cl	6-pack	24-pack		
45 cl	2-pack	4-pack	12-pack	20-pack

Technical Requirement 3 – Input handling
The start of the production line should be able to handle the crates that Grolsch uses. From Lines 2 and 4 the products will be transported in crates of either 24 or 16 loose bottles. The machine should be able get the bottles out of the crates and either transport the crates to a later stage of the line or out of the line to an empty crate warehouse. Grolsch keeps stock on pallets. The crates enter the line on a pallet and therefore the line should be able to handle getting the crates of the pallet and onto the production line. At the end of the production line the crates or boxes should be put back on a pallet.

Besides, if Line 7 is also added to the production line, bottles need to be transported from this line. As Line 7 is unable to handle crates and only puts bottles in carton boxes, bottles transportation to the new production line is different compared to transportation of products from Line 2 or 4. Line 6, where the new production line will be placed, and Line 7 are not located near each other, as there is a garden and Line 1 in between. Figure 4.1 displays the lay-out of the production lines. In order to get the bottles to the new line, there are two options. The first option is to put the bottles in sealed carton boxes on Line 7 and transport these on pallets to the new production line. The boxes have to be sealed with tape as otherwise it is not possible to stack the boxes without the loss of strength in the boxes, which would increase the chance to damage the bottles. The second option is to create a transportation line from Line 7 to the new line.

We choose for the second option because taking bottles out of sealed carton boxes is extremely difficult for a machine, thus increasing the investment costs. It is also not possible to reuse the box, which means that Grolsch would throw away all the carton that it uses to transport the bottles to the new line. Taking into account that Grolsch is trying to eliminate the use of carton as much as possible, and eliminate waste in general, this is not an option.

Technical Requirement 4 – Output handling
There should be a machine to put a plastic cover over pallets with boxes in case the new production line also produces SKUs that are put into boxes. As boxes tend to move more easily during transport, Grolsch puts a pallet cover over the boxes to ensure movement is minimised.

Besides, all output pallets should receive a pallet sticker for handling in the warehouse and traceability of the pallets.

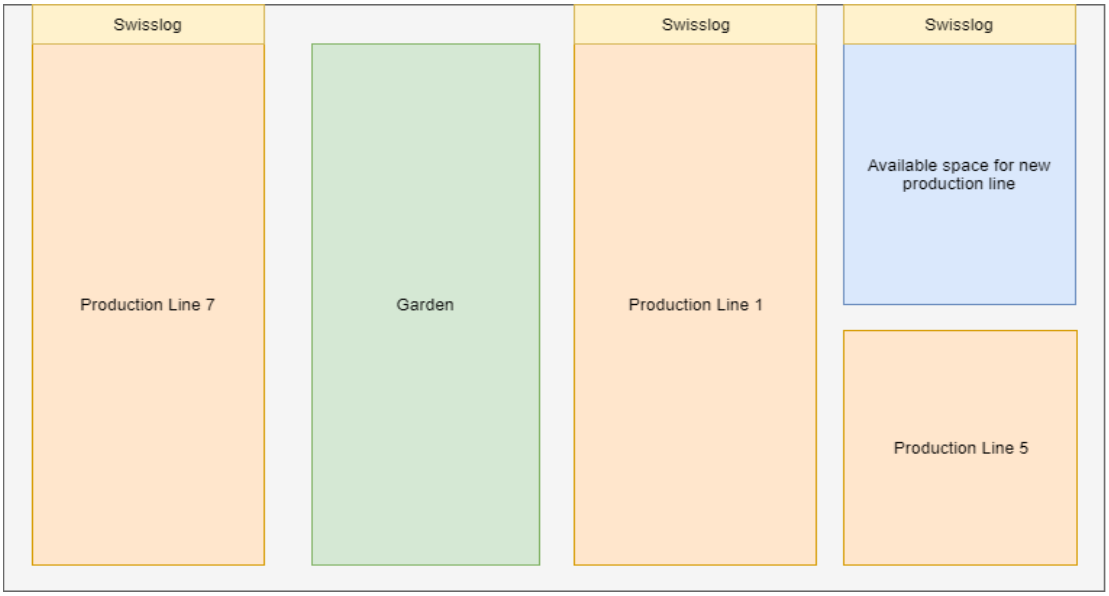

Figure 4.1: Lay-out production lines

Technical Requirement 5 – Input and output locations
Figure 4.1 shows the lay-out of the production lines at Grolsch. The blue part in the upper right corner is the available space for the automated offline repacking machine.

A technical requirement is that the start of the production line should be at the upper right side of the available space for the new production line in Figure 4.1. The end of the product line should be at the upper left side of the available space. This is due to the fact that this is the way that SwissLog operates, which is the warehouse IT system that Grolsch uses.

Technical Requirement 6 – Forklift lane
Between the new production line and Production Line 1 a lane must be kept free for forklift drivers. This is required to ensure access to both Production Line 5 and the start of Production Line 1.

Technical Requirement 7 – Link with existing information systems
Grolsch has a semi-automated warehousing system called SwissLog. Production lines give a signal to this system that a pallet is ready. The system then sends a robot picker to pick up the pallet and put it close to the spot in the warehouse where it will be stored. Here a forklift driver picks up the pallet and transports it to that location. If the production line is unable to link to SwissLog, we are unable to transport pallet back to the warehouse, since this would not be registered. It is therefore required that the new production line can be linked with SwissLog. Besides SwissLog, Grolsch uses the ERP system SAP. The current production lines have a link with SAP so that it is possible to track in real time the available stock of a product. Besides, in SAP the different batches get batch codes. This is necessary for the traceability of the products. The new production line obviously needs this link as well.

4.1.2. Organizational Requirements and Wishes

From an organizational point of view, there are a few requirements and wishes constraints. For example, brand managers may foresee changes in configurations or the delisting of certain configurations. It is therefore important to determine all the organizational requirements and wishes, in order to find a solution that fits the needs of Grolsch in the future.

Organizational Requirement 1 – Packaging configurations

The production line should handle all generic packaging configurations that Grolsch has. We divide the packaging configurations between secondary and tertiary. Secondary packaging is considered to be the 'packs' in which loose bottles are put. Tertiary packaging is the packaging in which packs with bottles are put. This means that a crate is considered secondary packaging for 24 loose bottles, but becomes tertiary packaging once eight 3-packs are put in this crate. Table 4.2 shows all the relevant pack configurations per bottle type that the solution should cover. These are also the relevant configurations that Grolsch will use in the foreseeable future. Other packaging configurations are unlikely, as these configurations are the most common for beer and are also efficient to transport on pallets. Other configurations, for example 5-packs, require different spacing techniques which means that less bottles per pallet can be transported. There are also no current complaints known from customers about the lack of certain packaging configurations and no wishes about new packaging configurations at Grolsch in the foreseeable future. We do see a switch happening from 3-packs to 4-packs, possibly eliminating 3-packs. This is due to the supermarkets. 4-packs are divided in a 2x2 setting, while 3-packs are divided in a 3x1 setting. This means that 4-packs require less space on the racks in the supermarket, which is something that the supermarkets have requested.

Organizational Wish 1 – Cratecover machine
An organizational wish is a cratecover machine. Cratecovers are a great way to promote the brand. These carton covers on top of the crates cover a large area which provides high visibility in supermarkets. Another advantage of cratecovers is the improved quality of the beer. UV-light reduces the quality of beer. A cratecover on top of the crate reduces the amount of UV-light that reaches the beer inside the bottles, thus maintaining the quality of the beer.

Organizational Wish 2 – Flexibility in handling new products
Another organizational wish is the flexibility that a solution offers. Currently, the engineers are limited by the available machines and the range of bottles, packs and cartons these machines can handle. A new production line should ideally provide a higher level of flexibility in the design of these packages. For example, the current carton machine on Line 7 can only handle relatively thick carton. If the new machine is able to handle other, lighter, types of carton, this may result in benefits for Grolsch. There is a saving on the amount of carton required and this is also more environmentally friendly. Grolsch tries to be as green as possible, making a potential saving on the required amount of carton interesting.

4.2. Design of alternatives

Based on the technical and organizational requirements and wishes, we design a layout that contains the required processes. Figure 4.2 shows the proposed layout of the new production line, using all requirements and wishes. This layout is thus an overview of the most extensive option with all processes. Each yellow process in Figure 4.2 represents a machine. We propose this layout as this is the logical order in which the machines should be placed. For example, we start with a de-palletizer as we first need to take the crates off the pallets, before other handling can be done. The natural modus of SwissLog is to have the input at the right side and the output at the left side, which is the case in Figure 4.2. Changing this involves costs that we expect to be higher than the required extension of the conveyor belt from Line 7 to the pack machine.

The line starts and ends linked to SwissLog, which was one of the technical requirements. Next, the palletizer and de-palletizer are required to handle incoming crates on pallets and to put the crates back on pallets once handling is done. This way, the pallets can be handled by SwissLog. The crate unpacker is required to be able to take the bottles out of the crates. At the pack machine the loose bottles are put into the required pack. Next the crate packer or box packer is required to put the loose bottles or packs back into respectively crates or boxes. The box stacker is necessary to put the filled boxes on pallets. The MSK is the pallet cover machine that seals these pallets with a plastic cover in order to make the pallet ready to go into the warehouse via SwissLog. Finally each pallet goes through the pallet sticker machine where it gets a sticker for traceability and easy handling. The forklift lane is located left as this is the lane that is required to reach both Line 5 and Line 1, which was also a technical requirement.

The white process represents one of the organizational wishes, the cratecover machine. The path that a crate might take when using this machine is illustrated by the green path. Obviously when the machine is only used for cratecovers, we do not require the bottles to be taken out of the crates and the crates can simply be transported to this machine directly from the de-palletizer.

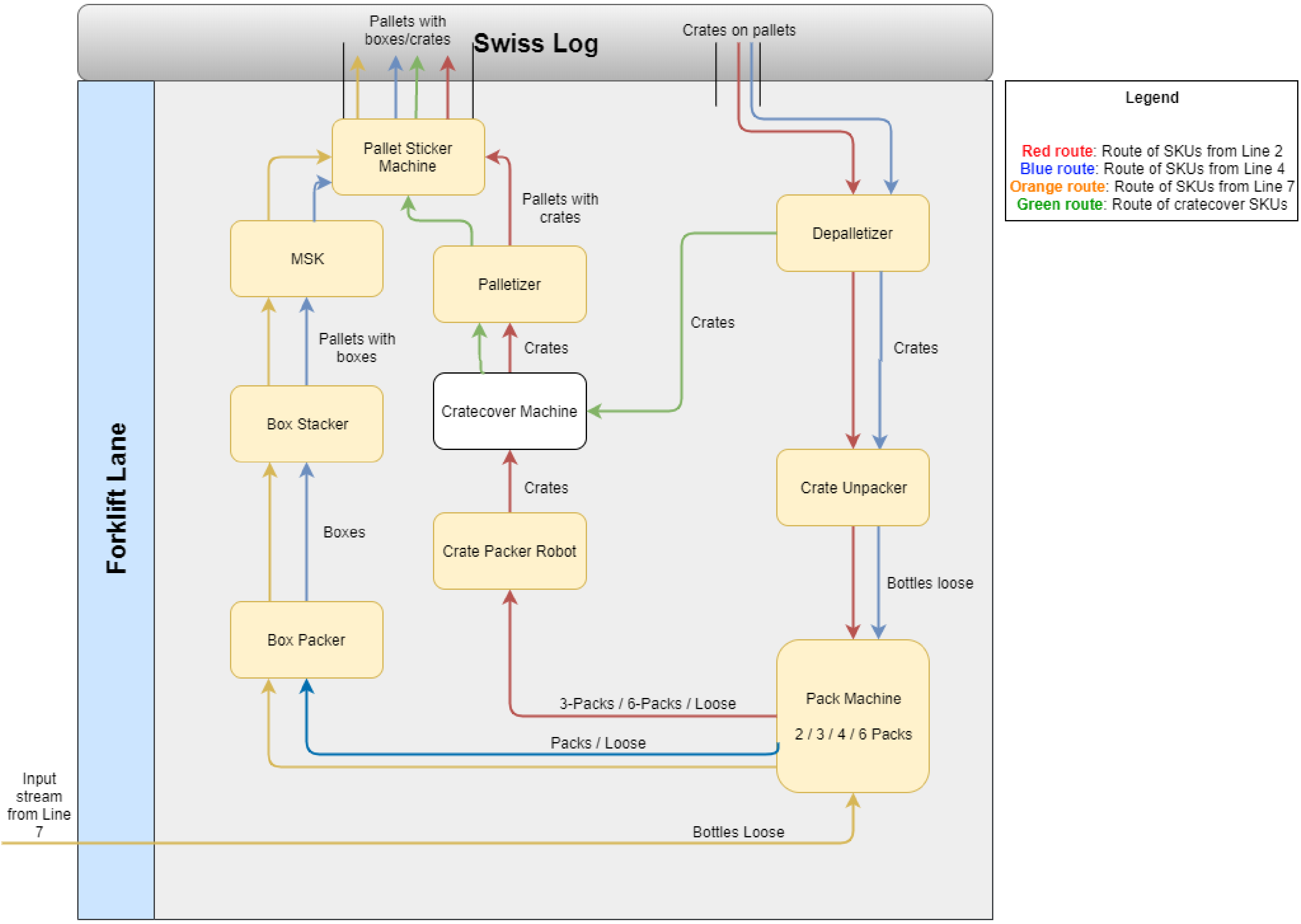

Figure 4.2: schematic layout of the new machines

Choice of alternatives

In the layout of Figure 4.2 we see multiple routes, depicted by different colours. Each route is required for a certain type of products. The red route corresponds with the route that SKUs coming from Production Line 2 take. These enter the production line in crates, are put into packs and then return into crates. The blue route corresponds with the route that SKUs from Production Line 4 take. These SKUs enter the production line in crates, are then either packed in packs and later in boxes or directly into boxes. The green route is based on an organizational wish for a cratecover machine. In this route the crates come in the line, receive a cratecover and go out as crates. Finally, the orange route corresponds with SKUs from Line 7. As mentioned, these arrive through a transportation line directly linked to Line 7. Then, the bottles are either packaged in packs and then into boxes or directly into boxes.

Given that we have 3 main routes (see Figure 4.2), there are 7 possible combinations of these routes for an automated offline repacking machine. The additional, green route is for cratecovers, which we consider not to be a main route. This simply is an addition to the alternative if the benefits of adding the green route outweigh the costs for that alternative. The production line suppliers give us the options to run a production line at either 15,000, 30,000 or 48,000 bottles per hour. The investment costs increase once the speed increases. Table 4.3 gives an overview of the 7 possible route combinations and shows the possible speeds that each combination can handle. Combinations with the orange route only have one possible speed, 48,000 bottles per hour. This is due to the fact that this route is linked to Production Line 7, which means that these lines have to operate at equal speeds. Since Line 7 has an operating speed of 48,000 bottles per hour, an alternative with the orange route included should have the same speed.

Table 4.3: Possible alternatives for an automated offline repacking machine

Combination of routes	Originating production line(s)	Possible speeds (*1000 bottles/h)
Red	2	15, 30, 48
Blue	4	15, 30, 48
Orange	7	48
Red, Blue	2, 4	15, 30, 48
Red, Orange	2, 7	48
Blue, Orange	4, 7	48
Red, Blue, Orange	2, 4, 7	48

Alternative 1 – Automated repacking of bottles of Line 2 at low speed
The first alternative we choose is the red route at 15,000 bottles per hour. This means only SKUs that originate from Production Line 2 will be repacking automatically on the new production line. We choose this alternative for four reasons.

First of all, Line 2 has the highest expected costs for repacking activities. In Section 2.2.2 we see that Line 2 has almost 70% of the total expected repacking costs in 2019 excluding cratecovers. Next, the expected time due to changeovers is the highest. In 2019 Grolsch expects 275 hours of changeover on Line 2, compared to 43 hours on Line 4 and 262 hours on Line 7. Third, due to the fact that these products are first produced on Line 2 and later transported to the new line, we profit from inventory aggregation. Finally, the idle time of Line 2 is the lowest of the three production lines.

This alternative has a total expected volume of 86,145 HL in 2020. This translates to 28,715,000 bottles. With a nominal speed of 15,000 bottles per hour, this would take 1,914 hours to produce. We thus find it a feasible speed to investigate in the alternative.

Alternative 2 – Automated repacking of bottles of Line 2 at medium speed
The second alternative is similar to Alternative 1, with the only different that the production line of this alternative will run at 30,000 bottles per hour. We choose this alternative as the expected nominal production hours are 50% of Alternative 1. We therefore investigate the trade-off between a lower speed and lower investment costs, or a higher speed and higher investment costs. This can be a good choice when the required production volumes are expected to increase in the future and the lower speed may not be able to handle the increased volume.

Alternative 3 – Automated repacking of bottles of Lines 2 and 4 at low speed
Alternative 3 includes both the red route and the blue route from Figure 4.2 at a speed of 15,000 bottles per hour. In this alternative we include SKUs from both Line 2 and Line 4. We choose this alternative for three reasons.

First of all, Line 4 also uses crates which means that the benefits from inventory aggregation for Grolsch increase. Second, Line 4 currently has 17 SKUs of which 12 are carton products. This means that the production schedule of Line 4 can be simplified. Third, Line 4 has the remaining 30% of the repack activities, thus this alternative eliminates all repack activities within the scope of this research, excluding cratecovers.

This alternative has a total of 213,166 HL. Based on the fact that products from Line 2 are 30cl and products from Line 4 are 45cl, this translates to 56,942,000 bottles which we expect to take 3,796 hours based on a nominal speed of 15,000 bottles per hour. This is roughly 76 hours per week based on a production schedule of 50 weeks. We find this feasible.

Alternative 4 – Automated repacking of bottles of Lines 2 and 4 at medium speed
The fourth alternative is similar to Alternative 3, with the only difference being that the production line of this alternative will run at 30,000 bottles per hour. We choose this alternative as the expected nominal production hours are 50% of Alternative 3. We therefore investigate the trade-off between a lower speed and lower investment costs, or a higher speed and higher investment costs.

Alternative 5 – Automated repacking of bottles of Lines 2, 4 and 7 at high speed
Alternative 5 offers the complete layout of Figure 4.2 excluding the green route. This alternative thus includes all three production lines. We choose this alternative as it offers a total production line that fulfils all technical and organizational requirements and constraints. This production line will run at 48,000 bottles per hour. This is required, because this is also the speed of Production Line 7 and in this alternative, the new production line will be linked to Line 7 using a transportation line. It therefore needs the same speed to prevent bottlenecks.

Exclusion of other alternatives
There are multiple other alternatives that we do not choose. First of all, we exclude alternatives that do not include the red route of Figure 4.2. This is due to the fact that the products of this route originate from Line 2. This production line currently has the smallest idle time and the most repack products compared to Lines 4 and 7.

We exclude the option of either the red route or a combination of the red route and blue route at 48,000 bottles per hour. As mentioned in the choice of Alternatives 1 and 3, even at the low speed of 15,000 bottles per hour we find that the speed is sufficient to cover the expected yearly production volume of 2020. A high speed alternative would increase the investment costs while the high speed is not required, which is undesirable.

Finally, we exclude any option that combines the red or the blue route with the orange route. There are no side benefits from adding the orange route as the products of this route has no repack products and no possible inventory aggregation. It is therefore only included in the most extensive alternative, which covers all routes, since it offers the most flexibility in terms of bottle and packaging range.

Production process
Figure 4.3 shows the flowchart of the alternatives, based on the layout from Figure 4.2. We start the flowchart with a decision. If bottles are coming directly from Line 7, these enter the production process directly at the pack machine. Otherwise the bottles enter the production process in crates via SwissLog. Warehouse employees bring the oldest stock that was created on Line 2 or 4 to SwissLog which brings the pallets to the new production line. The crates are unpacked and the bottles are transported to the pack machine. From here the packs move to the Crate Packer Robot

which puts the packs back into crates. Next the crates are stacked on a pallet, a pallet sticker is added and the pallet goes back to SwissLog. Each yellow process corresponds with a machine of Figure 4.2.

The part with the orange background in the upper corner corresponds with the addition required for the orange route in Figure 4.2, in other words the transportation line from Production Line 7 to the new production line in Alternative 5. This bypasses the first part of the machine, where the crates are unpacked. This is obviously not needed for bottles coming from Line 7, as these are transported directly from the line instead of in crates.

The part with the blue background is added for Alternative 3, 4 and 5. Looking at Figure 4.2 this is the part that starts at the box packer up until the pallet sticker machine. In the flowchart we start with a decision right after the pack machine. When the packs do go into boxes instead of crates, the bottles follow the blue route of Figure 4.2 instead of the red route.

Finally the green part in Figure 4.3 corresponds with the path that crates follow when they require a cratecover. In this case the crates are only depalletized and not unpacked, since this is not necessary. Next the cratecover is put on the crate and the crates are palletized again.

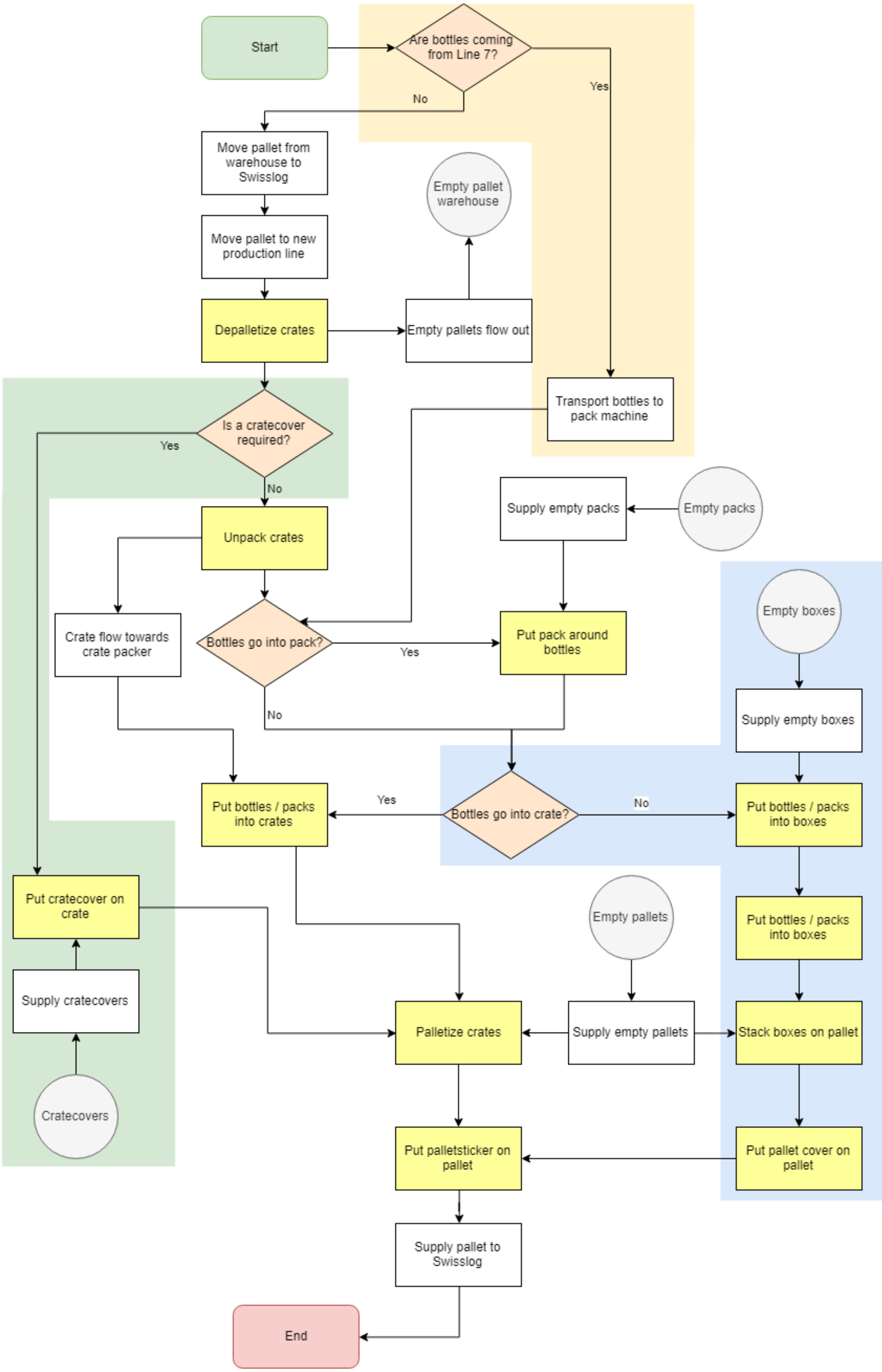

Figure 4.3: Flowchart production process new production line

4.2.1. Alternative 1 and 2: Automated repacking of bottles from Line 2

The first two alternatives that we propose are an automated offline repacking machine for part of the bottles that currently are filled on Production Line 2. Looking at Figure 4.2, these alternatives are represented by the red path. Alternative 1 offers a production speed of 15,000 bottles per hour, while Alternative 2 offers a production speed of 30,000 bottles per hour. We choose these alternatives for four reasons.

First of all, Line 2 has the most repack products. The total volume of these SKUs in 2019 is expected to be 11,516 HL out of the total 19,030 HL expected from Line 2, 4 and 7, excluding the cratecover volume. This thus eliminates a big part of the required manual repacking and the costs involved.

Second, Line 2 has bottles in crates as input and output. Crates are easy to handle and can be unpacked easily once they have been filled, in contrary to boxes. Filling the crates with bottles at Line 2 and then transporting these to the new production line is an efficient, waste-free process as crates are reusable.

Third, Line 2 has the highest changeover costs of the three production lines, as we have seen in Section 2.2.3. We reduce the required amount of changeovers by reducing the number of SKUs produced on Line 2. This creates a more efficient production schedule for Line 2 and lowers the costs due to changeovers.

Finally, Line 2 only has 7.4 hours of idle time weekly on average. As we have described in Section 1.3, there are multiple reasons why this idle time is becoming insufficient. Creating more idle time by reducing the required changeover time for this production line is therefore important.

In Section 2.1 we showed the division of the packaging configurations per production line for the current situation. With the new production line this division changes. Table 4.4 shows the new division of packaging configurations over the production lines. We see that the new production line now has all the offline configurations of Line 2. Besides, it also produces crates with four 6-packs. We see that Line 2 also still has crates with four 6-packs as a configuration. This is due to the fact that part of the 6-packs that Grolsch produces do not have a 24-loose variant. It does not make sense to produce these SKUs as a 24-loose variant on Line 2 and then produce them as 6-packs on the new production line if the 24-loose variant is only a semi-finished product. This would only result in increasing the production costs for these SKUs and would offer no benefits.

Table 4.4: Packaging configurations division per production line Alternative 1 and 2

Production Line	Configurations online				Configurations repacked offline	
Line 2	Crate 1x24	Crate 4x6			None	
Line 4	Crate 1x16	Carton 1x12			Carton 3x4	Carton 1x20
	Carton 1x20	Carton 6x4				
Line 7	Carton 1x24	Carton 1x20	Carton 1x12		None	
New Line	Crate 1x24 crate cover	Crate 4x6	Crate 8x3	Crate 6x4	None	

With the new production line in these alternatives, bottles are first filled at Line 2. These bottles are then put into crates as 24 loose bottles per crate. From Line 2, pallets stacked with crates containing 24 loose bottles are sent to SwissLog, which can transport the pallets to the warehouse or directly to the new production line. We choose to transport the pallets to the warehouse and later transport these to the new production line when necessary. This has three reasons.

First of all, if the products would directly be transported from Line 2 to the new production line, it is basically the same situation as Grolsch currently has, with the only difference being that the carton part of the machine is not connected to Line 2. This makes production slower due to the extra steps in the process, e.g. transportation from Line 2 to the new line or taking the bottles out of the crates at the new line.

Second, we do not take advantage of the pooling of the stock. When stock is put into the warehouse as loose bottles in crates, we have the option to put the Customer Order Decoupling Point (CODP) further downstream for the 3-packs, 4-packs and part of the 6-packs. Grolsch does not have to dedicate the available stock and can create the desired packaging configurations once it is known what the demand will be. This decreases the chance of stock becoming obsolete, as older stock can be sold in whichever packaging configuration the customer requires first. It also lowers the required amount of stock, as Grolsch does not need to keep stock for each packaging configuration.

Third, Grolsch is more flexible with the production plan of the new production line. The production plan is not stuck with the production plan of Line 2, which means that Grolsch can produce what is required on the new production line based on demand instead of what is produced at Line 2 at that moment.

Table 4.5 shows the production volumes of the SKUs that will be processed on the new production line for Alternative 1 and 2 in 2020. We see that there is an expected total production volume of 86,145 HL for the new production line. There are three different packaging configurations and 7 SKUs. There are only three 6-packs that we move from Line 2 to the new production line. This is due to the fact that the other 6-pack are not sold as loose bottles in crates. As mentioned, it does not benefit Grolsch to create a semi-finished product of the 24-loose bottles for the other 6-packs if Grolsch does not sell this variant.

Table 4.5: Production volume per SKU for Alternative 1 and 2 in 2020

SKU ID	Packaging configuration	Total Volume 2020 (HL)
92117	6-pack	Confidential
92122	6-pack	
92192	6-pack	
91844	3-pack	
92090	3-pack	
92138	3-pack	
92299	4-pack	
Total		

4.2.2. Alternative 3 and 4: Automated repacking of bottles from Lines 2 and 4

Alternative 3 and 4 consist of a production line for bottles of Line 2 and Line 4. Looking at Figure 4.2, this solution is represented by the red and blue paths. Alternative 3 offers a production speed of 15,000 bottles per hour, while Alternative 4 offers a production speed of 30,000 bottles per hour. Alternative 3 and 4 are thus equal to respectively Alternative 1 and 2, with the difference being the addition of bottles from Line 4 to the new line, i.e. the blue route. We choose to add the bottles of Line 4 to these alternatives for 3 reasons.

First of all, both Line 2 and Line 4 produce in crates. Compared to the production line proposed in Alternative 1 and 2, there are no changes required to the line from start to the pack machine. It is only after the pack machine that new machines will be added.

Second, Line 4 currently has repack products. These alternatives thus eliminate the second part of the manual repack volume.

Third, Line 4 currently has 17 SKUs. 12 of these SKUs are carton products. In this solution we can thus lower the required number of SKUs produced on Line 4 from 17 to 5. This means less changeovers, a better machine efficiency and an easier production schedule for this line.

Table 4.6 shows the new division of packaging configurations over the production lines. We see that, compared to the current situation shown in Section 2.1, Line 2 will now only produce crates with 24 loose bottles and also some 6-packs that have no loose variant. Line 4 only produces crates with 16 loose bottles. Also there are no configurations left that require manual repacking for the 3 production lines.

Table 4.6: Packaging configurations division per production line Alternative 3 and 4

Production Line	Original prod. line	Configurations online				Configurations repacked offline
Line 2		Crate 1x24	Crate 4x6			None
Line 4		Crate 1x16				None
Line 7		Carton 1x24	Carton 1x20	Carton 1x12		None
New Line	2	Crate 1x24 crate cover	Crate 4x6	Crate 8x3	Crate 6x4	None
	4	Carton 1x12	Carton 3x4	Carton 1x20	Carton6x4	

In Section 4.2.1 we described why we choose to send created SKUs on Line 2 to the warehouse first and produce it later on the new production line. The addition of Line 4 configurations does not change this reasoning, so we decide for these alternatives to also send the loose bottle SKUs to the warehouse first.

Table 4.7 shows the production volumes of the SKUs that will be processed on the new production line for Solution 2 in 2020. We see that there is an expected total production volume of 213,166 HL for the new production line. There are three different packaging configurations and 7 SKUs from Line 2. There are three different packaging configurations and 15 SKUs from Line 4. We thus have 6 different packaging configurations and 22 SKUs for the new production line.

Table 4.7: Production volume per SKU for Alternative 3 and 4 in 2020

SKU ID	Production Line	Packaging configuration	Total Volume 2020
92117	2	6-pack	Confidental
92122	2	6-pack	
92192	2	6-pack	
91844	2	3-pack	
92090	2	3-pack	
92138	2	3-pack	
92299	2	4-pack	
90991	4	4-pack	
90995	4	4-pack	
92092	4	4-pack	
90997	4	4-pack	

92084	4	4-pack	
92136	4	12-pack	
92308	4	12-pack	
92377	4	12-pack	
90847	4	12-pack	
91810	4	20-pack	Confidential
91808	4	20-pack	
92220	4	20-pack	
92245	4	20-pack	
91655	4	20-pack	
Total			**213,166**

4.2.3. Alternative 5: Automated repacking for bottles of Line 2, 4 and 7

The fifth and final alternative that we propose is a production line for bottles of Line 2, 4 and 7. This alternative takes all the configurations into account for the Lines 2, 4 and 7.

Table 4.8 shows the new division of packaging configurations over the production lines. We see that, compared to the current situation, Line 2 will now produce crates with 24 loose bottles and a part of the crates with four 6-packs that have no loose variant. Line 4 only produces crates with 16 loose bottles. Also there are no configurations left that require manual repacking for the 3 production lines. The configurations of Line 7 are both online for Line 7 and the new line. This is due to the fact that in this solution, Line 7 will be linked to the new production line. This means that when Production Line 7 is running with one of these configurations, the new production line will be an extension of Line 7. We do this because these configurations currently all use one packaging machine on Line 7. This machine is old and inefficient. With this solution, Grolsch may be able to part with this machine or reduce the production hours required on this machine.

Table 4.8: Packaging configurations division per production line Alternative 5

Production Line	Original prod. line	Configurations online				Configurations repacked offline
Line 2		Crate 1x24	Crate 4x6			None
Line 4		Crate 1x16				None
Line 7		Carton 1x24	Carton 1x20	Carton 1x12		None
New Line	2	Crate 1x24	Crate 4x6	Crate 8x3	Crate 6x4	None
	4	Carton 1x12	Carton 3x4	Carton 1x20	Carton6x4	
	7	Carton 1x24	Carton 1x20	Carton 1x12		

Organization of production

In this alternative we send the crates with loose bottles from Lines 2 and 4 directly to the warehouse. Once they are required, we transport these to the new production line for the final steps of production. The products of Line 7 are obviously not transported to the warehouse first, as these go directly to the new production line after filling on Line 7 with a conveyor belt.

Due to the link with Production Line 7, the production process of the automated offline repacking machine becomes different compared to the other alternatives. This link creates an extra organizational aspect. To deal with this organizational aspect, we assume that the production schedule of Line 7 will be created in such a way that Grolsch produces the SKUs that go to the new production line for packaging once every two weeks. The SKUs that go to the new production line have a total production volume of 93,754 HL in 2020. This is 46% of the total volume of Production Line 7 and only 31% of the total volume for the new production line in this alternative. This way, linking Line 7 to the new production line disrupts the production process the least and scheduling becomes easier.

Table 4.9 shows the production volumes of the SKUs that will be processed on the new production line for Alternative 5 in 2020. There are a total of 8 different packaging configurations. 38 SKUs are divided over these configurations. The total expected production volume is 306,920 HL for the new production line in 2020.

Table 4.9: Production volume per SKU for Alternative 5 in 2020

Packaging configuration	Production Line	Number of SKUs	Total Volume 2020
6-pack	2	3	Confidential
3-pack	2	3	
4-pack	2	1	
4-pack	4	5	
12-pack	4	4	
20-pack	4	5	
6-pack	7	12	
24-pack	7	5	
Total		**38**	**306,920**

4.3. Conclusion

In this chapter we have designed five alternatives for an automated offline repacking machine in order to answer our third research question:
" Which alternatives are suitable for an automated offline repacking machine at Grolsch? "

We found five alternatives that comply with the technical requirements and the organizational requirements and wishes that we have determined in Section 4.1. Table 4.10 gives an overview of these five alternatives. We see that Alternatives 1 and 3 have a speed of 15,000 bottles per hour. This translates to 45HL/h for 30cl bottles. These alternatives are chosen because the price of the required machines is lower due to the lower operating speeds. We found that the expected yearly production volumes are not too high for a machine running at this speed. Alternatives 2 and 4 have a speed of 30,000 bottles per hour. These alternatives are chosen to make a comparison between the higher investment costs versus the lower production costs due to the higher production speed. The speed of Alternative 5 is 48,000 bottles per hour. This is equal to the speed of Line 7, which was a requirement due to the linkage of both production lines. Furthermore, Alternatives 1 and 2 have products that originate from Line 2, as this line currently has the least idle time and most repack SKUs. Alternatives 3 and 4 include products from Line 4 to eliminate manual repacking for these items. Finally Alternative 5 offers the most extensive option which also includes products from Line 7.

Table 4.10: Overview of the 5 alternatives

Alternative	Current production lines included	Speed (bottles/hour)	Total production volume in 2020 (HL)
Alternative 1	2	15,000	86,145
Alternative 2	2	30,000	86,145
Alternative 3	2 and 4	15,000	213,166
Alternative 4	2 and 4	30,000	213,166
Alternative 5	2, 4 and 7	48,000	306,920

5. Evaluating Alternatives

Now that we have determined five alternatives in Chapter 4, we research these in order to compare them. We start in Section 5.1, where we calculate or determine the input values required to calculate the costs and benefits per alternative. In Section 5.2 we calculate the benefits of each alternative. Benefits are financial or qualitative improvements of the current production process due to the addition of a new production line. In Section 5.3 we determine the costs involved with each alternative. In Section 5.4 we calculate the payback period of a cratecover machine per alternative. We calculate payback period per alternative in Section 5.5. In Section 5.6 we perform a sensitivity analysis to determine the robustness of the comparison. Finally, Section 5.7 provides a conclusion.

Table 5.1 gives an overview of the subjects we discuss in Section 5.1, 5.2 and 5.3. We start with the input required for the comparison. Next we calculate the 6 identified benefits for each alternative and evaluate the qualitative benefits. Finally we calculate the involved costs.

Table 5.1: Section overview Chapter 5

	Section	Subject
Input	5.1.1	Assumptions about new production line
	5.1.2	Forecasting production volume
	5.1.3	Hourly Rate
Benefits	5.2.1	Inventory aggregation
	5.2.2	ME improvements
	5.2.3	Reduction of required FTE
	5.2.4	Incremental volume 4-packs
	5.2.5	Reduction of repack activities
	5.2.6	Reduction of required maintenance
	5.2.7	Qualitative benefits
Costs	5.3.1	Investment costs
	5.3.2	Warehouse handling costs
	5.3.3	Production costs

5.1. Input for Comparison

In order to estimate the expected costs and benefits we require general input data. In this section we discuss the forecasting of the volumes during the lifetime of the new production lines, the hourly rate per alternative and other input variables such as the ME of the production line.

5.1.1. Assumptions about new production line

The new production line has characteristics that are currently unknown. However, these are required in order to determine the costs of operating this new production line. We make several assumptions about relevant characteristics of the new production line. These assumptions apply to each alternative. We make these assumptions in consultation with both packaging experts and production experts at Grolsch.

Assumption 1 – Machine efficiency new production line

We assume that the machine efficiency (ME) of the new production line is 80%. From the layout in Figure 4.2 we see that there are either 5 or 6 machines in series. From the manufacturers we know that a new machine has an expected uptime of 98%. The expected availability of the machines that are placed in series is then 0.98^5 = 90% or 0.98^6 = 89%. We assume the true ME is lower because of two reasons. First of all, manufacturers often overestimate the actual performance of a machine.

This also happened before at Grolsch, which is why Grolsch is hesitant to accept these numbers. Besides, there are other factors that can influence the ME as well, as mentioned in Section 2.4. Based on the ME of the other machines at Grolsch and in consultation with experts at the packaging department of Grolsch we determine that the actual ME should be lower. We therefore assume the ME of the new production line in each alternative to be 80%.

Assumption 2 – Start-up and shutdown times new production line
Start-up and shutdown occur each running week. From the current start-up and shutdown times of the other production lines at Grolsch we assume that the start-up of the new line is 0.5 hours and the shutdown is 1 hour.

Assumption 3 – Service stops new production line
The time loss due to service stops is expected to be 2%. As mentioned in Section 2.4, service stops are time losses due to factors outside of the production control, such as breakdowns or small stoppages. This new production line is fairly simple with less machines than most of the other production lines Grolsch has. Grolsch expects 3% service stops for the keg line, Production Line 1. Grolsch expects 2% for Line 4 and Line 7. We assume that the service stops of the new production line should be equal to the service stops of Lines 4 and 7 and thus be 2%.

Assumption 4 – Number of operational weeks new production line
We expect the new production line to require periodic maintenance for 2 weeks per year. This corresponds with the current maintenance schedule of other production lines at Grolsch with similar machines. This means that the new production line will be operational for at most 50 weeks per year.

Assumption 5 – Lifetime new production line
We assume the new production line to have a lifetime of 15 years. This is the lifetime that the suppliers indicate and is also the lifetime that Grolsch uses for the other production lines.

Assumption 6 – Production start new production line
We assume that production with the new production line can start in 2020.

Assumption 7 – Weekly M&C hours new production line
We assume that the Maintenance & Cleaning (M&C) time is 12 hours per running week. Grolsch has a similar pack machine to the one that would be used in this new production line. It currently takes Grolsch about 8 hours to maintain and clean this machine every running week, this is the longest time of all the machines in this production line. Besides, Grolsch holds planned periodic maintenance (PPM) every running week, which takes about 4 hours. We therefore assume that M&C in each alternative takes 12 hours per week.

Table 5.2 gives an overview of the assumptions made for the five input variables.

Table 5.2: Assumption of input variables

Input variable	Assumption
ME	80%
Start-up	0.5 hours
Shutdown	1 hour
Service stops	2%
Number of operational weeks	50 weeks
Start of production new production line	2020
Lifetime of new production line	15 years
Maintenance & Cleaning	12 hours

5.1.2. Forecasting Production Volume

The new production line has an expected lifetime of 15 years. Grolsch currently has a production volume forecast for the years 2019 to 2022. We therefore need to forecast in order to determine the benefits and costs over the complete lifetime of the new production line.

Grolsch has historical data on the production volume for the years 2016 to 2018. We use this as the basis for the forecasting model. As we believe that three data points are not enough to create a good estimate for the level and trend, we decide to use the forecasts of 2019 to 2022 to create better estimates. For each SKU we determine the years 2016 to 2018 to be the first three datapoints. We use Equation 5.1 to apply linear regression between demand and time to obtain an initial estimate of the level and trend.

$$D_t = at + b \tag{5.1}$$

Here, D_t = Demand for period t;
b = Intercept;
a = Slope;
t = Time period.

The slope that we find using Equation 5.1 shows the initial trend, the intercept shows the initial level. Table 5.3 shows the initial level and trend estimates based on the actual production volumes for the years 2016 to 2018 and the forecasted production volumes for the years 2019 to 2022 for SKU ID 92122.

Table 5.3: Initial estimate Level and Trend of SKU ID 92122

Actual Production Volume (HL)			Forecasted Production Volume (HL)				Initial Estimate	
2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Level**	**Trend**
27,430	27,331	30,478	28,242	27,648	27,648	27,648	28,281	-55

With these estimates, we apply Equations 3.10 and 3.11 to determine the forecast of each SKU. We compare the created forecasts for the years 2016 to 2018 with the actual production volumes and for the years 2019 to 2022 with the forecasts created by Grolsch. That way, we are able to determine the smoothing factors to minimise the Mean Absolute Deviation (MAD) compared to both the actual volumes and the forecasts created by Grolsch. Using the Solver in Excel, we find the optimal value for the smoothing factors of both the level and the trend for each SKU.

Figure 5.1 shows a comparison between different values of the smoothing factors for level and trend. We see that the forecast created with the smoothing factors found using the Solver in Excel is the most similar to the actual production volumes and forecasts of Grolsch. For SKU ID 92122 we find that the optimal smoothing factor of level α is 0.98. The optimal smoothing factor of the trend β is 0.05. This leads to a MAD of 158.

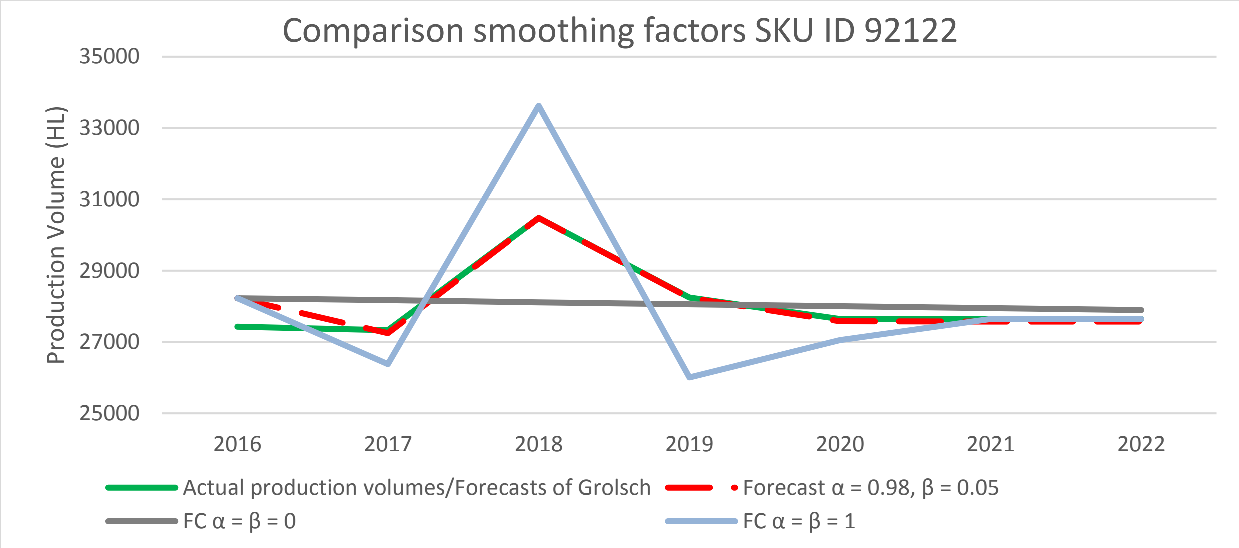

Figure 5.1: Comparison smoothing factors

Table 5.4 shows the MAD of several combinations of the two smoothing factors. We see that the solver offers a solid reduction of the MAD compared to other values.

Table 5.4: Mean Absolute Deviation different smoothing factors SKU ID 92122

α	β	Mean Absolute Deviation
0	**0**	727
0.5	**0.5**	518
0.98	**0.05**	158
1	**1**	1,103

Now that we have the level and trend estimates of the year 2022, we use these to create the forecast for the years 2023 to 2034. Table 5.5 shows the created forecast of SKU ID 92122 using this method.

Table 5.5: Forecast using Holt's model of SKU ID 92122

Year	Actual Production Volume (HL)	Forecast of Grolsch (HL)	Forecast (HL)
2016	27,430		28,226
2017	27,331		27,248
2018	30,478		30,478
2019		28,242	28,237
2020		27,648	27,579
2021		27,648	27,570
2022		27,648	27,574
2023			27,501
2024			27,428
2025			27,356
2026			27,283
2027			27,210
2028			27,137
2029			27,065
2030			26,992
2031			26,919
2032			26,847
2033			26,774
2034			26,701

Not every SKU of Grolsch has historical data going back to 2016. This is due to the fact that part of these SKUs are New Product Developments (NPDs) starting later than 2016. For these SKUs we start with the initial estimation of the level and trend in the year where demand is first observed or forecasted. That way, the years where the SKU did not exist do not influence the calculations. Obviously, this means that we create forecasts based on less available data points, which lowers the quality of the forecast.

Combining the forecasts of all SKUs gives us the expected production volumes per year for the automated offline repacking machine in each alternative. Table 5.6 gives an overview of the total forecasted production volumes. We see that the expected production volumes increase every year. The average yearly increase is 5.5%. This is in line with the goals of Grolsch.

Table 5.6: Total yearly forecasted production volumes

	Forecast by Grolsch			**Created forecast using Holt's model**				
Year	**2020**	**2021**	**2022**	**2023**	**2024**	**...**	**2033**	**2034**
Production Volume (HL)	329,529	359,130	392,513	430,467	457,472	...	707,741	735,891

5.1.3. Hourly Rate per Alternative

To calculate the costs involved with running the new production line, we estimate the expected hourly rate per alternative. At Grolsch the hourly rate of a production line consists of fixed and variable costs.

Fixed costs
Grolsch identifies three costs that make up the fixed part of the hourly rate of a production line: (1) operators, (2) depreciation, and (3) maintenance.

Fixed cost 1 – Operators
After talks with the unit managers of the production lines, we determine that the new production line requires 2 operators to be functional. It does not matter which alternative, as in each alternative one operator can work on the first part of the machine and the second operator works on one of the 2 paths that's operational after the pack machine. With an average hourly rate of €42.50 per operator, the fixed hourly costs for operators is considered to be €85.

Fixed cost 2 – Hourly depreciation
Depreciation is the reduction of the value of an asset over time. Grolsch uses the machine hour rate method for calculating depreciation. This means that depreciation is added to the hourly rate of the machine. To determine the hourly rate of depreciation, we use Equation 5.2.

$$Hourly\ rate\ of\ depreciation = \frac{Investment\ cost - Rest\ market\ value}{Expected\ working\ hours\ of\ machine} \tag{5.2}$$

We assume that there is no rest market value at the end of the lifetime. Based on the forecasted production volumes we can determine the expected working hours of the production line. Table 5.7 shows the determination of the total expected hours per alternative and the calculation of the hourly depreciation rate per alternative. In the expected production hours we have accounted for the expected ME of 80%, as the machine is only 80% effective and thus produces longer than expected with the nominal speed.

Table 5.7: Hourly depreciation per alternative

Alternative	Speed (bottles /hour)	Investment	Expected production hours 2020	2021	2022	Total during lifetime	Hourly rate of depreciation
Alternative 1	15,000	€ 3,680,000	3,021	3,293	3,568	73,249	**€ 50.24**
Alternative 2	30,000	€ 3,990,000	1,510	1,646	1,784	36,625	**€ 108.94**
Alternative 3	15,000	€ 5,340,000	6,549	6,875	7,073	118,408	**€ 45.10**
Alternative 4	30,000	€ 5,640,000	3,275	3,438	3,536	59,204	**€ 95.26**
Alternative 5	48,000	€ 6,465,000	2,860	3,117	3,407	60,613	**€ 106.66**

Fixed cost 3 – Maintenance

When Grolsch buys a new production line, they often choose to conclude a maintenance contract with the supplier in order to keep the machine in a good condition. We assume that Grolsch will follow this strategy for this production line as well. Based on the maintenance costs of the other production lines at Grolsch we assume that the total fixed maintenance costs per year are equal to €40,000. To determine the hourly rate of these maintenance costs we divide this value by the expected production hours of 2020. Table 5.8 shows the hourly fixed maintenance costs per alternative.

Table 5.8: Hourly fixed maintenance costs per alternative

Alternative	Maintenance cost	Expected production hours 2020	Hourly maintenance rate
Alternative 1	€ 40,000	3,021	**€ 13.24**
Alternative 2	€ 40,000	1,510	**€ 26.48**
Alternative 3	€ 40,000	6,549	**€ 7.44**
Alternative 4	€ 40,000	3,275	**€ 14.89**
Alternative 5	€ 40,000	2,860	**€ 16.54**

Variable costs

Grolsch identifies four costs that make up the variable part of the hourly rate of a production line: (1) maintenance, (2) heat, (3) electricity, and (4) water.

Variable cost 1 – Maintenance

Variable maintenance is assumed to be €30,000 per year. This is based on yearly maintenance costs of the machines in the production line for which a similar machine already in use at Grolsch. Table 5.9 shows the hourly variable maintenance costs per alternative.

Table 5.9: Hourly variable maintenance costs per alternative

Alternative	Maintenance cost	Expected production hours 2020	Hourly maintenance rate
Alternative 1	€ 30,000	3,021	**€ 9.93**
Alternative 2	€ 30,000	1,510	**€ 19.86**
Alternative 3	€ 30,000	6,549	**€ 5.58**
Alternative 4	€ 30,000	3,275	**€ 11.17**
Alternative 5	€ 30,000	2,860	**€ 12.40**

Variable cost 2 – Heat

The next variable hourly rate cost is heat. The processes in this new production line require no heat to operate, as there is no filling part in this production line. We therefore assume that the costs of heat per hour for all alternatives are €0.

Variable cost 3 – Electricity
The new machine does use electricity. After discussing with the unit managers of the production lines at Grolsch, we decided to assume that the usage of electricity of this new production line would be equal to the usage of Production Line 1. We therefore assume that the variable hourly cost of electricity is €3.26 for each alternative.

Variable cost 4 – Water
The last variable cost is water. As this machine uses no water to cool, fill or clean, we assume that the hourly cost of water for this machine is €0.

Table 5.9 gives an overview of the hourly rate for each alternative based on determined fixed and variable costs in this section. We see that Alternative 1 and 3 have lower hourly rates compared to Alternative 2 and 4, which are equal but have higher production speeds. The difference is the fact that Alternative 1 and 3 require more production hours, which lowers the hourly deprecation.

Table 5.10: Overview hourly rate per alternative

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Fixed cost / hour					
Maintenance	€ 13.24	€ 26.48	€ 7.44	€ 14.89	€ 16.54
Depreciation	€ 50.24	€ 108.94	€ 45.10	€ 95.26	€ 106.66
Operators	€ 85.00	€ 85.00	€ 85.00	€ 85.00	€ 85.00
Variable cost / hour					
Maintenance	€ 9.93	€ 19.86	€ 5.58	€ 11.17	€ 12.40
Electricity	€ 3.26	€ 3.26	€ 3.26	€ 3.26	€ 3.26
Total	**€ 161.67**	**€ 243.55**	**€ 146.39**	**€ 209.58**	**€ 223.86**

5.2. Benefit Estimation per Alternative

In this section we estimate the 6 benefits for each alternative. In Section 5.2.1 we discuss the benefits due to inventory aggregation, in Section 5.2.2 the machine efficiency improvements for the current production lines due to the alternatives. Next, in Section 5.2.3 we discuss the benefit of incremental volumes and in Section 5.2.4 we discuss the reduction of costs for the repacking department. Then in Section 5.2.5 we estimate the reduction of maintenance costs on the current production lines and finally in Section 5.2.6 we determine the savings on reducing the required number of operators on the current production lines. Section 5.2.7 then gives an overview of the qualitative benefits of the alternatives and finally Section 5.2.8 summarises the benefits.

5.2.1. Inventory Aggregation

With the new automated offline repacking machine Grolsch can produce products on Line 2 and Line 4 in their 24-loose or 16-loose bottle variant and store this variant in the warehouse. By doing so, Grolsch can lower the required inventory of, for example, a 6-pack SKU and produce the 6-pack variant only when required. This means that the 6-pack SKU is produced following an assemble-to-order principle, while originally all the SKUs of Grolsch were produced following a make-to-stock principle.

To look at the effect of inventory aggregation we look at 5 different parts: (1) which SKUs are merged, (2) how to calculate safety stock and cycle stock, (3) the impact on the safety stock, (4) the impact on the cycle stock, and (5) the impact on the production schedule. We discuss the impact on the production schedule of Production Lines 2 and 4 in Section 5.2.2.

Determination of SKUs to use for inventory aggregation

The first step of applying inventory aggregation is to determine which SKUs are included and which are not. We only look at SKUs of Production Lines 2 and 4. This is due to the fact that here we have SKUs in crates that both have a 24-loose or 16-loose variant and at least one other packaging configuration. Line 7 is excluded since, only in Alternative 5, it will be linked directly to the new production line which gives no benefits due to inventory aggregation.

As mentioned in Section 4.2, we only look at SKUs that have both a 24-loose or 16-loose variant and at least one other configuration. This is due to the fact that not all SKUs also have a 24-loose or 16-loose variant. It does not make sense to keep this semi-finished variant in stock if Grolsch does not actually sell this, unless there are multiple variants of this SKU. This does not make sense for Grolsch, since this would mean that Grolsch would always require an extra production step before this SKU can be sold, while producing it directly in the only variant that Grolsch sells means that it can be sold from stock. We do not apply inventory aggregation on the SKUs that Grolsch does not sell as 24-loose or 16-loose variants without multiple variants. Appendix A gives an overview of all the SKUs that we include in the calculations of inventory aggregation.

Now that we know the SKUs that we want to apply inventory aggregation to, we determine how the inventory of these SKUs is currently built up. For the calculations we use one example from the data set. Table 5.11 shows the input variables of this example. We see two SKUs that have the same beer, bottle and crate. The only difference is that article 92196 is a crate with 24 loose bottles and article 92117 a crate with four 6-packs. Article 92196 has a minimal Days of Cover (DoC) of 10 work days, i.e. 2 weeks. Article 92117 has a minimal DoC of 2.5 weeks. This is thus the safety stock that Grolsch keeps on these SKUs. The production volume of the 6-pack SKU is much higher than the volume of the 24 loose SKU. The production frequency of article 92196 is 4.3. This means that this article is currently produced on average once every 4.3 weeks, or 12 times per year.

Table 5.11: Input variables of two example SKUs current situation

SKU ID	SKU name	Days of Cover	Total volume 2020 (HL)	Production frequency	HL per pallet
92196	Confidential	10	5,543	4.3	5.04
92117		12.5	43,442	2.7	5.04

Equations for the determination of Safety Stock and Cycle Stock

As Grolsch uses the minimal Days of Cover principle in the determination of their safety stock levels, we cannot directly apply the theory of Section 3.3. Instead, we have to determine equations that work with the DoC principle of Grolsch.

Safety Stock

To determine the safety stock levels in pallets based on the minimal Days of Cover (DoC) criteria used by Grolsch, we use Equations 5.3 and 5.4:

$$\mu_i = \frac{DoC_i}{5} * \frac{A_i}{52} \tag{5.3}$$

$$SS_i = \frac{\mu_i}{h_i} \tag{5.4}$$

Here, μ = Average safety stock level in HL for SKU i;
DoC_i = Minimal Days of Cover determined for SKU i;
A_i = Annual sales volume of SKU i;
SS_i = Safety Stock level of SKU i;
h_i = Conversion rate of SKU i from HL to pallets.

Equation 5.3 determines the average expected weekly safety stock level per SKU in HL. As mentioned in Section 2.3, Grolsch uses the minimal DoC method to determine the safety stock levels. This means that a minimal DoC of 5 days determines that the safety stock is equal to the demand of the next 5 days, or 1 week since a week has 5 working days. Dividing the annual sales volume by 52 gives us the average sales volume per week. Multiplying the minimal DoC expressed in number of weeks with the average sales volume in HL per week gives us the average expected safety stock level in HL. We use Equation 5.4 to converse this safety stock level from HL to pallets.

Cycle Stock

With the production frequency from Table 5.11, we determine the cycle stock by using Equations 5.5, 5.6 and 5.7.

$$F_i = \left(\frac{52}{f_i}\right) \tag{5.5}$$

$$Avg. Batch\ size = \frac{P_i}{F_i}/h_i \tag{5.6}$$

$$Cycle\ Stock = avg.\ batch\ size/2 \tag{5.7}$$

Here, F_i = number of productions per year for SKU i;
P_i = Annual production volume of SKU i;
f_i = Frequency of production of SKU i;
h_i = Conversion rate of SKU i from HL to pallets.

Equation 5.5 gives us the weekly expected frequency. f_i is the frequency of production. If, for example, f_i is 4, this means that Grolsch produces SKU i once every 4 weeks. Dividing the number of weeks per year, 52, by this frequency gives us the expected number of productions per year, which is 13 times in this example.

Equation 5.6 gives us the average expected batch size based on the annual production volume and the number of productions per year, conversed to pallets. We use Equation 5.7 to determine the cycle stock based on the average batch size.

Determination current Safety Stock and Cycle Stock Levels

Table 5.12 shows the safety stock and cycle stock level we find after applying Equations 5.3 to 5.7 to the two SKUs of Table 5.11. We see that the total average expected stock level of the two SKUs combined equals 731 pallets in 2020.

Table 5.12: Safety Stock and Cycle Stock of two example SKUs

SKU ID	Safety Stock (pallets)	Cycle Stock (pallets)	Average expected stock level (pallets)
92196	43	46	89
92117	415	227	642
Total	**458**	**273**	**731**

Applying Equations 5.3 to 5.7 to all relevant SKUs from Line 2 and 4 we find a total expected average stock level of 4,936 pallets in 2020. 2,217 pallets are safety stock and 2,719 pallets are cycle stock. We find that currently 30% of the total average stock is kept for the loose bottle variants. The other 70% is kept for the other packaging configurations.

Calculating new minimal Days of Cover

Since we aggregate the inventory in the loose variant, the safety stock levels, or minimal DoC, changes. As the minimal DoC levels are determined by Grolsch, we use a weighted average of the current minimal DoC levels for the aggregated products to determine the new minimal DoC level. We use Equation 5.8 to determine the minimal DoC level of aggregated products.

(5.8)

$$\min DoC\ (days) = f_{new} * \sum_{i=0}^{j} \left(\frac{DoC_i}{f_i} * \frac{A_i}{\sum_{i=0}^{j} A_j} \right)$$

Here, f_{new} = New production frequency of aggregated product;
DoC_i = Current minimal DoC for SKU i;
f_i = Current production frequency for SKU i;
A_i = Annual production volume for SKU i.

Equation 5.8 determines how high the new minimal DoC should be, based on the production frequency of the new aggregated product. For example, if the minimal DoC is 2 weeks and production takes place every 4 weeks, the current safety stock is thus 50% of the expected sales during the lead time. Next it weighs this by the production volume of each SKU, which means that a SKU with a higher production volume has more impact on the new minimal DoC. Table 5.11 gives an overview of the characteristics of SKUs 92196 and 92117. Using these and Equation 5.8, we find the minimal DoC of the new aggregated product:

$$Min\ DoC\ SKU\ 92196 = 2.0 * \left(\frac{10}{4.3} * \frac{5{,}543}{48{,}985} + \frac{12.5}{2.7} * \frac{43{,}442}{48{,}985} \right) = 8.7\ days$$

We see that for a production frequency of 2, once every 2 weeks, for SKU 92196, the required minimal DoC for SKU 92196 should be 8.7 days, based on the current minimal DoC levels and frequencies of the aggregated SKUs.

For the non-aggregated products we also determine new minimal DoC levels. As the SCP department at Grolsch currently determines these levels based on experience and insights, it is not a good option to keep the same minimal DoC levels to the non-aggregated products that have new production frequencies. For example, SKU ID 92117 will now be produced every week on the new production line. It does not make sense to keep the minimal DoC at 12.5 days with this new production frequency. We find that Grolsch currently has an average minimal DoC for all SKUs of 25% of the lead time or time between productions. We decide that the minimal DoC for all non-aggregated SKUs in the new situation will be 40%. This means that a SKU that is produced every week has a safety stock of 2 days. This is high enough for these SKUs since production takes place every week and Grolsch is thus able to increase the production quantity within the week if necessary.

Impact on Safety Stock and Cycle Stock

Now that we know the current safety stock and cycle stock levels, we calculate these levels for the new situation. To do so, we first determine what the minimal batch size of the new production line should be. With the minimal batch size of the new production line, we calculate the expected production frequency of the products and thus calculate the cycle stock levels in the new situation. We want to determine a minimal batch size as this gives us a trade-off between changeover costs, holding costs and transportation costs. For example, we expect a lower minimal batch size to require more changeovers, since the frequency of slow-movers will be higher. However, this also lowers cycle stock levels and thus lowers holding and transportation costs.

Determination of minimal batch size new production line

To determine the minimal batch size of the new production line, we first determine the frequency of production of each SKU based on the minimal batch size. We apply this only to Alternative 3, 4 and 5. In Alternative 1 and 2, there are only 3 SKUs on the new production line. Each of these SKUs has a total expected production volume of at least 8,400HL. This means that even if we produce these SKUs every week, we automatically have a minimal batch size of at least 168HL, which we find sufficient. Changing the minimal batch size of these SKUs will therefore have a very limited impact on the production line schedule.

To determine the frequency of production on the new line we use Equation 5.9.

$$f_i = 1 \, / \, MAX\left(1\,;\frac{T*B}{P_i}\right) \tag{5.9}$$

Here, f_i = Frequency of production of SKU i;
T = The number of producing weeks per year, in this case 50;
P_i = Annual production volume of SKU i;
B = Minimal batch size for the new production line.

We determine based on the minimal batch size and the annual production volume of a SKU what the frequency of production should be on the new production line. If The frequency is 4, we expect Grolsch to produce once every 4 weeks. If the annual production volume of a SKU is higher than 50 times the minimal batch size, The weekly frequency of this SKU is 1, which means that the SKU is produced every week.

We apply Equation 5.9 to SKU ID 92192. This SKU has an expected production volume of 8,388 HL in 2020. The conversion rate from HL to pallets is 5. Table 5.13 shows the effect of changing the minimal batch size on the stock level of this SKU.

Table 5.13: Effect of minimal batch size on SKU ID 92192

Minimal batch size (HL)	Frequency	Average expected batch size (HL)	Average expected batch size (pallets)	Average expected stock level (pallets)
100 HL	1.0	168 HL	33	17
150 HL	1.0	168 HL	33	17
200 HL	1.2	200 HL	40	20
250 HL	1.5	250 HL	50	25

In Table 5.13, we see that based on the annual production volume of SKU ID 92192, the minimal weekly batch size should be 168HL if we produce 50 weeks per year. Increasing the minimal batch size lowers the number of productions per year, with 100HL or 150HL we produce 50 times per year, while with 250HL we only produce 33 times per year. This means that we lower the expected number of changeovers, but increase the expect stock levels.

Figure 5.2 shows the average batch sizes for the 21 SKUs of Lines 2 and 4 if we would produce each SKU every week. We see that most of the SKUs have a batch size lower than or equal to 200 HL if we were to produce each SKU weekly.

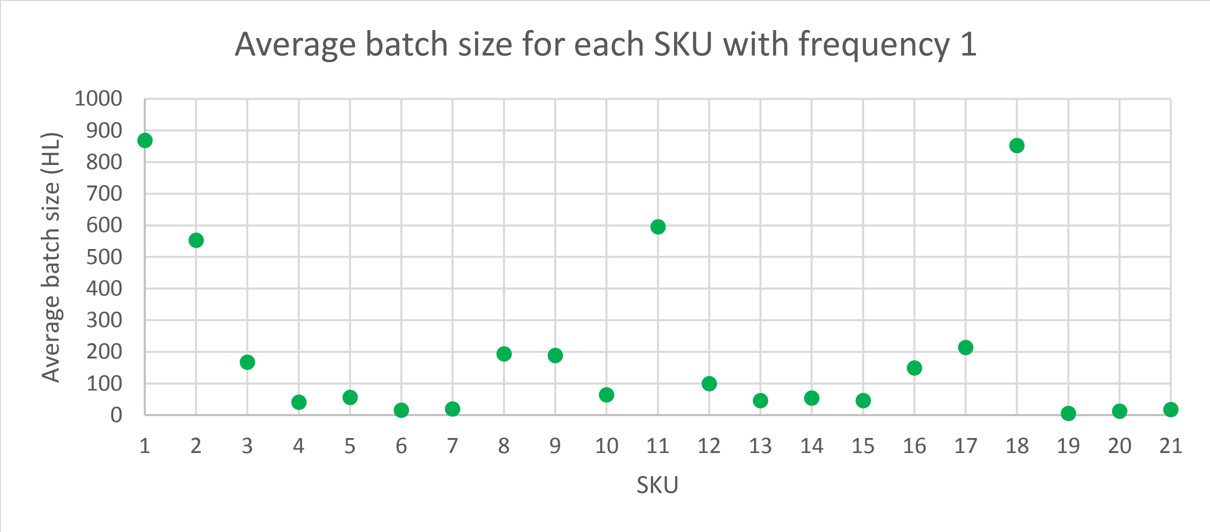

Figure 5.2: Expected batch size if each SKU was produced weekly

Based on the average batch sizes shown in Figure 5.2 we decide that the actual minimal batch size for the new production line should be between 0 and 200 HL. Higher batch sizes would mean that these products all have high inventory levels, which is something we want to avoid.

Now that we have determined the range in which the minimal batch size should be, we compare different minimal batch sizes. Table 5.14 shows the comparison between 8 different minimal batch sizes. We start with a minimal batch size of 0HL and increase the minimal batch size with 25HL per step.

The expected changeover time is found by a summation of the expected frequency of the SKUs per week. We elaborate further on the determination of changeover times in Section 5.3.3.

The average Days of Cover (DoC) is found by dividing the average batch size by the expected weekly sales. This gives us the weeks of cover. Multiplying this with 5, as there are 5 working days per week, gives us the average DoC. This is thus the average Days of Cover that is created when for each SKU 1 batch is created.

The number of SKUs within 80% of 90% of their shelf life is found by looking at the Days of Cover after producing a batch. If, for example, a SKU has 48 DoC after the production of 1 minimal batch, and the shelf life is 50 days, this SKU is considered to be within both 80% and 90% of their shelf life.

Table 5.14: Comparison between minimal batch sizes for new production line on Alternatives 3 and 4

Minimal batch size (HL)	Expected changeover time (hours)	Average DoC of production batch (work days)	Nr. of SKUs within 80% of shelf life	Nr. of SKUs within 90% of shelf life
0	22	14.1	3	0
25	20	18.7	4	1
50	19	21.8	4	1
75	17	25.2	5	1
100	15	28.6	5	2
125	14	32.3	6	2
150	14	36.1	8	3
175	13	39.9	8	5
200	12	43.7	9	5

From Table 5.14 we conclude that 6 options are not feasible for Grolsch. A minimal batch size of 0 HL, 25HL, 50 HL or 75 HL will not happen at Grolsch. In Section 5.1, we determined that changeovers on this production line will take about 1 hour between products of the same originating machine and 3 hours between products of different originating production lines. In Alternative 3 we have a nominal speed of 15,000 bottles per hour, while in Alternative 4 we have a nominal speed of 30,000 HL per hour. For Alternative 4, this would mean that 12 of the 21 SKUs have an average batch size that is lower than the hourly production speed of the machine. That means that the expected changeover time of 1 hour is longer than the actual production time, which is highly undesirable for Grolsch.

A minimal batch size of 150 HL, 175 HL or 200 HL results in an average DoC of at least 36.1 days. We find that for a minimal batch size of 150 HL, 3 SKUs have an expected DoC of 90% of their shelf life. 8 SKUs have an expected DoC of 80% of their shelf life. For a minimal batch of 200 HL this increases to 5 SKUs within 90% of their shelf life and 9 SKUs within 80%. Besides, a higher minimal batch size would increase the amount of stock that would become obsolete, thus increasing the obsolete costs. We consider this to be too much risk in becoming obsoletes and we therefore exclude these 3 options. This also results in high stock levels for slow-moving products, which we want to avoid.

Choosing between minimal batch sizes of 100HL and 125HL

Now that we have only two remaining batch sizes, we make a choice based on three costs: (1) the changeover costs, (2) the holding costs, and (3) the transportation costs.

First of all, the changeover costs. These are calculated using the expected changeover time in hours from Table 5.14 and the hourly rate of the new production line in the three alternatives. Using Equation 5.10 we calculate the yearly changeover costs of both minimal batch sizes in each of the three alternatives.

$$Yearly\ changeover\ costs = R_i * CO_j * T \tag{5.10}$$

Here, T = The number of operational weeks per year, in this case 50;
R_i = Hourly rate of alternative i;
CO_j = Expected changeover time per week for minimal batch size j.

Table 5.15 shows the yearly changeover costs per alternative and minimal batch size. The new production line is operational for 50 weeks per year, as stated in Section 5.1. Based on this, we calculate the yearly changeover costs. We see that a higher minimal batch size requires fewer changeover time per week and thus reduces the expected changeover costs.

Table 5.15: Changeover costs for minimal batch sizes 100 HL and 125 HL

	Alternative 3		Alternative 4		Alternative 5	
Minimal Batch Size (HL)	**Changeover time per week (hours)**	**Total costs changeovers**	**Changeover time per week (hours)**	**Total costs changeovers**	**Changeover time per week (hours)**	**Total costs changeovers**
100	15	€ 110,365	15	€ 158,363	18	€ 200,838
125	14	€ 103,007	14	€ 147,805	17	€ 189,680

Second, the holding costs of the pallets for each of the minimal batch sizes. As we have seen in Section 2.3.1 Grolsch has a WACC of 5.1% and an average cost price per pallet of €270.44. From Table 5.14 we get the average expected stock levels for the two minimal batch sizes. Applying Equation 2.1 gives us the expected holding costs per alternative. Table 5.16 shows the total yearly holding costs for each of the minimal batch sizes. As there is no effect on the stock levels of Production Line 7 SKUs, the stock levels in Alternative 5 are equal to the stock levels of Alternative 3 and 4.

Table 5.16: Yearly holding costs for minimal batch sizes 100 HL and 125 HL

Minimal Batch Size	Average weekly stock level	Weekly holding costs	Yearly holding costs
100 HL	4,615	€ 1,224	€ 63,650
125 HL	4,655	€ 1,235	€ 64,204

Finally, the reduction in transportation costs to the harbour. To determine the effect of the average inventory level on the transportation costs to the harbour we created a heuristic using VBA in Excel. This heuristic determines the required amount of pallets that need to be transported to the harbour in order to keep the stock level in the warehouse at Grolsch below a determined maximum. The pseudo code of this heuristic is shown in Appendix B.

This heuristic starts with creating a transportation scheme that is equal to the production scheme, meaning that all created stock for the designated SKUs will be transported to the harbour. By doing so, the expected stock levels in the warehouse at Grolsch are low, since each production is stored at the harbour. This has high costs since each pallet transported costs €6.51, as calculated in Section 2.3. Next the heuristic looks at whether setting the transportation of a SKU to 0, i.e. keeping it in stock at the warehouse of Grolsch instead of the harbour, will put the stock level at the warehouse above the practical limit of 18,500 pallets in any of the weeks. If this is the case, the transportation remains in the scheme. Otherwise, the transportation is taken out of the scheme and the pallets will thus be stored at the warehouse of Grolsch. For this heuristic, we identified 8 SKUs that are the most interesting to ship to the harbour.

Grolsch has identified 8 SKUs that should be stored at the warehouse. As the heuristic takes the warehouse stock level of all SKUs of Grolsch, we can determine the effects of lowering the average stock of the other SKUs by a certain number of pallets. Table 5.17 shows the yearly transportation costs for the two minimal batch sizes. In this case the costs are also equal for Alternative 3, 4 and 5 as there is no change in stock levels due to the addition on Production Line 7. We see that a minimal batch size of 100 HL costs €1,031 less compared to a minimal batch size of 125 HL.

Table 5.17: Yearly transportation costs minimal batch sizes 100 HL and 125 HL

Minimal batch size	Number of pallets moved to harbour	Total transportation costs
100 HL	39,075	€ 254,375
125 HL	39,698	€ 258,432

Table 5.18 gives an overview of the three costs for both minimal batch sizes. We conclude that a minimal batch size of 125 HL is the best option for the new production line, since the costs are lower. This is the case for each alternative.

Table 5.18: Cost comparison between minimal batch sizes 100 HL and 125 HL Alternative 3

Batch Size	Changeover costs	Holding costs	Transportation costs	Total costs
100	€ 110,365	€ 63,650	€ 254,375	€ 428,390
125	€ 103,007	€ 64,204	€ 258,432	€ 425,643

Calculating the impact on Safety Stock and Cycle Stock levels

Now that we have determined the minimal batch size is 125 HL, we calculate the impact of inventory aggregation on the safety stock and cycle stock levels using equations 5.3 to 5.8. Table 5.19 shows the comparison between the current and the new safety stock and cycle stock levels for SKUs ID 92196 and 92117.

In Table 5.11 we see that SKU ID 92196 has a minimal DoC of 10 days, or 2 weeks, is produced every 4.3 weeks and has an expected yearly production volume of 5,543 HL in 2020. SKU ID 92117 has a minimal DoC of 12.5 days, or 2.5 weeks, is produced every 2.7 weeks and has an expected yearly production volume of 43,442 HL in 2020. The new frequency of the aggregated product is 2, which means it is produced every 2 weeks. Using Equation 5.8 we get:

$$\min DoC\ SKU\ ID\ 92196\ (weeks) = 2 * \left(\frac{2}{4.3} * \frac{5{,}543}{48{,}985} + \frac{2.5}{2.7} * \frac{43{,}442}{48{,}985}\right) = 1.75\ weeks = 8.7\ days$$

Table 5.19: Safety Stock and Cycle Stock Comparison

	SKU ID	Packaging configuration	Frequency	Minimal DoC (days)	Safety Stock (pallets)	Cycle Stock (pallets)	Average expected stock level (pallets)
Current	92196	24-loose 30cl	4.3	10	43	46	88
	92117	4x6-pack 30cl	2.7	12.5	415	227	641
	Total				**458**	**273**	**731**
New	92196	24-loose 30cl	2.0	8.7	325	194	568
	92117	4x6-pack 30cl	1.0	2	68	86	86
	Total				**393**	**280**	**673**

SKU ID 92117 has an annual production volume of 43,442HL in 2020. This means that Grolsch will produce this SKU every producing week, resulting in an average batch size of 869HL. Conversing this to pallets gives us an average batch size of 172 pallets. The cycle stock of SKU ID 92117 is therefore 86 pallets. The safety stock of 92117 becomes 68, since this is 40% of the average weekly demand.

Furthermore, we see in Table 5.19 that the safety stock of SKU ID 92196 is increased from 43 pallets to 325 pallets in the new situation. However, the total safety stock of both SKUs is still reduced by 65. The total cycle stock of both SKUs combined increases with 7 pallets. Overall, we find that for these 2 SKUs the total average expected stock level drops from 731 pallets to 673 pallets.

Calculating savings due to inventory aggregation

We calculate the savings compared to the current situation for each year. Following the method in this section, we find that the SKUs of Line 2 lower the expected inventory level with 184 pallets. The SKUs of Line 4 lower the inventory levels with another 97 pallets to a total reduction of 281 pallets in Alternatives 3, 4 and 5.

Using the heuristic of Appendix B, we find that in the current situation Grolsch expects to pay €289,989 for transportation costs to the harbour in 2020. From Table 5.17 we get that the savings for Alternative 3, 4 and 5 are €31,557 on transportation. Lowering the expected weekly inventory level with 281 pallets saves Grolsch an expected €3,878 per year.

Table 5.20 shows an overview of the expected savings due to inventory aggregation for the years 2020 to 2022. We see that Alternatives 1 and 2 have equal expected savings, as these only have savings for SKUs that originate from Line 2. Alternatives 3,4 and 5 also have savings from SKUs that originate from Production Line 4.

Table 5.20: Overview expected savings inventory aggregation years 2020 to 2022

	Expected savings		
Year	**2020**	**2021**	**2022**
Alternative 1	€ 18,528	€ 20,196	€ 21,885
Alternative 2			
Alternative 3	€ 35,435	€ 37,464	€ 38,940
Alternative 4			
Alternative 5			

5.2.2. Machine Efficiency Improvements and Changeover Reduction

As certain SKUs will now no longer be done in their original form on Production Line 2 or 4, but instead be produced as loose bottles in crates, the production schedule of these lines changes. Due to the reduction of SKUs we expect a reduction in the number of required changeovers and the crates with loose bottles might have a higher ME than the SKUs that use carton, since there are less machines in the production line required.

Production Line 2

To determine the machine efficiency improvements to Production Line 2 we look at the possible reduction of changeover time and the effect of shifting the volume of 6-packs to their 24 loose variant.

Determining the current expected changeover time in 2020

To determine changeover times we first look at the current plan. Grolsch created a budget plan for 2020. In 2020, Grolsch currently expects 193 changeovers to occur. To determine the expected length of a changeover we look at the actual production schedule of the first half year of 2019. We do this to create a good representation of the actual average changeover time, based on the schedule that the Supply Chain Department at Grolsch has made. By taking the actual production schedule, we incorporate scheduling decisions done during that week. It therefore takes into account all the restrictions that the scheduler faces over the course of multiple weeks. We therefore assume that this schedule is fairly representative for the actual scheduling in the future.

Table 5.21 shows the production schedule for week 14 of 2019. We see that this week started with SKU 92193 and ended with SKU 91135. The expected changeover time is calculated based on the changeover matrices that Grolsch uses. These are made by the production managers to determine the expected changeover time from one SKU to another based on the required operations during that changeover, such as changing to a new crate. For example, the changeover between 92193 and 92012 takes 210 minutes due to a change in crates. SKU 92193 is a Kornuit product with a Kornuit crate, while 92012 is a Grolsch product with a BNR (common grey plastic) crate.

The changeover time to each first SKU of the week is considered to be 0, since this changeover is done during the shutdown in the week before or the start-up at the begin of the week and thus no extra time is required. The changeover times in Table 5.21 are the required changeover times towards an SKU. This means that we expect a changeover from 92193 to 92012 to take 210 minutes.

We find that Grolsch currently has an expected average changeover time of 92 minutes on Production Line 2. Looking at the 193 changeovers Grolsch expects to do in 2020, we expect Grolsch to have a total changeover time of 295 hours on Line 2 in 2020.

Table 5.21: Production schedule Line 2 in week 14, 2019

Production date	SKU	Production Quantity (HL)	Expected changeover time (min)
01-04-2019	92193	244	0
01-04-2019	92193	244	15
01-04-2019	92012	868	210
02-04-2019	92119	465	60
02-04-2019	92125	527	60
03-04-2019	92124	509	60
03-04-2019	92122	1,470	45
04-04-2019	92196	571	60
04-04-2019	91135	175	150

Determining the new expected changeover time in 2020

In the new situation created in each of the proposed alternatives, we substitute 6-pack SKUs by their 24-loose variant, if this exists. This has an impact on the production schedule. To determine the new average expected changeover time, we look at the same production schedule, the first half year of 2019. Substituting 6-packs by 24-loose bottle variants obviously reduces the quality of the schedule. This is due to the fact that changeovers between the same configuration are faster than changeovers between different configurations and the current production schedule is made in such a way that long changeovers are avoided.

To adjust for the reduced quality of the production schedule we recreate the production schedule of the first half of 2019 as if the SKUs that are changed to their 24 loose bottle variant are not in the schedule. This means that the changeover times between these SKUs and the others before or after them are ignored. We have two reasons for adjusting the schedule this way.

First of all, inserting a 24 loose bottle in the middle of a 6-pack series increases the changeover time. For example, the average changeover time between a SKU with 24 loose bottles in a BNR crate takes 100 minutes. Changing towards a 6-pack SKU in a BNR crate takes an average 173 minutes of changeover time. The schedulers of Grolsch try to avoid switching between different packaging configurations as much as possible. This results in runs with multiple 6-pack SKUs directly after each other. If we change one to a 24-loose variant, we increase the changeover time compared to the original schedule, while in reality the schedule would be changed to prevent this changeover.

Second, the volume for the 6-pack SKU is now added to the volume for the 24 loose SKU. Tactical planning will create a new production schedule based on the new combined demand volume from the two demand streams. This means that, based on the new weekly expected demand of the 24-loose SKU, it might be possible that the SKU is not even produced in the same week compared to the current production schedule. For example, a 6-pack SKU is currently produced once every 3 weeks and the 24-loose variant is produced once every 2 weeks. In the new situation, the demand stream of the 6-pack SKU is added to the production schedule of the 24-loose variant. This means that the production will occur at least once every 2 weeks and the batch size will increase to cover both demand streams. Based on this new tactical plan the scheduler will start optimizing the production schedule and avoid inefficient changeovers, such as 6-pack to 24-loose to 6-pack.

Table 5.22 shows the new production schedule. We see that SKU 92122 is now changed to its 24-loose variant SKU, 92133. This means that the changeover time from the previous SKU to this new SKU is ignored and is thus 0. Also the changeover time from this SKU to the next SKU is ignored and thus set to 0.

Table 5.22: New production schedule Line 2 in week 14, 2019

Prod. date	SKU	New SKU	Production Quantity (HL)	Expected changeover time (min)
01-04-2019	92193		244	0
01-04-2019	92193		244	15
01-04-2019	92012		868	210
02-04-2019	92119		465	60
02-04-2019	92125		527	60
03-04-2019	92124		509	60
03-04-2019	92122	92133	1,470	0
04-04-2019	92196		571	0
04-04-2019	91135		175	150

In this new schedule, the average changeover time lowers to 70 minutes. Compared to the original average changeover time of 92 minutes, this is a 24% reduction.

The effect on the production schedule of Line 2 through combining demand streams of SKUs

Now that we have determined that the new average changeover time for Production Line 2 lowers from 92 minutes to 70 minutes, we look at the effect of combined the demand streams of 6-pack SKU and their 24-loose variant on the production schedule of Line 2.

Table 5.23 shows the current tactical plan for the two variants of the Radler 0% Citroen beer. As we see, Grolsch currently expect to produce both variants in weeks 2, 6 and 8. In the new plan, the volumes are aggregated on SKU ID 92196. We therefore expect to have 1 less changeover in weeks 2, 6 and 8 on Line 2 due to the aggregation of these 2 SKUs.

Table 5.23: Tactical Production Plan 2020 Radler 0% Citroen

SKU ID	SKU Variant	wk 1	wk 2	wk 3	wk 4	wk 5	wk 6	wk 7	wk 8	wk 9	wk 10
92117	6-pack	0	1000	0	0	0	1500	0	1500	0	0
92196	24 loose	0	500	0	0	0	500	0	500	0	0

Combining the demand streams of all 6-pack SKUs that have a 24 loose variant and creating a production schedule for this new combined SKU, we find that the total required number of changeovers lowers from 193 to 163. These changeovers have an expected average changeover time of 70 minutes, instead of the 92 minutes in the current production schedule. In the new situation, we expect the changeovers to take 191 hours.

Calculating changeover time savings on Line 2

We conclude that adding the demand streams of 6-pack SKUs to their 24-loose SKU variant lowers the required time for changeovers with 105 hours, as we expect 295 hours of changeover time in the current situation. In the new situation this lowers to 191 hours.

Production Line 2 has average factory hours of 108 hours per week. As mentioned in Section 2.4, factory hours consist of all required hours in a week, from production to required time for maintenance. By lowering the required changeover time with 105 hours, Grolsch should be able to reduce the required number of producing weeks by 1 for Line 2. This also means that Grolsch reduces the required start-ups, shutdowns and M&Cs by 1. This sums up to an extra reduction of 28 hours.

In total we expect to save **XX** hours from these changes. With an hourly rate of €XX for Production Line 2, we expect to save €117,427 in 2020. To determine these savings for the other years we make an assumption that the savings of these changes increase once the volume of the aggregated SKUs increases. We make this assumption as aggregating the SKUs lowers the average required changeover time from 92 minutes to 70 minutes. Also, the required number of changeovers lowers. If the production volume of these SKUs increases, we expect the effect on the changeover time to increase accordingly and thus the savings increase compared to the current situation as well. Table 5.24 shows the overview of the expected savings based on these aggregated production volumes. As Production Line 2 is included in each of the 5 alternatives, the expected savings are equal for each alternative.

Table 5.24: Expected savings from lowering changeover time on Production Line 2

Year	2020	2021	2022
Production volume aggregated SKUs (HL)	79,478	86,586	93,573
Expected savings	€ 117,427	€ 127,929	€ 138,251

Production Line 4

Production Line 4 currently produces a number of SKUs out of the same beer. Changing the production on Line 4 to produce solely crates with 16 loose 45cl bottles will lower the number of SKUs from 17 to 5. Table 5.25 shows for the two main beers on Line 4 the division over the loose and other variants. Besides these two beer variants, Grolsch produces 3 other beers on Production Line 4. These are all produced in just 1 variant. We see that Lager beer has 11 SKUs that are currently done on Line 4 that contain carton.

Table 5.25: Production volume division per beer

Beer	Loose variant SKU ID	Number of other variants	Volume loose (HL)	Volume other variants (HL)
Confidential	90988	1	81,540	9,684
	90986	11	2,082	110,037

Because we are left with only 5 SKUs, we create a new production schedule for Line 4. To determine the effect of the changes, we first look at the current production schedule. Table 5.26 shows the current production schedule for the first 10 weeks of 2020. We see that each week consists of multiple SKUs, which thus requires multiple changeovers. Weeks 6 and 7 are empty because those are maintenance weeks where no production can take place. In the final row we see the expected number of changeovers per production week.

Table 5.26: Current production schedule Line 4 first 10 weeks of 2020

SKU ID	wk 1	wk 2	wk 3	wk 4	wk 5	wk 6	wk 7	wk 8	wk 9	wk 10
90847					314				403	
90986		2,000			6,000				7,000	
90988					352					
90989					566				573	
90991		500		750				500		
90995		795						628		
90997				1,875				2,685		
91000		1,657								611
91808				2,194				1,193		3,059
91810		1,734								1,012
92084				417				417		
92095		277								277
92135										
92220										105
92245										
92318										
92376					700					
#CO		5		3	4			4	2	4

Table 5.27 shows an overview of the most important KPIs to determine the quality of the production schedule. We see that the machine is running for 34 weeks in 2020, where the total loss due to changeovers, start-ups, shutdown, cleaning and M&C is 907,2 hours. The ME loss is **XX** hours and the total paid factory hours are expected to be **XX**. With an hourly rate of €**XX** we currently expect the costs of running Line 4 to be €4,029,960 in 2020.

Table 5.27: Overview KPIs current production schedule Line 4 2020

KPI	Value
Number of producing weeks	34
Planned ME	Confidential
Total expected changeover time	44.3
Total Start-up, shutdown & cleaning	386.9
Total M&C	476.0
Total ME Loss	1082.6
Total factory hours	3784.0

We also see that the planned ME is **XX**%. This is calculated using Equation 5.10. We see that with this equation we find the average weighted ME of all packaging configurations.

$$ME_i = \frac{\sum_j ME_j * P_{i,j}}{\sum_j P_{i,j}} \tag{5.10}$$

Here, ME_i = The planned ME in week i;
ME_j = Planned ME of packaging configuration j;
$P_{i,j}$ = Production hours of packaging configuration j in week i.

To create the new production schedule we first determine the frequency of the two aggregated SKUs. We do this because the current frequency of, for example the loose lager beer is extremely low due to the low annual volume. Following this frequency we would produce only 3 of 4 times a year. Given that the new production volume of this SKU is now 112,119HL, producing only 3 or 4 times a year would result in extremely high cycle stocks. We determine, based on products with similar demand streams and required production volumes that the optimal frequency of production for both items is 17 times per year, i.e. once every 3 weeks. This way, we are able to create a 3-week cycle production schedule that has one week for Lager, the next week for Pilsner and the other 3 SKUs and the next week free.

Now, based on the expected sales volumes we create a production schedule for the 5 SKUs. Table 5.28 shows the first 10 weeks of this new schedule. Comparing this schedule to the schedule shown in Table 5.26 it is easy to see the amount of changeovers will be significantly lower. In the new production schedule we expect 3 changeovers with a total expected changeover time of 135 minutes in the first 10 weeks, while in the old schedule we expect a total of 22 changeovers with an expected total changeover time of 541 minutes. We also expect to produce one week less than in the current production schedule.

Table 5.28: New production schedule first 10 weeks of 2020 for Line 4

	wk 1	wk 2	wk 3	wk 4	wk 5	wk 6	wk 7	wk 8	wk 9	wk 10
90986			5,260		5,260				5,260	
90988		8,280			3,000			8,280		
92135									700	
92318										
92376			700							
# CO			1		1				1	

Table 5.29 gives the overview of the KPIs for the new created production schedule for Line 4 in 2020. We see that the required number of producing weeks is lowered with 5 weeks from 34 weeks to 29 weeks. We also see a rise in the planned ME of 7.7% comparing the new situation to the current situation. This is due to the fact that the ME of crates higher than other packaging configurations, thus increasing the ME.

Table 5.29: Overview KPIs new production schedule Line 4 2020

KPI	Value
Number of producing weeks	29
Planned ME	Confidential
Total expected changeover time (hours)	11.3
Total Start-up, shutdown & cleaning (hours)	330.5
Total M&C (hours)	406.0
Total ME Loss (hours)	768.5
Total factory hours	3,200

In total, we expect Grolsch to pay **XX** factory hours in 2020. As mentioned, the hourly rate of Line 4 is €**XX**. We thus expect Grolsch to pay €3,408,000 for operating Line 4 in 2020. This amounts to a reduction of costs equal to €621,960. Table 5.30 shows the overview of the expected savings per alternative.

Table 5.30: Expected savings from changes on Production Line 4

	Expected savings		
Year	**2020**	**2021**	**2022**
Alternative 1	€ 0	€ 0	€ 0
Alternative 2			
Alternative 3	€ 621,960	€ 637,862	€ 643,091
Alternative 4			
Alternative 5			

We assume that there are no ME improvements possible on Line 7 in Alternative 5. As there is no aggregation of SKUs and the changeover times do not change we determine that the costs for Line 7 remain equal to the current situation.

Combining the savings of Table 5.24 and Table 5.30 gives us the total expected yearly savings on ME improvements for each alternative. Table 5.31 gives this overview.

Table 5.31: Expected savings from ME improvements on Lines 2 and 4 for each alternative in 2020 to 2022

	Expected savings		
Year	**2020**	**2021**	**2022**
Alternative 1	€ 117,427	€ 127,929	€ 138,251
Alternative 2			
Alternative 3	€ 739,387	€ 762,015	€ 772,133
Alternative 4			
Alternative 5			

5.2.3. Reduction of Operators on Production Lines 2, 4 and 7

When the new line is added, Grolsch can eliminate certain processes from their current production lines, as these will now be carried out on the new line.

Production Line 2
Production Line 2 currently has 7 operators. These operators are always required when the production line is running. It does not matter whether the line produces crates with 24 loose 30cl bottles or it produces 6-packs. We therefore conclude that there is no benefit possible due to the reduction of operators on Line 2.

Production Line 4

Production Line 4 currently has 8 operators. One of these operators is only required when this production line is producing SKUs that go into boxes. If we start to produce only crates with 16 loose 45cl bottles on Line 4 and take the carton part of the process to the new production line, we save the costs of this extra operator.

Table 5.32 shows the input variables for the 3 packaging configurations that Line 4 has that contain carton packaging and are thus transferred to the new production line. To determine the actual processing hours the extra operator is required at Line 4, we use Equation 5.11.

Table 5.32: Input variables FTE reduction Line 4

Packaging configuration	Nominal speed on Line 4 (HL/h)	Machine Efficiency (%)	Expected Production Volume 2020
12-pack 45cl bottle	105	Confidential	
4-pack 45cl bottle	135		
20-pack 45cl bottle	135		

$$Req. production\ hours\ year\ T = \sum_{i=1}^{N} \frac{P_{i,T}}{S_i * ME_i} \tag{5.11}$$

Here, T = Production year;
$P_{i,T}$ = Production volume of packaging configuration i in year T;
S_i = Nominal speed of packaging configuration i;
ME_i = Machine efficiency of packaging configuration i.

Applying Equation 5.11 to Production Line 4 in 2020 results in an expected total production time of 1,721 hours. With the average hourly rate of an operator at Grolsch of €42.50, we find the expected benefits of reducing this operator on Line 4 for the carton products to be €73,150.

Production Line 7

Production Line 7 currently has 5 operators. 2 of these operators are required to maintain the carton part of the machine. When we add the new production line in Alternative 5, part of the SKUs of Line 7 will no longer go through the carton part of Line 7, but instead are transported to the new line. We therefore can save the costs of the 2 operators of the carton part of the machine for the production of these SKUs. Table 5.33 shows the input variables for the 4 packaging configurations of Line 7 that can have their carton processing done at the new production line.

Table 5.33: Input variables FTE reduction Line 7

Packaging configuration	Nominal speed on Line 4 (HL/h)	Machine Efficiency (%)	Expected Production Volume 2020 (HL)
6-pack 25cl bottle	100	Confidential	
24-pack 25cl bottle	100		
6-pack 33cl bottle	120		
24-pack 33cl bottle	120		

Applying Equation 5.11 to Production Line 7 in 2020 results in an expected total production time of 1,328 hours. With the average hourly rate of an operator at Grolsch of €42.50, we find the expected benefits of reducing 2 operators on Line 7 for the carton products to be €112,921.

Table 5.34 gives an overview of the expected savings per alternative due to the reduction of operators of Lines 4 and 7. In Alternative 1 and 2, the savings are equal to €0. This is due to the fact that in these alternatives, neither Line 4 nor Line 7 is changed and therefore no savings are possible.

In Alternative 3 and 4, Production Line 4 is changed and thus the savings of reducing the required operators on Line 4 is possible. In Alternative 5 the savings on Line 7 are also added.

Table 5.34: Expected savings per alternative for the reduction of operators on Line 4 and 7

	Expected savings		
Year	**2020**	**2021**	**2022**
Alternative 1	€ 0	€ 0	€ 0
Alternative 2			
Alternative 3	€ 73,150	€ 74,410	€ 73,136
Alternative 4			
Alternative 5	€ 186,072	€ 208,353	€ 237,910

5.2.4. Incremental Volumes of New Packaging Configurations

Grolsch currently expects to produce 4,723 HL of 3-packs in 2020. With the new packing machine, which will be added in all three solutions, it is possible to produce both 3-packs and 4-packs for 30cl bottles on the new production line. Grolsch currently has one SKU that uses a 4-pack. Supermarkets have requested Grolsch to deliver more 4-packs and to reduce the amount of 3-packs. This is due to the space the product takes in the supermarket racks. Supermarkets try to have one loose bottle next to the product in the original pack, as some customers prefer to buy just one or two loose bottles and do not want to buy the pack. If the supermarkets only sell packs, customers either do not buy the product or take one bottle out of the original pack, which are both undesirable options for the supermarkets. For 3-packs, this means that it takes 4 spaces in the rack. 4-packs only take 3 places in the rack and are thus preferred by supermarkets.

Besides the request from supermarkets for 4-packs, it also has the advantage for Grolsch that the rate of sales would increase. As customers will now buy four bottles instead of three, thus increasing sales per SKU of 33%. However, we do not expect customers to keep the same purchasing patterns, as they will now also buy one bottle extra and are thus less quickly coming back to buy more. We assume that the rate of sale increases by 20% when going from 3-packs to 4-packs, this assumption is also backed by the experts at the financial department of Grolsch.

Table 5.35 shows the expected sales in 2020 of the 3-pack SKUs that Grolsch has. We see that Grolsch expects total sales of 4,723 HL in 2020. In the third column we calculate the profit that Grolsch expects to make from the sales in 2020. Adding the surplus of 20% to these profits ultimately finds a total expected increased profit of €76,704.

Table 5.35: Increased profit of incremental volumes 4-packs

Article	Expected production volume 2020 (HL)	Expected profit 3-packs	Expected production volume as 4-pack 2020 (HL)	Expected profit 4-packs	Increased profit
91844	1,721	€ 126,675	2,065	€ 152,010	€ 25,335
92090	2,348	€ 194,034	2,818	€ 232,841	€ 38,807
92138	654	€ 62,808	785	€ 75,370	€ 12,562
Total	**4,723**	**€ 383,518**	**5,667**	**€ 460,221**	**€ 76,704**

Table 5.36 gives an overview of expected yearly profit of this benefit for the years 2020-2022. Grolsch currently produces 3-packs on Production Line 2. This means that this benefit is applicable for each of the alternatives we research and the expected increased profit due to the incremental volumes of turning 3-packs into 4-packs is the same for each alternative.

Table 5.36: Expected increased profit for incremental volume of turning 3-packs to 4-packs

Year	2020	2021	2022
Incremental volume increased profit	€ 76,704	€ 83,639	€ 91,203

5.2.5. Reduction of Repack Activities

When the new line is added, we eliminate certain repack activities that Grolsch will be able to do on the production line instead of having manual workers perform these activities.

The hourly rate of manual workers at the repacking department is €29.28. Table 5.37 shows the speed at which manual workers perform the repack activities and the expected production volume for 2020. We also include the incremental volume of turning 3-packs to 4-packs in the production volumes, as calculated in Section 5.1.1.

Table 5.37: Speed and production volumes 2020 of repack activities

Activity	Production Line	Speed manual worker (HL/h)	Production volume 2020 (HL)
4-pack 30 CL bottle	2	1.89	6,667
12-pack 45 CL bottle	4	6.75	5,000
4-pack 45CL bottle	4	2.59	3,199
20-pack 45CL bottle	4	6.75	903

Based on the data of Table 5.37 we expect that the repack activities for products that originate from Production Line 2 will cost €103,291 in 2020. The repack activities for products that originate from Production Line 4 are expected to cost €61,764.

In Alternative 1 and 2 there are no changes that impact SKUs from Production Line 4, only Line 2. The expected savings due to the reduction of repack activities are thus equal to €103,291 in 2020. In Alternative 3, 4 and 5 the items of Production Line 4 are included and therefore the expected savings in these alternatives equal €165,055 in 2020. Table 5.38 gives an overview of the expected savings per alternative for the years 2020 to 2022.

Table 5.38: Expected savings per alternative for the reduction of repack activities

	Expected savings		
Year	2020	2021	2022
Alternative 1	€ 103,291	€ 112,623	€ 122,799
Alternative 2			
Alternative 3	€ 165,055	€ 180,626	€ 197,495
Alternative 4			
Alternative 5			

5.2.6. Reduction of Maintenance Costs

By implementing the new production line we are able to remove carton machines from the lines or reduce the usage of these machines. We therefore expect a reduction of the maintenance costs for these machines.

Production Line 2

Production Line 2 will use the carton machine less than originally. In the current situation, we expect to do 205,677 HL of 6-packs on Line 2 in 2020. With the addition of the new production line, we expect 79,478 HL of this volume to shift towards 24 loose bottles in a crate instead of 6-packs. This equals 39% of the total volume.

In 2018 Grolsch paid a total of €29,888 for maintenance on the carton part of Production Line 2. Grolsch produced 186,976 HL of 6-packs in 2018. We assume that reducing the volume over a certain machine will lower the expected maintenance costs of this machine. We therefore expect that Grolsch will pay €29,888 / 189,976 * 205,677 = €32,358 for maintenance on the carton machines in 2020. Lowering the volume of 6-packs on Line 2 from 205,677 HL to 126,199 HL due to the new production line gives us expected maintenance costs of €19,854. By shifting 79,478 HL of 6-pack volume to 24 loose bottles volume, we thus expect to reduce the maintenance costs by €12,504 in 2020.

Production Line 4

Line 4 will – in Alternative 3, 4 and 5 – no longer require the carton machines currently used, as Line 4 will become a production line that only produces crates with 16 loose 45cl bottles and all the carton configurations will be done on the new production line. We therefore are able to save the entire yearly expected costs on maintenance on the carton machines of Line 4.

In 2018 Grolsch paid €29,331 for maintenance on the carton machines of Line 4. The production volume of SKUs that require carton was equal to 123,033 HL in 2018. In 2020 the expected production volume equals 127,021 HL. We therefore expect Grolsch to save 127,021 / 123,033 * €29,331 = €30,261 on maintenance costs for Line 4 in 2020, when Alternative 3, 4 or 5 is implemented.

Production Line 7

We find that Grolsch paid €2,317 for maintenance on the carton machines of Line 7 in 2018. This is quite low compared to the costs of the other 2 production lines. We find that Line 7 required barely any maintenance outside the available maintenance & cleaning time each week the line is running. In Alternative 5, we transport 93,754 HL to the new production line and only 111,589 HL of the total 205,343 HL remains on the current carton machines.

In 2018 Grolsch produced 191,251 HL on Production Line 7. We therefore expect Grolsch to have maintenance costs of €2,488 in 2020. Implementing Alternative 5 will lower these costs to €1,352 in 2020, thus saving Grolsch €1,136 in 2020.

Table 5.39 shows the expected savings on maintenance costs per alternative for the years 2020-2022. In the current situation the expected savings are equal to €0. In Alternative 1 and 2 we expect savings from Production Line 2. In Alternative 3 and 4 savings from Production Line 4 come on top of the savings for Line 2. In Alternative 5 the savings from lowering the maintenance costs of Production Lines 2, 4 and 7 are aggregated.

Table 5.39: Expected savings per alternative for the reduction of maintenance costs

	Expected savings		
Year	**2020**	**2021**	**2022**
Alternative 1	€ 12,504	€ 13,622	€ 14,721
Alternative 2			
Alternative 3	€ 42,765	€ 44,345	€ 44,778
Alternative 4			
Alternative 5	€ 43,901	€ 45,697	€ 46,449

5.2.7. Qualitative Benefits

In this section we discuss the qualitative benefits of the proposed alternatives and the logistical organization behind the alternatives. We find 4 relevant qualitative benefits:

1. The Customer Order Decoupling Point
2. Reduction of obsoletes
3. Flexibility of production
4. Flexibility in NPDs

The Customer Order Decoupling Point
The CODP changes for the SKUs that now have the final production process done on the new production line. Twede et al. (2000) call this full postponement. Gattorna (1998) calls this manufacturing postponement.

Grolsch now delays the final production step until closer to the actual customer orders. Most of the SKUs will now be produced each week. This has two advantages.

First of all, Grolsch is able to delay the final production step, which has costs involved. Now, these costs are only made once Grolsch is (almost) sure that it will sell the product.

Second, Grolsch can wait with putting the stock into one packaging configuration. Now Grolsch has the choice to keep the stock in a 24-loose or 16-loose bottle variant. This way, Grolsch can create the products that are actually required by the customers and the chance of having stock that stays in a certain packaging configuration decreases.

Reduction of obsoletes
Inventory aggregation reduces the chance of obsoletes. In the current situation the SKUs are produced in batches of the same packaging configuration. If the sales disappoint, Grolsch risks obsoletes. As mentioned in Section 2.3, the costs of obsoletes were €**XXXX** in 2018 and are expected to rise.

With inventory aggregation we only keep stock of the 24-loose or 16-loose bottle variant. From this stock, Grolsch can use the oldest stock for either fulfilling orders of the loose variant or to transport to the new production line where it will be processed into another packaging configuration. This way, we reduce the chance of obsoletes as the oldest stock can be used for whatever is required first.

Flexibility of production
The new production line will be operational for 50 weeks per year in each alternative. The other 2 weeks it requires periodic maintenance. Due to the fact that it is operational for 50 weeks per year, the production process for the SKUs that use this production line is flexible. Grolsch does not need to keep large amounts of stock for these SKUs, as there is a possibility for production almost every week. The production schedule can be changed more easily than the production schedule of the

current production lines. For example, beer can only stay in the Bright Beer tanks for a couple of days before production must take place. It can happen that, considering the lead time of making beer, it actually would no longer be required due to disappointing sales. With the new production line Grolsch can simply cancel the production.

Flexibility in NPDs

New product developments are currently bound by the ranges of bottles, packaging configurations, boxes or crates that the current product lines can handle. This new production line is able to handle a larger range of packaging materials, creating more options for NPDs.

5.2.8. Summary of Benefits

We have calculated six quantitative benefits for each alternative. In this section we give an overview of the benefits for the alternatives. Table 5.40 displays this overview. We see that Alternative 1 and 2 have the same expected benefits. This makes sense, as the benefits are derived from savings on the current, existing production lines. Changing the speed of the new automated offline repacking production line does not influence other production lines and therefore has no impact on the benefits derived from other lines. The same goes for Alternative 3 and 4. Alternative 5 has the highest expected yearly benefits, which makes sense as this is the most comprehensive alternative.

Table 5.40: Overview of benefits per alternative in 2020

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Inventory aggregation	€ 18,528	€ 18,528	€ 35,435	€ 35,435	€ 35,435
ME improvements	€ 117,427	€ 117,427	€ 739,387	€ 739,387	€ 739,387
FTE reductions	€ 0	€ 0	€ 73,150	€ 73,150	€ 186,072
Incremental volumes	€ 76,704	€ 76,704	€ 76,704	€ 76,704	€ 76,704
Repack reductions	€ 103,291	€ 103,291	€ 165,055	€ 165,055	€ 165,055
Maintenance reductions	€ 14,931	€ 12,504	€ 42,765	€ 42,765	€ 43,901
Total expected yearly benefit	**€ 328,453**	**€ 328,453**	**€ 1,132,495**	**€ 1,132,495**	**€ 1,246,552**

5.3. Cost Estimation per Alternative

In this section we estimate the three costs for each alternative. In Section 5.3.1 we discuss the investment costs of each alternative, in Section 5.3.2 the extra handling costs in the warehouse and in Section 5.3.3 we determine the expected production costs of running the new production line in the alternatives.

5.3.1. Investment Costs

If Grolsch implements any of the 5 proposed alternatives, it will have to purchase an entire new production line. There are thus investment costs involved. With the requirements, constraints and wishes determined in Section 4.1 we met with two suppliers. Based on the 5 alternatives the suppliers created quotes for the expected investment costs. Table 5.41 shows the best quotes received from the suppliers for each alternative. We see that the increased speed of Alternative 2 compared to Alternative 1 results in extra investments costs of €310,000. This is due to the fact that the increased speed also required machines that are faster. For example, the palletizer/de-palletizer combination costs €350,000 when the speed is 15,000 bottles per hour. This increases to €550,000 when the speed is 30,000 bottles per hour.

Table 5.41: Investment costs per alternative

Alternative	Investment costs
Alternative 1	€ 3,680,000
Alternative 2	€ 3,990,000
Alternative 3	€ 5,340,000
Alternative 4	€ 5,640,000
Alternative 5	€ 6,465,000

5.3.2. Warehouse Handling Costs

When Grolsch implements the new automated offline repacking machine the handling costs in the warehouse increase, due to the extra transportation between the warehouse and the new production line.

Currently, Grolsch produces SKUs on one of the production lines and once a pallet is done, it goes to the warehouse. However, for a part of the products of Line 2 and Line 4 this will no longer be the case. The pallets will first be moved from either Line 2 or 4 to the warehouse and will later be transported back to the new production line. After processing is done on the new line, the pallets are transported to the warehouse where they sit until being sold.

It takes a forklift driver an average of 3 minutes to move 2 pallets simultaneously from the production line to the warehouse or vice versa. The hourly rate of a warehouse employee equals €42,50. Table 5.42 shows per configuration the production volume in 2020 and the number of pallets that will require extra movement. We do not include the products that are currently repacked in these volumes, because these are also transported from the warehouse to the repacking department and back once repacking is done. We assume that the time this takes equals the time it takes to move pallets from the production line to the warehouse or vice versa and that therefore there are no extra costs involved by producing on the new production line instead of at the repacking department.

Table 5.42: Expected number of pallets with extra handling costs

Packaging configuration	Production Line	HL per pallet	Production volume 2020	Expected nr of pallets
6-pack 30cl bottle	2	5.04	79,478	15,769
4-pack 45cl bottle	4	5.184	9,767	2,010
12-pack 45cl bottle	4	4.86	53,902	10,398
20-pack 45cl bottle	4	4.05	54,251	13,395

Using the hourly rate of €42,50 for warehouse employees and the average transportation time of 3 minutes for moving 2 pallets from the production lines to the warehouse and vice versa, we calculate that the expected extra handling costs for products originating from Production Line 2 are equal to €33,510 in 2020. For products originating from Production Line 4 this equals to €54,831.

Production Line 7 does not have increased handling costs. As products from Line 7 will be transported immediately towards the new production line in Alternative 5, i.e. the products will not be stored in the warehouse first and transported later, there are no extra handling costs for these products.

Table 5.43 shows the expected additional handling costs due to the addition of the new production line. In Alternative 1 and 2 we expect the costs for Lines 4 and 7 to be equal to the current situation, while the costs increase for products of Line 2. In Alternative 3, 4 and 5 we also include the extra costs on Line 4.

Table 5.43: Expected handling costs warehouse for the years 2020 to 2022

	Expected additional handling costs		
Year	2020	2021	2022
Alternative 1	€ 33,510	€ 36,507	€ 39,453
Alternative 2			
Alternative 3	€ 88,341	€ 91,283	€ 91,433
Alternative 4			
Alternative 5			

5.3.3. Production Costs

Running the new production line involves production costs. In Section 5.1.3 we have already calculated the hourly rate in each alternative. In this section we determine the required production hours of each packaging configuration in each of the alternatives. Based on these hours, we determine the optimal amount of shifts per week to fulfil the required production volume in a year.

To determine the required amount of shifts we need to calculate the required factory hours. We determine the required factory hours with Equation 5.12. This equation sums up all the losses that Figure 2.8 displays. Here, Production hours plus ME loss equal Machine Hours in Figure 2.8.

$$\text{Factory hours} = \text{Production hours} + \text{ME Loss} + \text{Service stops} + \text{changeover time} \\ + \text{start-up time} + \text{shutdown time} + \text{M\&C time} \tag{5.12}$$

Production hours
Production hours are the expected hours it would take to produce the volume considering the nominal speed. This is the optimal situation, meaning this is the best time it could take to produce a certain volume. Table 5.44 shows the production volumes of each configuration in 2020. Based on these volumes we calculate the expected production hours for each alternative.

Table 5.44: Production volume per packaging configuration and current production line in 2020

Configuration	Originating Production Line	Production Volume (HL)
3-packs	2	5,667
4-packs	2	1,000
6-packs	2	79,478
4-packs	4	57,100
12-packs	4	14,767
20-packs	4	55,153
6-packs	7	69,312
24-packs	7	24,442

Table 5.45 shows the nominal production hours per alternative in 2020. These hours are thus the expected production hours without any losses due to, for example, machine efficiencies or changeovers. We see that Alternative 2 has the lowest expected production hours, which makes sense as this is the alternative with the lowest amount of volume while having a speed of 90 HL/h.

Table 5.45: Production hours per alternative 2020

		Production hours									
		Production Line 2			Production Line 4			Production Line 7			
Alternative	Speed (HL/h)	3-packs	4-packs	6-packs	4-packs	12-packs	20-packs	6-packs	12-packs	24-packs	Total
Alternative 1	45	126	22	1,766							**1,914**
Alternative 2	90	63	11	883							**957**
Alternative 3	45	126	22	1,766	1,269	328	1,226				**4,737**
Alternative 4	90	63	11	883	634	164	613				**2,369**
Alternative 5	144	39	7	552	397	103	383	481	0	170	**2,131**

ME Loss and service stops
In Section 5.1.2 we have seen that we assume the ME of the new production line to be 80%. Machine hours are calculated by dividing the production hours by the ME. ME loss is the difference between the machine hours and the production hours.

Service stops are stops due to factors that are outside the control of the Production Line, but within the control of the Plant management. For example, quality issues with the packaging materials that require further inspection at the line before being used.

For the new production line, we assume that service stops take up 2% of the time. Service stops are calculated over the machine hours of the production line, as these are the actual expected running hours of the production line.

In Table 5.46 we show the ME loss per alternative based on the assumed ME of 80%. Based on the machine hours, we calculate the expected service stops per alternative.

Table 5.46: ME Loss per alternative 2020

Alternative	ME (%)	Production hours	Machine hours	ME Loss	Service stops (hours)
Alternative 1	80%	1,914	2,393	**479**	**48**
Alternative 2	80%	957	1,196	**239**	**24**
Alternative 3	80%	4,737	5,921	**1,184**	**118**
Alternative 4	80%	2,369	2,961	**592**	**59**
Alternative 5	80%	2,131	2,664	**533**	**53**

Changeovers
In Section 5.2.1 we have seen that we decide to use a minimal batch size of 125HL for the new production line. We expect the changeovers between products that have the same bottle size to be 1 hour. This is due to the fact that this only requires changes to the pack machine and the box machine, if used. Also about half an hour is required to fill the production line with products before use. This means that the conveyor belts of the entire production line are filled before the actual production starts. Grolsch adds this half hour to the changeover time. We expect a changeover between products from two separate lines, e.g. from a 30cl bottle of Line 2 to a 45cl bottle of Line 4 to be 3 hours. This is due to the fact that each machine in the production line requires a changeover.

For Alternative 1 and 2 we have seen in Section 4.2.1 that there will only be 7 SKUs processed on the new production line. Based on the minimal batch size of 125HL, we apply Equation 5.8 to determine the frequency of production for each of the SKUs on the new production line. Table 5.47 shows the frequencies of the Line 2 SKUs. We see that the first 3 SKUs have a frequency of 1, as the expected number of minimal batches is higher than the 50 production weeks for the new production line. The other SKUs have a lower production volume and we thus can produce the minimal batch size every couple of weeks. The weekly frequency is used to determine the expected number of SKUs per week. This is calculated by inversing the frequency. For example, a SKU that produces every 3 weeks is expected to produce 0.33 times per week on average.

Table 5.47: Frequency of Line 2 products based on minimal batch size of 125HL

SKU ID	Expected Production Volume 2020 (HL)	Number of minimal batches size 125HL	Frequency	Weekly frequency
92117	43,442	348	1.00	1.00
92122	27,648	221	1.00	1.00
92192	8,388	67	1.00	1.00
91844	2,065	17	3.03	0.33
92090	2,818	23	2.22	0.45
92138	785	6	7.96	0.13
92299	1,000	8	6.25	0.16

We find that the expected number of SKUs per week is 4.07. This is rounded up to ensure we are not underestimating the required number of changeovers. Thus, the expected number of SKUs per week is 5. The expected number of changeovers per week is then 4. This leads to an expected weekly changeover time of 4 hours.

For Alternative 3, 4 and 5 we have determined the expected number of changeovers in Section 5.2.1. For Alternative 3 and 4 the expected number of changeovers per week was 12 and the changeover time 14 hours per week. This is due to the fact that we expect a changeover between Line 2 SKUs and Line 4 SKUs, which we expect to take 3 hours. For Alternative 5 the total number of changeovers per week is 15. The expected changeover time per week is 17 hours. We see that the SKUs of Line 7 have a low frequency. The fastest SKU is produces once every 4.3 weeks. We therefore expect that the SCP department can create a schedule where once every 4 to 5 weeks there is space for Line 7 products and there is thus only one long changeover between products originating from different production lines per week. This saves a changeover of 3 hours per week.

We conclude that Alternative 1 and 2 have 4 hours of changeover time per week. Alternative 3 and 4 have 14 hours of changeover time per week and Alternative 5 has 17 hours per week.

Start-up, Shutdown and Maintenance & Cleaning

The final required hours to determine the factory hours are the start-up, shutdown and M&C hours. We have discussed these in Section 5.1.2.

For each of the alternatives we expect the weekly start-up and shutdown hours to be 30 minutes and 1 hour, respectively. The M&C hours are expected to be 12 hours per running week.

Factory hours

With all the gathered data in this section we calculate the required factory hours per week. Table 5.48 shows the calculation steps for Alternative 1 to determine the required factory hours per week. This represents the build-up of production capacity shown in Figure 2.8, albeit upside down. We conclude that for Alternative 1 with a nominal speed of 45HL/h it would take 38.3 hours per week to produce the required volume. This increases to a total of 67 required factory hours per week.

A shift for an operator takes 8 hours. On average, Grolsch loses 1.9 hours per week due to public holidays that fall within the production weeks, for example Easter or Christmas. The total available weekly factory hours based on the number of shift is thus 1.9 hours lower. This means that 10 shifts of 8 hours per week create 78.1 available factory hours.

Table 5.48: Determination factory hours Alternative 1

Variable	Value
Production Hours	38.3
ME loss	9.6
Machine hours	47.9
Service stops	1.3
Processing hours	49.2
Changeovers	4
Line start-up	0.5
Line shutdown	1
Operating hours	54.7
M&C	66.7
Factory hours	**79.5**

Table 5.49 shows the yearly expected production costs for 2020 for each alternative. We see that Alternative 3 required 19 shifts per week to be able to produce the required volume. We see that there is a huge difference in the required number of shifts comparing either Alternative 1 to 2 or Alternative 3 to 4. This is due to the fact that the speed for Alternative 2 and 4 is twice as high. However, due to the higher hourly rate in these alternatives, the yearly production costs are comparable.

Table 5.49: Yearly expected production costs per alternative for 2020

Alternative	Required weekly factory hours	Required weekly number of shifts	Hourly rate of production line	Yearly production costs 2020
Alternative 1	67	9	€ 161.67	**€ 582,016**
Alternative 2	42	6	€ 243.55	**€ 584,512**
Alternative 3	149	19	€ 146.39	**€ 1,112,535**
Alternative 4	88	12	€ 209.58	**€ 1,005,982**
Alternative 5	85	11	€ 223.86	**€ 984,975**

Table 5.50 gives an overview of the expected yearly costs per alternative for the years 2020 to 2022. We see that the costs of Alternative 1 and 2 are about equal. This is due to the fact that the hourly rate of Alternative 2 is 52% higher than the hourly rate of Alternative 1. The other 3 alternatives also all have similar yearly production costs, due to the different hourly rates, production volumes and production speeds.

Table 5.50: Expected production costs per alternative for the years 2020 to 2022

	Expected yearly production costs		
Year	2020	2021	2022
Alternative 1	€ 582,016	€ 634,409	€ 687,436
Alternative 2	€ 584,512	€ 637,131	€ 690,423
Alternative 3	€ 1,112,535	€ 1,176,267	€ 1,222,587
Alternative 4	€ 1,005,982	€ 1,063,610	€ 1,105,494
Alternative 5	€ 984,975	€ 1,041,400	€ 1,082,410

5.3.4. Summary of Costs

We have described the three costs involved with each alternative. In this section we give an overview of the costs estimated for each alternative. Table 5.51 gives this overview.

Table 5.51: Summary of cost estimates for alternatives in 2020

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Investment costs	€ 3,680,000	€ 3,990,000	€ 5,340,000	€ 5,640,000	€ 6,465,000
Handling costs	€ 33,510	€ 33,510	€ 88,341	€ 88,341	€ 88,341
Production costs	€ 582,016	€ 584,512	€ 1,112,535	€ 1,005,982	€ 984,975
Yearly costs	**€ 615,526**	**€ 618,022**	**€ 1,200,875**	**€ 1,094,322**	**€ 1,073,316**
One-time costs	**€ 3,680,000**	**€ 3,990,000**	**€ 5,340,000**	**€ 5,640,000**	**€ 6,465,000**

5.4. Cratecover Machine

In Section 4.1 we mentioned a cratecover machine as an organizational wish for Grolsch. We see a cratecover machine as an optional addition for Grolsch. This addition can either be to the alternatives, or to Production Line 2. This is due to the fact that this line produces the crates that need cratecovers. Whether an automated offline repacking machine is feasible or not, it is still interesting to look at the feasibility of a cratecover machine given the expenses Grolsch currently makes on repacking the SKUs that have cratecovers.

From the suppliers we know that a cratecover machine costs €150,000. A cratecover machine has an expected lifetime of 15 years. In Section 2.2 we mentioned the expected costs of manually repacking cratecovers for the years 2020 to 2022. Combining this with the forecasts done in Section 5.1, we calculate the expected benefits of a cratecover machine due to the reduction of repacking costs.

Based on the hourly rate of a production line, the ME and the speed of the production line, we are also able to determine the costs of a cratecover machine. Table 5.52 gives an overview of these 3 variables for each alternative and Production Line 2. The hourly rate of Line 2 is €787. However, given the fact that if a cratecover machine is added to Line 2, the production can take place simultaneously with the filling of the bottles, we assume, in consultation with the packaging experts at Grolsch, that the hourly rate for using the cratecover machine is €100. This consists of the hourly rate of 2 operators required for running the cratecover machine and some extra costs for maintenance and electricity.

Table 5.52: Overview variables for cratecover calculations

Production Line	Hourly Rate	ME	Speed (HL/h)
Alternative 1	€162	80%	45
Alternative 2	€244	80%	90
Alternative 3	€146	80%	45
Alternative 4	€210	80%	90
Alternative 5	€224	80%	144
Production Line 2	€100	62%	180

With this data we calculate the present worth and the payback period for a cratecover machine for the 5 alternatives and Production Line 2. The Present Worth calculations are shown in Appendix C. Table 5.53 shows the PW and payback period for the 5 alternatives and Production Line 2. We see that the first 3 alternatives have no payback period. Alternative 4 and 5 have a payback period. Adding a cratecover machine to Production Line 2 has a payback period of just 4 years. We conclude that the most interesting option is to add a cratecover machine to the original production line instead of the automated offline repacking machine.

Table 5.53: PW and Payback period Cratecover machine

Production Line	Present Worth	Payback Period
Alternative 1	-€ 220,365	None
Alternative 2	-€ 29,105	None
Alternative 3	-€ 147,093	None
Alternative 4	€ 52,310	11 years
Alternative 5	€ 219,296	6 years
Production Line 2	€ 400,009	4 years

5.5. Financial Comparison

With the benefits and costs determined in Section 5.1 we create a financial comparison between the three solutions. To compare the three solutions we use three different methods: (1) the Present Worth, (2) Annual Worth, and (3) payback period.

The PW method uses discounted future cashflows to determine the present worth of an investment. We use Equation 3.5 to determine the PW. As we know the yearly cashflows, we can determine the payback period using Equation 3.7. Using Equation 3.6 we determine the AW of each alternative.

The PW calculations of the alternatives are shown in Appendix D. Table 5.54 shows the PW, annual worth and payback period of each alternative. We see that only Alternative 5 has a positive PW and is therefore the only alternative with a payback period and is a feasible option. We see that the annual worth method ranks the alternatives in the order of the PW of each alternative. is Furthermore, we also see that both the PW and the annual worth method rank the alternatives the same.

Table 5.54: Financial comparison between alternatives

Alternative	PW	Annual worth	Payback period
Alternative 1	-€ 5,998,565	- € 609,271	None
Alternative 2	-€ 6,106,080	- € 617,990	None
Alternative 3	-€ 4,650,712	- € 487,645	None
Alternative 4	-€ 1,456,328	- € 144,564	None
Alternative 5	€ 902,557	€ 100,160	13 years

5.6. Sensitivity Analysis

In our research we made some assumptions in order to estimate the economic feasibility of the alternatives. In this section, we motivate some assumptions done for the alternatives studied in this research. We identify 3 assumptions on which we perform a sensitivity analysis to determine the percentual change required to breakeven.

The first assumption is the production volume of the relevant SKUs. In our research we use the forecast for the years 2020 to 2022 and create a forecast for the next 12 years based on these volumes. Grolsch is interested in the required volumes that make alternatives feasible. We are also interested in the possible decrease in the production volumes to breakeven.

The second assumption is the machine efficiency of the new production line. In Section 5.1.2 we make the assumption that the ME is 80%. The ME has a big impact, since ME loss is one of the biggest costs found in Section 5.2.2. We want to determine the required ME to make a currently infeasible alternative feasible.

The final assumption on which we perform a sensitivity analysis is the investment costs. For the determination of the investment costs we requested quotes from two suppliers. These quotes are rough, with basic estimates for the costs of each machine and the required conveyor belts, electric circuits and assembly costs. The real investment costs will thus likely differ from the received quotes.

We look at the possibility for decision reversal via sensitivity analysis by changing the three identified assumptions for each alternative in this section.

Alternative 1
Alternative 1 currently has a Present Worth (PW) of -€ 5,998,565. We see that the investment costs are €3,680,000, which means that this alternative currently has negative discounted cashflows for the duration of its lifetime. This tells us that by lowering the investment costs, we do not breakeven.

We find that Alternative 1 never reaches a present worth of 0. Even if the production volumes decrease with 68% and the investment costs are reduced with 100%, the PW is still -€ 841,256. We therefore conclude that Alternative 1 is never feasible.

Alternative 2
Alternative 2 currently has a PW of -€ 6,106,080. The investment costs are €3,990,000. This creates a similar situation to Alternative 1, where the yearly cashflows are negative. This also means that this alternative has no real possibility to breakeven. We find that the PW of Alternative 2 is 0 when the ME is 80%, the investment costs are reduced with 100% and the production volumes increase by 23%. We therefore conclude that Alternative 2 is never feasible.

Alternative 3
Alternative 3 has a PW of -€4,650,712. The investment costs are €5,340,000. We see that the expected loss on this alternative is so high, that a breakeven point would be difficult to, realistically, match.

We find several possibilities to breakeven:

1. ME at 90%, Production values do not change, a reduction of investment costs by 55%.
2. ME at 80%, Production values do not change, a reduction of investment costs by 71%.

We perceive a 55% reduction of the investment costs as unfeasible, besides it is highly uncertain that Grolsch would be able to achieve a ME of 90% for the entire lifetime of the machine. We therefore conclude that Alternative 3 is never feasible.

Alternative 4
Alternative 4 has a PW of -€ 1,456,328. The investment costs for this alternative are €5,640,000. This alternative also has a negative PW and is therefore with the current expectations not feasible. However, little improvements can make this alternative find a breakeven point. We find two possibilities to breakeven:

1. ME at 85%, Investment costs -10%.
2. ME at 80%, production volumes increase with 10% and a reduction of investment costs by 4%.

Both possibilities are not outside the expected bounds of these assumptions. For example, the investment costs are a rough estimation by suppliers. The real costs could be lower. We conclude that Alternative 4 has the possibility to breakeven, however this is perceived as unlikely.

Alternative 5

Alternative 5 has a positive PW of € 902,557. The ME can be lowered to 67% before the PW becomes negative, given that the other two assumptions do not change. The production volume can decrease with 6% before the PW becomes negative. The actual investment costs can increase with 10% before the PW becomes negative. We do not see these values as a possibility for decision reversal.

The most realistic situation where a decision reversal can take place for Alternative 5 is when the ME is 80%, the production volumes decrease with 3% and the investment costs are 5% higher than expected. We find this a realistic possibility for a decision reversal and we therefore conclude that Alternative 5 is not robust. A 3%-6% decrease in the forecasts for the next 15 years is not unlikely, given the fact that demand for beer might decrease in the future or more competitors will arise. Investment costs are made by rough estimates from suppliers, and therefore these could increase if the actual installation at Grolsch has more costs involved than foreseen.

5.6. Conclusion

In this chapter we developed a comparison between the 5 proposed alternatives based on 6 quantitative benefits and 3 quantitative costs. By doing so, Chapter 5 answered Research Question 4: *“ Which alternative is the best option for Grolsch and how feasible is this alternative? “*

We conclude that, based on the determined benefits and costs, Alternative 5 is the best option for Grolsch. This alternative is the only one with a positive Present Worth, which is € 902,557. Alternative 5 has a payback period of 13 years, which means that if Grolsch starts with production in 2020, Grolsch will start to make a return on its investment in 2032.

The sensitivity analysis showed that this alternative is not feasible. A decision reversal takes place when the ME drops to 67%, or when the production volumes decrease by 6% or when the investment costs increase with 10%. Combined, the decision reversal can take place when the production volume decreases by 3% and the investment costs increase with 5%.

6. Conclusion and Recommendations

This final chapter concludes this research by providing an answer to the research problem and gives recommendations. Section 6.1 outlines the main conclusions. Section 6.2 provides recommendations for Grolsch.

6.1. Conclusion

The goal of this research was:

“ To determine the feasibility of an automated offline repacking solution that will increase machine and factory efficiencies, increase flexibility of the production process, decrease stock levels and decrease repacking costs. “

To achieve this goal, five alternative options for an automated offline repacking machine were proposed. These alternatives were evaluated based on 6 quantitative benefits and 3 cost types. Using forecasts we determined the benefits and costs for the duration of the lifetime of the machines in the proposed alternatives. Using these benefits and costs we calculated the present worth and the payback period of the alternatives. Table 6.1 shows the main results of our research.

Table 6.1: PW and payback period per alternative

Alternative	PW	Payback period
Alternative 1	-€ 5,998,565	None
Alternative 2	-€ 6,106,080	None
Alternative 3	-€ 4,650,712	None
Alternative 4	-€ 1,456,328	None
Alternative 5	€ 902,557	13 years

We find that Alternative 5 is the only alternative that has a positive present worth and also a payback period, which is 13 years. Given the assumption that a production line has a lifetime of 15 years, this is long.

The benefits of an automated offline repacking machine to the current production lines are twofold. First of all, the production schedule of Production Lines 2 and 4 is simplified. The amount of SKUs produced on Line 4 lowers from 17 to 5. Less SKUs means that the production schedule is easier to optimise, resulting in better quality. Second, the planned machine efficiency of Production Line 4 increases from 59.3% for the current production schedule in 2020 to 67% in our production schedule. We reduce the required weeks of production from 34 weeks to 29 weeks in 2020. We also reduce the total required changeover time on Production Line 2 with 105 hours in 2020.

We increase flexibility of the production process in two ways.

First of all, we move the customer order decoupling point of several SKUs further upstream the supply chain from make-to-stock to assemble-to-stock. This gives Grolsch the opportunity to produce these SKUs only when there is actual demand and reduces the chance of obsoletes, since stock is not committed into one packaging configuration, but can be sold as either a 24-loose bottle SKU or assembled into another packaging configuration. By letting the automated offline repacking machine run for 50 weeks per year, we ensure that there is flexibility to produce orders when required.

Second, the new production line of Alternative 5 is able to handle a large range of bottles, crates, boxes and packaging configurations. Grolsch has more flexibility for new product developments. With the old packaging machines, Grolsch faced difficulties converting them to, for example, new bottles. This is not the case with the new production line. This gives Grolsch new opportunities for the development of new products.

Stock levels decrease through inventory aggregation. SKUs from Lines 2 and 4 that have a 24-loose or 16-loose variant do no longer keep safety stock. Instead, the safety stock of the 24-loose variant is increased to incorporate the risk. We find that inventory aggregation reduces that expected average stock with 281 pallets for the SKUs covered with the new production line in Alternatives 3, 4 and 5.

Finally, the automated offline repacking machine is able to eliminate the manual repacking of products that currently are produced first on Line 2 or 4 and then repacked. In the new situation, these are still first produced on Line 2 or 4 and then send to the warehouse. When needed, Grolsch produces these SKUs on the new production line.

We also find that a cratecover machine, which was an organizational wish, is an interesting option for Grolsch. The payback period of a cratecover machine for Alternative 5 is 6 years. However, adding a cratecover machine directly to Production Line 2 instead of to the automated offline repacking machine lowers the payback period to 4 years.

6.2. Recommendations

Based on the conclusion of Section 6.1, we come to multiple recommendations.

Firstly, we recommend Grolsch to look into adding a cratecover machine to Production Line 2. We believe that this is an interesting and fairly low investment that has a quick payback period.

Next, we recommend Grolsch to not invest in an automated offline repacking machine. The payback period of 14 years for Alternative 5 is too long given the lifetime of the machine is 15 years. We consider this too much risk for Grolsch. However, we still think that in the future there is a possibility for an automated offline repacking machine. For example, when the production volumes for the products on Production Line 2 becomes too high to handle with the production line, and the machine efficiency of the line has to be increased.

Next, given that the investment in a automated offline repacking machine is currently not profitable enough, we recommend Grolsch to investigate procuring a simple packing machine to reduce manual repacking. Besides cratecovers, there are also other manual tasks that could be done by just one machine. For example, a machine that creates 3-packs or 4-packs. This could lower costs and increase production rates.

Finally, we recommend Grolsch to further investigate changing the products that are currently in a 3-pack configuration to a 4-pack configuration. We expect Grolsch to increase their revenue by with €76,704 in 2020 by doing this.

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Appendix

Appendix A: Overview SKUs for Inventory Aggregation

Table A.1: Overview of SKUs for inventory aggregation

SKU ID	Packaging Configuration	Original Production Line	Loose Variant SKU ID
92117	6-pack 30cl	2	92196
92122	6-pack 30cl	2	92133
92192	6-pack 30cl	2	92193
91844	3-pack 30cl	2	91843
92090	3-pack 30cl	2	92089
92138	3-pack 30cl	2	92137
92299	4-pack 30cl	2	92298
90991	4-pack 45cl	4	90986
90995	4-pack 45cl	4	90988
92092	4-pack 45cl	4	90988
90997	4-pack 45cl	4	90988
92084	4-pack 45cl	4	90988
92136	12-pack 45cl	4	92135
92308	12-pack 45cl	4	92318
92377	12-pack 45cl	4	92376
90847	12-pack 45cl	4	90988
91810	20-pack 45cl	4	90988
91808	20-pack 45cl	4	90988
92220	20-pack 45cl	4	90988
92245	20-pack 45cl	4	90988
91655	20-pack 45cl	4	90988

Appendix B: Pseudo code harbour transportation heuristic

```
BEGIN

Max Stock = 18,500
Stock level = 0

Copy Production Scheme
Paste Production Scheme in Transportation Scheme

FOR each Week
        FOR each SKU
                Stock level WHS in Week = Stock level WHS in Week + Stock level SKU in week
        NEXT SKU
NEXT Week

FOR each Week
        FOR each SKU
                IF Stock level WHS in Week + Transportation level SKU in Week < Max Stock THEN
                        Stock level WHS in Week = Stock level WHS in Week + Transportation SKU
                        Transportation SKU = 0
                END IF
        NEXT SKU
NEXT Week

END
```

Appendix C: Present Worth Calculations Cratecover Machine

Alternative 1

	Year	2019	2020	2021	...	2034
	Discount Factor	1	0.951	0.905		0.474
Costs	Investment	-€ 150,000				
Costs	Production hours	€ 0	-€ 47,431	-€ 49,527		-€ 76,732
Costs	ME Loss	€ 0	-€ 11,858	-€ 12,382		-€ 19,183
Costs	**Total costs**	**-€ 150,000**	**-€ 59,288**	**-€ 61,909**	...	**-€ 95,915**
Benefits	Reduce in repack costs	0	€ 46,018	€ 48,052		€ 74,448
Benefits	Depreciation	€ 0	€ 10,000	€ 10,000		€ 10,000
Benefits	**Total benefits**	**€ 0**	**€ 56,018**	**€ 58,052**	...	**€ 84,448**
	Discounted cashflows	**-€ 150,000**	**-€ 3,111**	**-€ 3,491**	...	**-€ 5,438**
	Present Worth	-€ 220,365				

Figure A.1: PW calculation Cratecover Machine for Alternative 1

Alternative 2

	Year	2019	2020	2021	...	2034
	Discount Factor	1	0.951	0.905		0.474
Costs	Investment	-€ 150,000				
Costs	Production hours	€ 0	-€ 35,725	-€ 37,305		-€ 57,796
Costs	ME Loss	€ 0	-€ 8,931	-€ 9,326		-€ 14,449
Costs	**Total costs**	**-€ 150,000**	**-€ 44,657**	**-€ 46,631**	...	**-€ 72,245**
Benefits	Reduce in repack costs	0	€ 46,018	€ 48,052		€ 74,448
Benefits	Depreciation	€ 0	€ 10,000	€ 10,000		€ 10,000
Benefits	**Total benefits**	**€ 0**	**€ 56,018**	**€ 58,052**	...	**€ 84,448**
	Discounted cashflows	**-€ 150,000**	**€ 10,810**	**€ 10,340**	...	**€ 5,786**
	Present Worth	**-€ 29,105**				

Figure A.2: PW calculation Cratecover Machine for Alternative 2

Alternative 3

	Year	2019	2020	2021	...	2034
	Discount Factor	1	0.951	0.905		0.474
Costs	Investment	-€ 150,000				
	Production hours	€ 0	-€ 42,946	-€ 44,845		-€ 69,478
	ME Loss	€ 0	-€ 10,737	-€ 11,211		-€ 17,369
	Total costs	**-€ 150,000**	**-€ 53,683**	**-€ 56,056**	...	**-€ 86,847**
Benefits	Reduce in repack costs	0	€ 46,018	€ 48,052		€ 74,448
	Depreciation	€ 0	€ 10,000	€ 10,000		€ 10,000
	Total benefits	**€ 0**	**€ 56,018**	**€ 58,052**	...	**€ 84,448**
	Discounted cashflows	**-€ 150,000**	**€ 2,222**	**€ 1,808**	...	**-€ 1,138**
	Present Worth	**-€ 147,093**				

Figure A.3: PW calculation Cratecover Machine for Alternative 3

Alternative 4

	Year	2019	2020	2021	...	2034
	Discount Factor	1	0.951	0.905		0.474
Costs	Investment	-€ 150,000				
	Production hours	€ 0	-€ 30,743	-€ 32,102		-€ 49,735
	ME Loss	€ 0	-€ 7,686	-€ 8,025		-€ 12,434
	Total costs	**-€ 150,000**	**-€ 38,429**	**-€ 40,127**	...	**-€ 62,169**
Benefits	Reduce in repack costs	0	€ 46,018	€ 48,052		€ 74,448
	Depreciation	€ 0	€ 10,000	€ 10,000		€ 10,000
	Total benefits	**€ 0**	**€ 56,018**	**€ 58,052**	...	**€ 84,448**
	Discounted cashflows	**-€ 150,000**	**€ 16,736**	**€ 16,228**	...	**€ 10,564**
	Present Worth	**€ 52,310**				

Figure A.4: PW calculation Cratecover Machine for Alternative 4

Alternative 5

	Year	2019	2020	2021	...	2034
	Discount Factor	1	0.951	0.905		0.474
Costs	Investment	-€ 150,000				
	Production hours	€ 0	-€ 20,523	-€ 21,430		-€ 33,202
	ME Loss	€ 0	-€ 5,131	-€ 5,358		-€ 8,301
	Total costs	**-€ 150,000**	**-€ 25,654**	**-€ 26,788**	…	**-€ 41,503**
Benefits	Reduce in repack costs	0	€ 46,018	€ 48,052		€ 74,448
	Depreciation	€ 0	€ 10,000	€ 10,000		€ 10,000
	Total benefits	**€ 0**	**€ 56,018**	**€ 58,052**	…	**€ 84,448**
	Discounted cashflows	**-€ 150,000**	**€ 28,891**	**€ 28,304**	…	**€ 20,364**
	Present Worth	**€ 219,296**				

Figure A.5: PW calculation Cratecover Machine for Alternative 5

Addition to Production Line 2

	Year	2019	2020	2021	...	2034
	Discount Factor	1	0.951	0.905		0.474
Costs	Investment	-€ 150,000				
	Production hours	€ 0	-€ 9,464	-€ 9,882		-€ 15,310
	ME Loss	€ 0	-€ 2,366	-€ 2,471		-€ 3,828
	Total costs	**-€ 150,000**	**-€ 11,830**	**-€ 12,353**	…	**-€ 19,138**
Benefits	Reduce in repack costs	0	€ 46,018	€ 48,052		€ 74,448
	Depreciation	€ 0	€ 10,000	€ 10,000		€ 10,000
	Total benefits	**€ 0**	**€ 56,018**	**€ 58,052**	…	**€ 84,448**
	Discounted cashflows	**-€ 150,000**	**€ 42,044**	**€ 41,372**	…	**€ 30,970**
	Present Worth	**€ 400,009**				

Figure A.6: PW calculation Cratecover Machine for adding to Production Line 2

Appendix D: Present Worth Calculations Per Alternative

Alternative 1

	Year / Discount Factor	2019 / 1	2020 / 0.951	2021 / 0.905	...	2034 / 0.474
Costs	**Investment**	-€ 3,680,000				
	Production hours New	€ 0	-€ 582,016	-€ 634,409		-€ 1,314,965
	Handling	€ 0	-€ 33,510	-€ 36,507		-€ 74,672
	Total costs	**-€ 3,680,000**	**-€ 615,526**	**-€ 670,916**	...	**-€ 1,389,636**
Benefits	**Incremental Volumes**	€ 0	€ 76,704	€ 83,639		€ 242,821
	ME/FE Improvements	€ 0	€ 117,427	€ 127,997		€ 265,305
	Reduce in repack costs	0	€ 103,291	€ 103,291		€ 103,291
	Maintenance	€ 0	€ 12,504	€ 13,622		€ 27,863
	Inventory Aggregation	€ 0	€ 18,528	€ 20,196		€ 41,860
	Depreciation	€ 0	€ 245,333	€ 245,333		€ 245,333
	Total benefits	**€ 0**	**€ 573,786**	**€ 594,079**	...	**€ 926,474**
	Discounted cashflows	**-€ 3,680,000**	**-€ 39,714**	**-€ 69,561**	...	**-€ 219,630**

Figure A.7: PW calculation for Alternative 1

Alternative 2

	Year / Discount Factor	2019 / 1	2020 / 0.951	2021 / 0.905	…	2034 / 0.474
Costs	**Investment**	-€ 3,990,000				
	Production hours New	€ 0	-€ 584,512	-€ 637,131		-€ 1,287,472
	Handling	€ 0	-€ 33,510	-€ 36,507		-€ 74,672
	Total costs	**-€ 3,990,000**	**-€ 618,022**	**-€ 673,639**	…	**-€ 1,362,143**
Benefits	**Incremental Volumes**	€ 0	€ 76,704	€ 83,639		€ 242,821
	ME/FE Improvements	€ 0	€ 117,427	€ 127,998		€ 258,649
	Reduce in repack costs	0	€ 103,291	€ 103,291		€ 103,291
	Maintenance	€ 0	€ 12,504	€ 13,622		€ 27,863
	Inventory Aggregation	€ 0	€ 18,528	€ 20,196		€ 40,810.19
	Depreciation	€ 0	€ 266,000	€ 266,000		€ 266,000
	Total benefits	**€ 0**	**€ 594,453**	**€ 614,746**	…	**€ 939,435**
	Discounted cashflows	**-€ 3,990,000**	**-€ 22,425**	**-€ 53,315**	…	**-€ 200,447**

Figure A.8: PW calculation for Alternative 2

Alternative 3

	Year Discount Factor	2019 1	2020 0.951	2021 0.905	...	2034 0.474
Costs	**Investment**	-€ 5,340,000				
	Production hours New	€ 0	-€ 1,112,535	-€ 1,176,267		-€ 2,168,040
	Handling	€ 0	-€ 88,341	-€ 91,283		-€ 152,014
	Total costs	**-€ 5,340,000**	**-€ 1,200,875**	**-€ 1,267,549**	...	**-€ 2,320,054**
Benefits	**Incremental Volumes**	€ 0	€ 76,704	€ 83,639		€ 242,821
	ME Improvements L2	€ 0	€ 117,427	€ 124,153		€ 228,834
	Me Improvement L4	€ 0	€ 621,960	€ 637,862		€ 791,263
	Reduce in repack costs	€ 0	€ 165,055	€ 165,055		€ 165,055
	Maintenance	€ 0	€ 73,150	€ 74,410		€ 119,926
	Reduction FTE L4	€ 0	€ 42,765	€ 44,345		€ 76,966
	Inventory Aggregation	€ 0	€ 35,435	€ 37,464		€ 69,053
	Depreciation	€ 0	€ 356,000	€ 356,000		€ 356,000
	Total benefits	**€ 0**	**€ 1,488,495**	**€ 1,522,928**	...	**€ 2,049,918**
	Discounted cashflows	**-€ 5,340,000**	**€ 273,663**	**€ 231,195**	...	**-€ 128,098**

Figure A.9: PW calculation for Alternative 3

Alternative 4

	Year	2019	2020	2021	...	2034
	Discount Factor	1	0.951	0.905		0.474
Costs	**Investment**	-€ 5,640,000				
	Production hours New	€ 0	-€ 1,005,982	-€ 1,063,610		-€ 1,960,396
	Handling	€ 0	-€ 88,341	-€ 91,283		-€ 152,014
	Total costs	**-€ 5,640,000**	**-€ 1,094,322**	**-€ 1,154,892**	...	**-€ 2,112,410**
Benefits	**Incremental Volumes**	€ 0	€ 76,704	€ 83,639		€ 242,821
	ME Improvements L2	€ 0	€ 117,427	€ 124,153		€ 228,834
	Me Improvement L4	€ 0	€ 621,960	€ 637,862		€ 791,263
	Reduce in repack costs	€ 0	€ 165,055	€ 180,626		€ 558,649
	Maintenance	€ 0	€ 42,765	€ 44,345		€ 76,966
	Reduction FTE L4	€ 0	€ 73,150	€ 74,410		€ 119,926
	Inventory Aggregation	€ 0	€ 35,435	€ 37,464		€ 69,053
	Depreciation	€ 0	€ 376,000	€ 376,000		€ 376,000
	Total benefits	**€ 0**	**€ 1,508,495**	**€ 1,558,499**	...	**€ 2,463,512**
	Discounted cashflows	**-€ 5,640,000**	**€ 394,075**	**€ 365,387**	...	**€ 166,492**

Figure A.10: PW calculation for Alternative 4

Alternative 5

	Year	2019	2020	2021	…	2034
	Discount Factor	1	0.951	0.905		0.474
Costs	Investment	-€ 6,465,000				
	Production hours New	€ 0	-€ 984,975	-€ 1,041,400		-€ 1,919,460
	Handling	€ 0	-€ 88,341	-€ 91,283		-€ 152,014
	Total costs	**-€ 6,465,000**	**-€ 1,073,316**	**-€ 1,132,682**	…	**-€ 2,071,474**
Benefits	Incremental Volumes	€ 0	€ 76,704	€ 83,639		€ 242,821
	ME Improvements L2	€ 0	€ 117,427	€ 124,153		€ 228,834
	Me Improvement L4	€ 0	€ 621,960	€ 637,862		€ 791,263
	Reduce in repack costs	€ 0	€ 165,055	€ 180,626		€ 558,649
	Maintenance	€ 0	€ 43,901	€ 45,697		€ 80,483
	Reduction FTE L4 & L7	€ 0	€ 186,072	€ 208,353		€ 462,196
	Inventory Aggregation	€ 0	€ 35,435	€ 37,464		€ 69,053
	Depreciation	€ 0	€ 431,000	€ 431,000		€ 431,000
	Total benefits	**€ 0**	**€ 1,677,552**	**€ 1,748,795**	…	**€ 2,864,298**
	Discounted cashflows	**-€ 6,465,000**	**€ 574,916**	**€ 557,769**	…	**€ 375,955**

Figure A.11: PW calculation for Alternative 5