Master Thesis

Optimizing and Implementing the Inventory Control Policy of Finished Products within Bolletje's ERP System

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MSc Industrial Engineering & Management
Production & Logistic Management

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Management Summary

We conduct this research at Bolletje as a Master thesis for the study Industrial Engineering & Management. Bolletje B.V. is a Dutch industrial bakery that produces substitutes for bread and pastries. Currently, Bolletje's planners control the production planning manually. This costs much time and is subject to human mistakes. Because of mistakes, sometimes not all raw materials are available as the production starts. Furthermore, there is no clear inventory control policy at Bolletje and they do not know which safety stock level they should have for a 98.5% service level for their customers. The inventory control policy at Bolletje is dependent on multiple factors. One of them are the changeovers, a set of necessary but not value-adding activities that describe the change from producing the last good piece of one product to producing the first good piece of another. Changeover times are inconsistent and unexpectedly long. To solve these problems, we design the following research questions:

How can the finished products inventory control policy of Bolletje be improved and implemented in Bolletje's ERP system while keeping in mind the right balance between customer service level and inventory investment? Furthermore, how much finished products safety stock should be held and how can the changeover procedure be improved?

We perform this research for the default products of the *knäckebröd* production line R156. Currently, the planners plan the production in Excel and fill the orders manually in their ERP system which is called Microsoft AX. Planners first generate a Master Production Schedule, a production plan for 13 weeks. Then, they create a Detail Plan for the next week of production. This schedule includes the exact production quantities and planned downtime for maintenance and cleaning. The ERP system is only used as a point of reference. The most crucial factor that influences the inventory control policy at Bolletje is the changeover time. There are three different changeover types, depending on the activities that need to be conducted: long, medium, and short changeovers. On average, operators at Bolletje conduct eight changeovers within one week (three short, four medium and one long). The changeover times are rarely below the target time and changeovers take almost twice as long. To answer our research questions, we review literature on inventory control policies and safety stocks. Furthermore, we study methods about improving changeover times and root causes analysis methods.

Changeover time improvement is important for the inventory control policy. To cope with the unreliability of changeovers and the uncertainties those bring, Bolletje must hold more safety stock and loses production time. Moreover, with long changeover times it is less attractive to frequently switch between products. However, Bolletje produces different knäckebröd products and changeovers are a necessity. For the improvement of the changeover process, we decide to analyze the process according to the Single Minute Exchange of Dies method. The method promises reductions in changeover time by analyzing the process and converting internal activities (during production, i.e. with interfering production) to external activities (before or after the changeover, i.e. without interfering production). Currently, the long changeover counts 60 minutes of internal and 37 minutes of external activities. The biggest opportunity for a conversion from internal to external is for the trade box packaging machine, which has an internal changeover time of 60 minutes. Furthermore, we conduct a root cause analysis where we find 11 improvements for the decrease in changeover time. From those potential causes, we partly implement and partly propose improvement actions (high to low priority):

1. The handles of the packaging machines need to be loosened and fastened more easily by introducing a leverage or torch.
2. The changeover material rack needs to be accessible and items should be quickly found by including a color code.
3. Manuals and changeover matrices need to be up-to-date and regularly checked.
4. The planners and the operators should have better agreements about the planning and execution of changeovers.
5. Tasks and responsibilities of operators need to become clear. This can be achieved by reorganizing the work structure and taking a step towards more skilled and motivated employees needs to be taken.
6. An improvement of the production data registration can approve the data registration.

7. Operators should test the packaging machines before the production to reduce fine-tuning.
8. By implementing a buffer before the trade box packaging machine, the internal changeover activities can be converted to external activities.

After (partly) implementing improvement 2, 3, 4, 5 and 6 we can register a changeover time reduction. Improvement 8 has much impact on the process but is a costly improvement. We evaluate the changeover time reduction by using two scenarios. We conclude that with Scenario 1 (including buffer) we can reduce the internal changeover time to 27 minutes and with Scenario 2 (without buffer) to 45 minutes.

Bolletje desires an automated production planning that considers capacity, availability of the production line and the availability of raw materials. The idea is that Bolletje's ERP system, AX, is able to plan the production for them and the planners only need to monitor and approve this process. Within AX it is possible to implement two different versions of the (R,s,S) inventory control policy. While option A has fixed parameters, the parameters fluctuate in option B with the demand. Furthermore, option B is easier to implement. We chose this policy for Bolletje. We set up this system to function optimally under this policy. AX reviews the inventory position once a week and is responsible for planning procurement and production orders as well as scheduling the production according to a pre-determined family grouping. Families are a cluster of products with similar characteristics. By scheduling those products together, we reduce the changeover time. AX furthermore determines Bolletje's minimum inventory level according to historic demand. AX can calculate the level either according to a multiplicity factor which we can choose freely, or according to the service level. We validate the equations by simulating their performance and comparing their performance to the theory. The simulation shows that the service level equation performs the best when looking at the cost-stockout balance. The simulation shows that this equation can be used for the safety stock calculations.

We test the new manner of planning by making a Master Production Schedule for 13 weeks and comparing the new AX planning to the current planning. Since the start of this research, the performance of the production line R156 has decreased drastically. To test the new process, we assume that the production line is able to produce with 100% efficiency first. The AX planning automatically increases the inventory level of all products to above their minimum inventory level. Furthermore, it plans production quantities according to the capacity, demand and pre-determined minimum order quantity. This test plan shows that AX is capable of conducting the production planning. During the comparison of the two methods of planning, we see that they create similar production plans. The main difference is that AX holds a higher safety stock and has bigger production order quantities. However, there are also some disadvantages and problems with AX. AX pauses production orders during the weekend, thereby it is possible that production orders are split in sizes below their minimum order quantity. Moreover, the changeover matrices cannot be embedded in AX which is important since changeover time depends on the characteristics of the products produced before or after the changeover. To have a realistic plan, the planners need to adjust this. Furthermore, the current planning works with lower production norms than AX. The system assumes that the production lines can produce more than possible at the moment. Nevertheless, big advantages of AX are that the planners need to spend less time and the new plan is less prone to error. While updating the Master Production Schedule and creating a Detail Plan is typically a task that takes two days, AX can do it in a fraction of this time. Furthermore, AX automatically takes planned downtime into account. We conclude that this improvement makes it possible that raw materials are available, inventory levels account for uncertainty and planners have a reduced workload.

For the implementation, Bolletje needs to establish a project team with employees from different departments. They should follow the steps: identify processes, develop standard operating procedures, pre-test the database, user training and step-by-step implementation. The operators should start the implementation with the procurement tasks in AX. Then, the planners should start implementing the Master Production Schedule and finally the Detail Plan. However, the process does not stop here. The last step is the evaluation. During the following months and years, the key users clearly need to detect the processes that need improvement.

Acknowledgements

After an exciting and interesting half a year with ups and downs, it is time to finish my master assignment. This report is the final result of my Master research conducted at Bolletje B.V. for the study Industrial Engineering and Management (track Production and Logistics Management). Even before starting the graduating internship at Bolletje, the food industry has caught my interest. It is interesting to see how our food is produced and how long the food supply chain can be.

I am really glad that I received the chance to write my graduate assignment at Bolletje. First of all, I want to thank my supervisor at Bolletje Thijs Altena for his support and assistance. He encouraged me to look beyond the surface and helped me when AX frustratingly did not do what I assumed. Furthermore, I want to thank the employees from the Technical Department for taking me into their office, the employees of the Production Department for answering all my questions and the employees of the Logistic Department for their ongoing support. I am really happy that all employees had enough confidence in me to even offer me a one-year contract as Trainee Operations. I am looking forward to seeing my first project, the implementation of this assignment, evolve.

Moreover, I want to thank my supervisors from the university, Engin Topan and Marco Schutten for giving me helpful discussions, useful feedback and supporting me on my way. After a rocky start with changing thesis topics, we found a way to fit the needs of Bolletje and the university in one assignment.

Last but not least, I want to thank my friends, family and roommates for their support and help. Especially everyone who proofread my thesis has helped me to develop the thesis and myself.

Nina Rusch
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Table of Contents

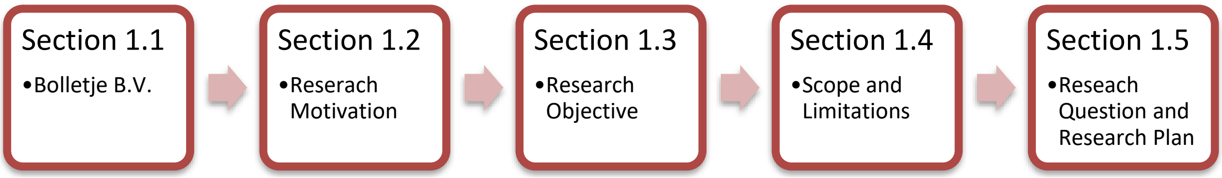
List of Abbreviations

Analytic Hierarchy Process	AHP	Make-to-Stock	MTS
Consumer (consumenteneenheid)	CE	Overall Equipment Effectiveness	OEE
Detail Plan	DP	Root Cause Analysis	RCA
Economic Order Quantity	EOQ	Single Minute Exchange of Die	SMED
Enterprise Resource Planning	ERP	Standard Operating Procedures	SOPs
First Expired First Out	FEFO	Stock Keeping Unit	SKU
First In – First Out	FIFO	Training within Industry	TWI
Trade (handelseenheid)	HE	Uiterste levercode	ULC
Master Production Schedule	MPS		

1. Introduction

Competing in a competitive market can be challenging for companies. Consumers go to the supermarket expecting to find their desired products on the shelves. Manufacturers of these products do their best not to miss the opportunity to sell products. Lost sales are the reason for poor customer service levels since the manufacturer cannot meet the consumer's immediate needs (Rao & Rao, 2009). Moreover, modern consumers like to have a variety of products to choose from. For manufacturing companies this means a more complex planning as well as changeovers from one product to another. The products sold in the supermarket have already been on a long journey and it has been carefully planned that the products reach their destination on time. To accommodate unexpected fluctuations in demand and supply, manufacturing firms need to manage their inventories and even maintain extra inventories: the safety stock (Rao & Rao, 2009). Within inventory a significant amount of capital is tied up and studies show that manufacturers often have over 60 days of on hand inventory, therefore efficient production planning and inventory policies are advised (Rao & Rao, 2009).

This first chapter introduces the project and outlines the research plan. Section 1.1 introduces Bolletje and provides relevant background information. Section 1.2 shows the motivation for this research. Furthermore, Section 1.3 and Section 1.4 respectively contain the research objective as well as the scope and limitations of the project. Finally, Section 1.5 specifies the research questions along with the research plan. During the course of this report we use figures like the one below to visualize and summarize the structure and organization of the chapters and sections.



1.1 Bolletje B.V.

The introduction of Bolletje starts with an outline of the company's origins in Section 1.1.1, followed in Section 1.1.2 by a brief description of the Operational Department, where we conduct our research.

1.1.1 The Origins

Figure 1.1 – Headquarter Bolletje Almelo

Gerardus Johannes ter Beek who opened a bakery with accompanying shop in the year 1867 laid the foundation for Bolletje B.V., back then a family company. The most famous Bolletje product is '*beschuit*', a round toasted bread that is crunchy and dry like a cracker. Until 1952 the company, back then stills named Ter Beeks Eierbeschuit, sold their products mainly at small bakeries. Since those bakeries did not like to sell products with the name of another bakery on them, they renamed their bakery. They came up with the idea, to name it after the little balls, dough '*bolletjes*', that are turning into *beschuit*. As soon as the name changed, they invented the timeless slogan '*Ik wil Bolletje!*'. The slogan is still present on marketing material and in the commercials of Bolletje. Dutch advertisers even selected the slogan as the best slogan of the 20th century (Bolletje, n.d.).

The competition grew in the years after the war and the company decided that it was too risky to focus only on their one main product, *beschuit.* In the mid-sixties they came up with a diversifying strategy and took over several companies in different segments of the market.

Since 1954, Bolletje's headquarter, including their biggest bakery, is on the Turfkade in Almelo. The company employs around 400 people in their bakeries in Almelo and Heerde. Over 60 different products, assorted in the five segments breakfast & lunch, in between (snacks), cookies, salty snacks, and seasonal products roll along their production lines. Besides in the Netherlands, Bolletje exports products to countries in Europe as well as other countries where Dutch emigrants live.

1.1.2 Operational Department

Within Bolletje, there are five major departments: Sales Department, Marketing Department, Financial Department, Human Resources Department, and Operational Department. The department in which we conduct this research is the Operational Department. Within this department, there are three sub departments: the Technical Department, the Production Department, and the Logistic Department.

The Technical Department is responsible for all maintenance, repair, and operation tasks within the bakery in Almelo. It is their task to minimize downtime during the production process and maximize the availability of all machines. They do this by providing technical support to the Production Department. The Production Department of Bolletje Almelo is responsible for converting the raw material into finished products through a series of production processes. Their main concern is to ensure that finished products are produced as efficiently as possible. Furthermore, they are responsible for setting up the machines after periods of planned downtime and executing changeovers. Moreover, the Logistic Department plans the production and inventory activities. They are responsible for ordering the needed raw materials and ensuring that the finished products reach the customers.

The production in Almelo is divided into four different production sections. A production section can have multiple production lines to produce products. A production line includes all production steps, from making the dough, over rising, to baking and packaging. **Error! Reference source not found.** presents more information about the production sections.

1.2 Research Motivation

Bolletje's mission is to make the everyday-life of consumers more enjoyable with tasty, authentic, and nutritious bakery goods. To do so, they need to ensure that every production line can produce high quality products at a constant level and without any major interruptions. Additionally, they have a responsibility to deliver ordered products to their customers. Since the products are perishable, meaning that products are only suitable for consumption for a limited time, the products need to be delivered to supermarkets at a certain percentage of their shelf life. By delivering the items at this point it is guaranteed that consumers can buy the products before their shelf life expires. In order to fulfill this mission, it is important that Bolletje uses an efficient inventory control policy. This policy needs to ensure that the planners place production orders at the right time and that there is enough safety stock for critical moments. Efficient planning also includes automation.

Instead of manually determining plans, software should make the work of planners easier and avoid human mistakes.

We distinguish between consumers and customers. Consumers are people who purchase products produced at Bolletje for their personal consumption. Bolletje does not sell products directly to consumers, but to their customers. The customers are on the demand side. They are distribution centers of supermarkets that sell the products to the consumers. They order with fluctuating batch sizes at Bolletje. On the supply side, there is Bolletje who produces enough products to meet the customers' needs. To deal with (unexpected) fluctuations in demand and supply as well as to mitigate the risk of stockouts, Bolletje needs to maintain an efficient inventory control policy as well as a safety stock of finished products. This enables them to ensure the satisfaction of the customers even in times of low supply uncertainty. However, keeping stock also has its downsides. Within the inventory, especially the safety stock, a significant amount of capital is tied up. A tradeoff between minimizing the costs of keeping inventory and maximizing the satisfaction of the customers is in Bolletje's best interest.

At the moment, Bolletje does not have a clear inventory control policy. Planners plan manually, meaning that they need to keep track of which operators will be working, which materials will be used, and which products will be produced. Bolletje employs four planners for this job. To make this process more efficient, Bolletje wants to focus on the optimization of inventory control and material flow through the production as well as on reaching the maximum efficiency of the production lines. At this moment, production is at times not possible since the long-term planning was not updated in time to order the right amount of raw and packaging material. To have real-time insight into business and supply chain information Bolletje implemented the Enterprise Resource Planning (ERP) system Microsoft AX. The system can help to optimize production flow by planning effectively, maximizing resource utilization, driving accurate delivery performance, and streamlining business processes. The Operational Department thinks that establishing a clear and automated inventory control policy for the production planning in AX helps to organize, structure and improve the production. Bolletje bases their production and procurement planning on a Make-to-Stock (MTS) policy. Bolletje produces their products anticipatively before the customers place an order. At all times, the planners plan in a manner that Bolletje holds one week of baseline stock and a standard two-week safety stock of finished products. Ensuring this inventory level has proven to be difficult with the manual planning and consequently Bolletje has shortages of products and a lower service level than anticipated. Bolletje wants to analyze if they consider the right balance between customer service and inventory investment. In the interest of establishing this, we find various factors that are important for their inventory control policy. Table 1.1 shows the factors and explains their effects.

Table 1.1 - Factors Influencing the Inventory Position at Bolletje

Factors	Effect on Inventory Position
Demand forecast accuracy	As the demand forecast is more reliable, the unexpected fluctuations in demand are lower and companies need less inventory to cope with fluctuations.
Line availability	When the line availability is high, companies need less inventory since more time is available to produce products.
Stability of production output	When there is a stable output of the production line, companies need less inventory since products can be produced more easily.
Changeovers	Changeover costs influence the inventory since more

	changeovers lead to less production time.
Shelf life	When storing products with a short shelf life, companies should hold less inventory to ensure that they delivere the products to the customer before it perishes.
Customer service level	When assuring a high service level to the customers, companies should hold higher inventory in order to prevent stockouts.

The demand forecast contains an expectation of the number of products that the different customers will order. This is the basis of the production planning. As the demand forecast is more reliable, the unexpected fluctuations in demand are lower and companies need less inventory to cope with the fluctuations. Furthermore, the stability of production output as well as the line availability influence the inventory level. The first considers the stability of the number of products that can be produced, while availability is the time a production line is available for production. If the production output is stable, companies need less inventory since the output reliability is greater. The stability of the production output is dependent on the specific product as well as the production line on which the product is produced. The availability is based on the planned and unplanned downtime. Planned downtime is the time in which no production is planned, for example maintenance stops or weekends. During unplanned downtime, production is planned but not possible due to failures. With an increasing amount of downtime, the production lines are less available, and a higher stock level is needed in order to serve customers from stock. Furthermore, the changeovers influence the inventory levels. Changeovers are a set of necessary activities that do not add value to the process. Gungor and Evans (2015) define them as change from producing the last good piece of one product to producing the first good piece of another product. Included in changeovers are also the setups, a start-up of the production line after times of planned downtime. Changeovers are necessary since different products need to be produced on the same production line. However, changeovers cost time and money and are causes of production losses at the Operational Department of Bolletje. Although, the time needed for changeovers is set, there are inconsistencies and unexpected durations that hold up the production process. When determining the production sequence and safety stock, changeovers need to be considered because changeover time is a constraint during production planning. With longer and more complex production, also the costs involved in this process increase. Likewise, the shelf life is a factor of importance since companies must ensure that they deliver their products to consumers before they expire. Hence, Bolletje should not hold high inventory of products with short shelf life. Finally, the customer service level is of importance. Bolletje assured their customers a 98.5% service level. This percentage of the customer orders needs to be satisfied from the on-hand stock without having a stockout. Since the service level is high, Bolletje needs to hold more inventory to prevent stockouts.

1.3 Research Objective

The main objective of this research is to optimize the planning and finished products inventory control policy of Bolletje. Hereby the balance between customer service level and inventory investment is important. There is a threefold of sub-objectives: First and foremost, we want to establish an automated planning within the ERP system of Bolletje. Therefore, we need to find out which factors influence the planning and inventory control policy. Second, we want to find a suitable inventory control policy within the ERP system of Bolletje and implement it. Here, we include a founded calculation of what their safety stock should be and consider the factors that influence the planning and control policy. Third, we analyze one of those factors deeper: the changeovers. Since currently the changeovers increase the planning complexity, we have a look at the root causes for the inconsistencies and unexpected durations and try to improve the process by means of a reorganization and standardization.

We define the objective of this research as:

Improve and implement an automated finished products inventory control policy in the ERP system of Bolletje while keeping in mind the balance between customer service level and inventory investment. Include the relevant factors, calculate the safety stock, and optimize the changeover procedures.

1.4 Scope and Limitations

Bolletje has two levels on which inventory can be held. These are the raw material level and the finished products level. It is not possible to have an intermediate inventory with work-in-process products. Because of the long production times of the products, Bolletje decided to mainly have safety stock at the finished products level. The determination of where to hold safety stock is not part of this research. Furthermore, this research is limited to the finished products safety stock. Other forms of safety stock, such as the raw material safety stock are not taken into consideration.

The facility in Almelo has ten different production lines. To be able to conduct this research within the restricted time, the focus lies on one production line, knäckebröd line R156. Bolletje wants to produce products mainly on the same, default, production line. However, some products can be produced interchangeably on production lines. This is useful in case of capacity problems, for example. Line R156 has 12 default products. Bolletje produces those products on this production line.

Although setups are also a type of changeovers, they are not considered in this research. Bolletje executes setups less frequently than changeovers and they therefore have less impact on the production loss. Furthermore, Bolletje recently improved and reviewed the procedures around the setups. Since there are fewer inconsistencies in times, we exclude them from this research.

For privacy and confidentiality reasons, we do not publicize the names of the private labels that produce at Bolletje. Furthermore, we protect Bolletje's data by hiding the identity of the different Bolletje products.

1.5 Research Question and Research Plan

The described problem leads to the following main research questions:

How can the finished products inventory control policy of Bolletje be improved and implemented in Bolletje's ERP system while keeping in mind the right balance between customer service level and inventory investment? Furthermore, how much finished products safety stock should be held and how can the changeover procedure be improved?

We use multiple research questions to structure this research. We present them in the order of the chapters and describe the methods to answer them.

Context Analysis – Chapter 2

1. *What is the current situation at Bolletje regarding the planning of production and inventory as well as the changeovers?*

Chapter 0 has the objective to get a detailed insight into the current situation at Bolletje. Here, we analyze the current way of planning production and inventory and have a look at the function of the safety stock. We furthermore analyze the factors that influence the inventory control policy and safety stock of finished products. Furthermore, we observe the changeover process and analyze the changeover durations. We answer this research question by conducting interviews and being part of the important processes, together with the relevant employees of Bolletje.

Literature study – Chapter 3

2. *Which methods are available in literature for improving the inventory control policy of production systems?*
    a. *Which methods for calculating safety stock of production systems and which inventory control policies are available in literature?*
    b. *Which classification methods for Stock Keeping Units are covered in literature?*
    c. *Which methods for conducting a root cause analysis are available in literature?*
    d. *Which methods to improve changeovers are covered in literature?*

After gaining insight in the current situation, we position this research in the existing literature and describe relevant research fields. The research question is split into for us relevant topics. We elaborate on the importance of those topics in Chapter 3. With the literature found, we can find techniques, methods, or models that can help to answer the following research questions as well as the main research question.

Root Cause Analysis – Chapter 4

3. *What are the root causes for the inconsistencies and unexpected duration of changeovers and how can those be improved?*

Currently, changeovers interfere with the valuable production time. The reason for this is unknown to the Operational Department, though they assume that there are several root causes. In Chapter 4 we conduct a root cause analysis to find out why changeovers take longer than expected. To analyze the process we use the Single Minute Exchange of Dies method. For the root cause analysis it is important that we include everyone involved in the changeovers. We furthermore propose improvement options for the problems found.

Solution Design – Chapter 5

4. *Which finished products inventory control policy is suitable for Bolletje and the ERP system and how can it be implemented?*

In Chapter 5 we look for a suitable inventory control policy and implement this in the ERP system that Bolletje uses. Here, we consider the factors named in Section 2.2.1 and explain how we can implement them in the system. Furthermore, we determine the importance of products with a SKU classification so that the planners can easily determine which products to produce in case of capacity problems. We also compare and validate the safety stock equations from the ERP system with equations from the theory.

Solution Test – Chapter 6

5. *What is the effect and improvement of the automatized inventory control policy and safety stock levels on the processes within Bolletje?*

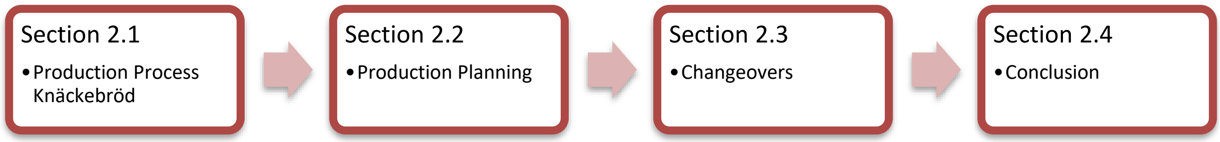
After having the theory implemented in the ERP system, we compare the old situation to the new one. Furthermore, we analyze the effects that the implementation will have on the different processes within Bolletje.

Conclusion and Recommendations – Chapter 7

Finally, we answer the main research question based on the results of the earlier findings. Moreover, we draw conclusions and give recommendations. These recommendations describe how the Operational Department of Bolletje Almelo should continue in the future. Furthermore, the recommendations include an implementation plan for Bolletje. We review which factors are importance during an ERP implementation and try to enforce them in the plan.

2. Current Situation

This chapter describes the current situation at Bolletje. First, Section **Error! Reference source not found.** outlines the production process of *knäckebröd*. Then, Section 2.1 describes how Bolletje conducts its production planning. Section 2.3 gives insights on the changeovers and their performance. Finally, Section 2.4 provides conclusions on the current situation.



2.1 Production Process Knäckebröd

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2.2 Production Planning

Bolletje produces according to an MTS policy under the push principle. They produce products and stock them in their warehouse before the customers place orders. Later, they use their inventory to meet the demand of their customers. Bolletje splits a year into 13 periods of 4 weeks and assumes that demand is evenly distributed over the weeks within a period. For Bolletje this means that they need to forecast how many products, of which kind, to produce by reviewing historical data such as past sales levels, forecasted orders and forecasted sales volumes from customers. This way of manufacturing offers Bolletje economies of scale as they can theoretically produce a full season's worth of inventory in one batch. However, since Bolletje has perishable products and too much capital would be caught up in stock which is not yet guaranteed to be sold, producing a full season's worth of stock is not possible in practice. Bolletje deals with different types of stock:

1. Baseline Stock: *Portion of inventory (planned to be) available for the normal demand during a given period, excluding excess stock and safety stock.*
2. Seasonal or Promotion Stock: *Portion of inventory (planned to be) available to meet seasonal fluctuation in demand or kept for promotions from supermarkets.*
3. Safety Stock: *Portion of inventory held as buffer against a mismatch between forecasted and actual demand and to prevent stockouts.*

Currently, the planners at Bolletje plan manually. Bolletje's planning process consists of four stages.

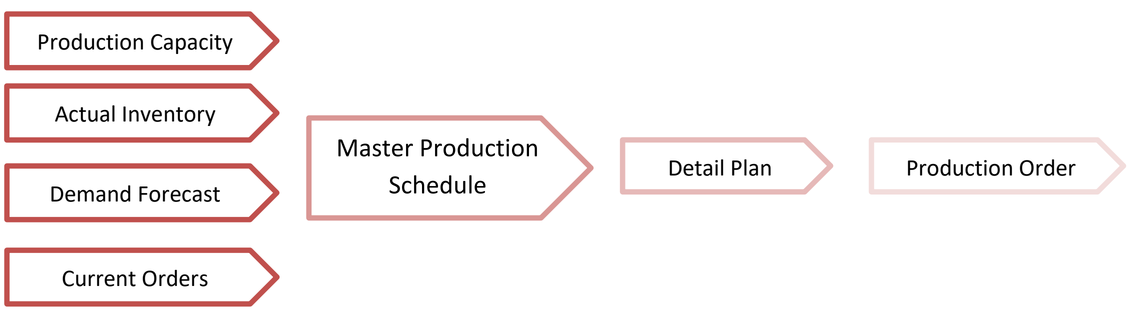


Figure 2.2 shows these stages and the arrows indicate the relevant input data for the process.

First, the planners gather data. The planning is driven by the demand forecast. For the forecast, the Demand Planner uses two different types of forecasts. They forecast the regular sales, also called baseline sales, as well as the promotion sales. Promotion sales are special offers for consumers from supermarkets. Bolletje uses historic data from the past four years to forecast their sales. In the first stage the planners need to check whether the necessary raw materials, tools and production equipment are available and ready for the production process. The planners carry those steps out in the ERP system, Microsoft AX. The planner's task is to check the raw material inventory levels and the status of the issued production orders. For the machine availability, they consult the Technical Department to see whether the equipment is available and not scheduled for maintenance. The Production Supervisor is responsible for providing reliable production norms. Since unrealistic production orders can cause high production output unreliability and a higher chance of stockout, reliable production norms are important for generating realistic production orders.

With the gathered data, Bolletje generates a Master Production Schedule (MPS). This is a schedule for 13 weeks (weeks x to x+12) in which the planners determine which production quantities to produce of which product and on which production line, in which week. The MPS is an Excel document. The planners have a look at the projected demand and inventory position for each week in AX and decide if a production order should be scheduled in the relevant weeks. They register an estimation of the production order quantity per week in Excel. The planners plan in such a way that Bolletje holds one week of baseline inventory and two weeks of safety stock in their warehouse. Furthermore, the planners try to use as much of the available production capacity as possible. The MPS is fixed at the beginning of each week and then the planners know the production quantity per Stock Keeping Unit (SKU) for the upcoming week.

After a weekly update of the MPS, the planners create a Detail Plan (DP) for the next week. In this plan the planner also includes the planned downtime for cleaning and maintenance. The DP includes the production schedule with exact production quantities per product per 8-hour shift. To determine the production schedule with production quantities, the planner needs to consider the production norms, set-ups, changeovers, and planned downtime (maintenance stops and cleaning). As soon as the Production Supervisor approves this plan, the planners issue the production orders and manually add the them in AX.

While planning, Bolletje's planners use a few rules of thumbs and restrictions:

1. A production run should at least take 8 hours.
2. There is a preferred production sequence (because of allergens and dough-making: *Goudbros* → *Sesam* → *Volkoren*).
3. Changeovers are preferably scheduled during the week in the day- or evening-shift and not at night or on the weekend (otherwise few technicians are available to solve problems).
4. When the line stops due to planned downtime, the planners should take into account a setup time of 2 hours afterwards.
5. The changeover times from one product to another are dependent on the two products in between the changeover.
6. Once a week as well as after the use of allergens, the production lines need to be cleaned.
7. Line R156 has 12 default products. **Error! Reference source not found.** shows if it is possible to produce the products on different production lines.

Inventory at Bolletje serves the objective to satisfy customer demand. The target service level is 98.5%. The service level measure at Bolletje is the fill rate, i.e. the fraction of demand that can be satisfied immediately from stock on hand. Furthermore, Bolletje needs to deliver the products before the ULC (uiterste levercode). This is a percentage of the shelf life of the product during which it needs to be in the supermarkets. This percentage differs between each product since they have varying shelf lives. In general, this percentage is approximately 2/3^{rds} of the shelf life.

Since Bolletje is a forecast-driven supplier, the customer orders arrive only a day before they need to be delivered. This is different for promotion demand. The Demand Planner sets the promotion with the supermarkets at the beginning of the year in the promotion calendar. In those weeks the demand is not assumed to be distributed evenly over the weeks in a period, but the demand peaks in the promotion week.

Microsoft Dynamics AX 2012

Microsoft Dynamics AX 2012, further referred to as AX, is an ERP solution that helps employees work effectively, manage change, and compete in the market. It provides functionalities for the whole company ranging from financials to human resources, and operations management. It works like the familiar Microsoft software and is a solution that automates and streamlines financial, business intelligence, and supply chain processes in a way that can help manage the business processes (Microsoft, n.d.).

Bolletje introduced AX in the beginning of 2018. Right now, employees mainly use it for managing the warehouse and for resource purchasing activities. Bolletje's planners do not use the functionalities of the program but use Excel sheets for production planning. They then enter production orders manually into AX. During several meetings, the planners name some barriers that prevent them from implementing AX:

1. Unskilled and IT illiterate employees make the implementation difficult.
2. Lack of training.
3. Lack of available time to test and get to know AX.
4. Lack of confidence in the system.
5. Lack of motivation for employees to endorse the new system.
6. The system requires new work flows and a shift in responsibilities.

Although the production planners at Bolletje do not use AX, the program is designed to execute the master planning for a company. AX is designed in such a way that the master planning within the program can perform the following business processes (Microsoft, n.d.):

- Run forecast scheduling to calculate gross requirements for forecasted demand;
- Run master scheduling to calculate net requirements for items to fulfill actual demand;
- Process planned orders;
- Respond quickly to changes in demand for materials and capacity;
- Reduce inventory levels through improved production planning and forecast scheduling.

2.2.1 Factors Influencing Inventory at Bolletje

There are factors that influence the inventory and its control policy. Bolletje can ease their effect by changing their parameters.

Demand forecasting is essential for Bolletje to enable the production of the required quantities at the right time and arrange for raw materials, packaging materials and workforce to be accessible well in advance. Reliable forecasts reduce uncertainties. Since customers at Bolletje place their order one day before the delivery date and to make sure that Bolletje can deliver the wished quantities, demand forecasts need to be as accurate as possible.

The line availability is dependent on the planned and unplanned downtime and is typically measured as a factor of its reliability. As reliability increases, so does availability. In order to react to the market demand, availability of the production line should be high. The inventory position should be adjusted to the availability of the line. An example of this are the maintenance weeks of Bolletje. These are weeks in which the Technical Department conducts preventive maintenance measures on a production line. During this week, the production line is not available. To deal with this unavailability, the inventory position should be higher than usual before this week.

The production outputs depend on the production lines and their availability. When the availability is high and thus no planned or unplanned downtime is recorded, the production output is high and stable. Since this is not always possible in a production environment, the inventory control policy should take the availability of the production line into account. Bolletje measures this within the Overall Equipment Effectiveness (OEE) tool.

Changeovers influence the inventory control policy and safety stock in two ways. First, changeovers are unplanned downtime and thus the availability of the line decreases with each changeover. Second, the changeovers cost time and money, especially if they are longer than indicated in the planning. This happens on regular basis at Bolletje. To show that changeovers have a considerable influence on the inventory control policy, Bolletje wants to include them in this research.

Bolletje constantly monitors the shelf life of its products. Their warehouse is handled following the First In – First Out (FIFO) method. This means that Bolletje delivers products to customers according to their production date, where the oldest (first) entry is processed first. This is done since products perish after some time and the customer contracts include an ULC date. Customers do not have to accept products that do not satisfy this ULC. Therefore, Bolletje needs to consider the shelf life in the inventory control policy. While it is advisable to produce big batches within an MTS production environment, Bolletje also needs to make sure that batches are not too big, and that they can still deliver those batches to the customers before the ULC.

Bolletje delivers products to multiple customers. With these customers they have contracts in which they ensure the customer a service level. This means that Bolletje ensures the customers that they will deliver 98.5% of the orders without experiencing a stockout.

2.2.2 Production Effectiveness Measure

The OEE measures the performance of the production lines. The OEE considers all losses and measures the truly productive manufacturing time. Operators register the performance of every production line on a physical OEE-board hourly. The OEE-board contains information about the output, the number of packaged consumer (consumenteneenheid CE) boxes and of the production line. It counts the products before the next packaging machine packages them into trade (handelseenheid HE) boxes. The operators monitor if the output in contrast to the production norm. To capture the reasons for deviation, operators fill in a logbook in the program 'OEE-toolkit' at the end of every shift. A sensor also counts the number of CE boxes on the production line. Eventually, employees use the OEE-toolkit to make reports and performance analysis.

The toolkit calculates the performance, OEE, of the production lines. The OEE is a function of the availability, performance, and quality (Muchiri & Pintelon, 2008). Figure 2.2 shows the different parts of the OEE. The availability considers all events that stop the planned production and tracks the cause of downtime. Planned production time is the time when the production lines produce products. It excludes the unscheduled time or planned downtime, for example for cleaning or maintenance, from the OEE calculation. The run time is simply the planned production time without the unplanned downtime. Unplanned downtime is the time where products should be produced but are not due to unplanned stops, such as breakdowns or changeovers. Although changeovers are planned, they are not considered as planned downtime in the OEE calculations. The reason for this is that the perceived availability would inherently improve since the toolkit would exclude changeovers from the calculation. This higher availability would be an illusion as the time is lost since the production line was not available. Next, the performance considers anything that causes the manufacturing process to run at less than the maximum possible speed. Finally, quality considers products that do not meet quality standards. Bolletje considers a constant 100% quality in the OEE calculations since it is not possible to rework products. Moreover, products which do not satisfy the quality standards are not even packaged and the production loss thus happens before packaging. Equation 2.1 introduces the relevant equations belonging to the OEE. The equations use the terms that Figure 2.2 introduces.

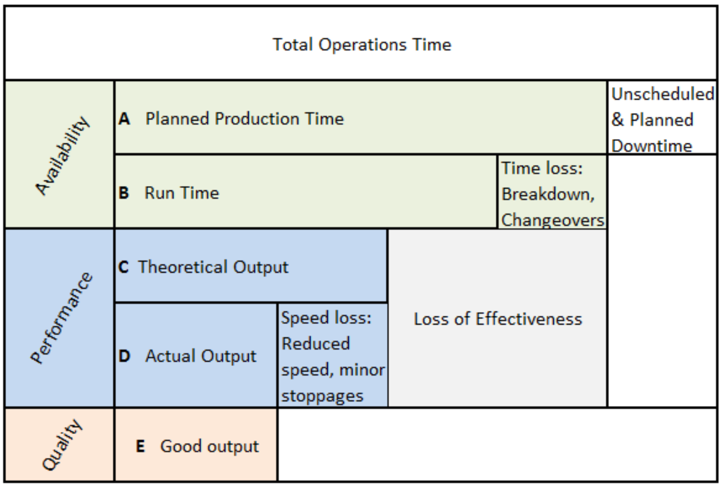


Figure 2.2 - Overall Equipment Effectiveness Measures

Equation 2.1 - OEE Function at Bolletje

$$\textit{Overall Equipment Effectiveness} = \textit{Availability rate} * \textit{Performance rate} * \textit{Quality rate}$$

$$\textit{where,}$$

$\textit{Availability rate}\ (\%) =$	$\frac{\boldsymbol{B}}{\boldsymbol{A}} = \frac{\textit{Run time}}{\textit{Planned Production Time}}$
$\textit{Performance rate}\ (\%) =$	$\frac{\boldsymbol{D}}{\boldsymbol{C}} = \frac{\textit{Actual output}}{\textit{Theoretical output}}$

$Quality\ rate\ (\%) =$	100

In the OEE-toolkit the operators can also indicate why the production line registered unplanned downtime. For this they have a computer that lists various categories for unplanned downtime. The operators generate an OEE report every morning. Figure 2.3 shows an example of this report. This report shows the performance of production line R156 on the 23rd of April in 2018. The OEE on that day was 60.3% and the line stopped 17.6% of the time for failures. The Langepack, CE packaging machine of this line, registered the biggest failure time on that day. Because of failures on this machine, the line stopped for about 2.5 hours.

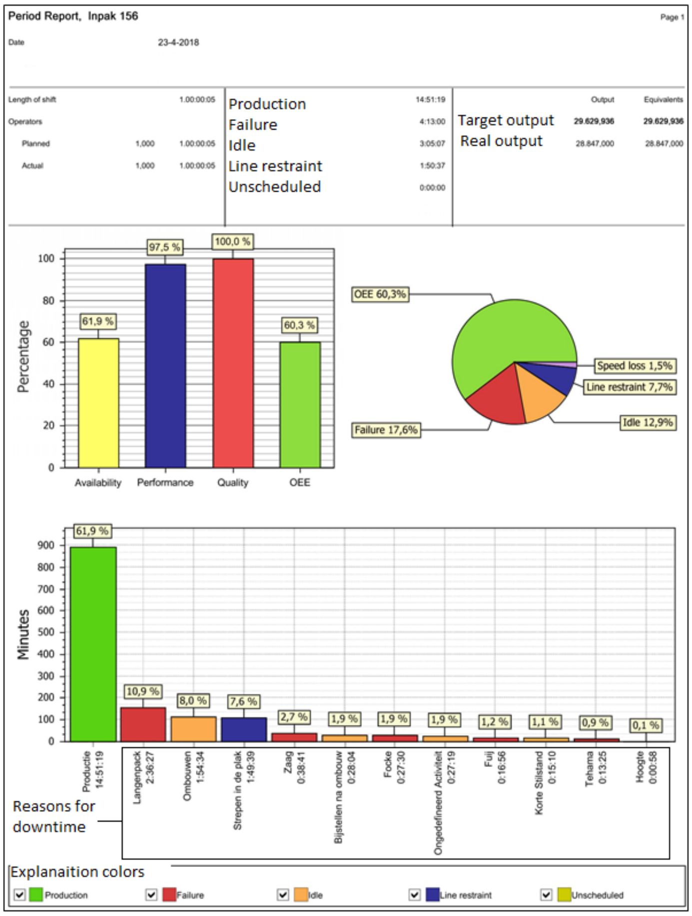


Figure 2.3 - OEE Rapport

2.3 Changeovers

Changeovers from one product to another are a necessity at Bolletje because they produce multiple products, from their own brand but also products for private labels. Furthermore, they need to plan downtime for maintenance and cleaning. After planned downtime, the machine needs to be setup again. A setup is also a form of changeover. Currently, changeovers are an obstruction to the production process, since the activities cause more downtime and production loss than anticipated. Ferradás and Salonitis (2013) describe that better changeovers and setups are the key to enabling responsive production and to improve line productivity by reducing downtime losses. Therefore, the Operational Department would like to find the root causes and improve the processes.

For confidential reasons, the rest of this chapter is moved to the confidential appendix **Error! Reference source not found. Error! Reference source not found.**.

2.4 Conclusion

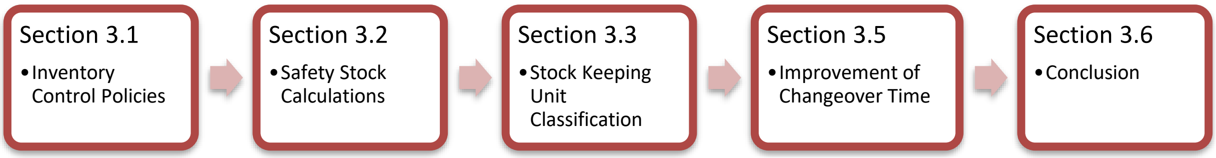
This chapter we reviewed the current situation at Bolletje, by answering the first research question: "*What is the current situation at Bolletje regarding the planning of production and inventory as well as the changeovers?".*

We conclude that right now, no clear inventory control policy is established at Bolletje. Bolletje plans under the condition that inventory for week x and until x+3 needs to be on hand at all times. This is one week of baseline inventory and two weeks of safety stock. When optimizing the safety stock, we need to review the current policy and formulate a clear inventory control policy. Furthermore, there are a few factors which need to be taken into consideration during this research. Their role in the ERP system and measurability will be determined in Chapter 5. Right now, the employees at Bolletje are not using the functions of the ERP system but plan the production manually.

Concerning the changeovers we observed inconsistencies, high frequencies and long durations. The causes for this are not clear yet. Furthermore, we observed that there is no structure in the changeovers and different employees use different methods to conduct them. A root cause analysis will be done in Chapter 4.

3. Literature Review

This chapter gives an overview of the literature which is useful for this thesis. We start with an overview of the inventory control policies and the determination of safety stocks in Section 3.1 and 3.2 respectively. Next, in Section 3.2.2, we address techniques for SKU classifications. Then, Section 3.4 discusses theory about improvement options of changeovers and theory about root cause analysis. Finally, Section 3.5 provides a conclusion.



3.1 Inventory Control Policies

The purpose of inventory control policies is to determine when and how much to order, as well as how to maintain appropriate stock levels to avoid shortages. The decision when and how much to order should be based on the stock situation, the anticipated demand, and the lead time (Axsäter, 2015). Inventory policies are often described in terms of inventory position. Inventory position includes physical stock and outstanding orders that have not yet been stocked as well as backorders, which are units that have been demanded but not yet delivered. Equation 3.1 shows the inventory position according to Axsäter (2015).

Equation 3.1 - Inventory Position Formula (Axsäter, 2015)

$$Inventory\ position = stock\ on\ hand + outstanding\ orders - backorders$$

There are different inventory control policies. The biggest difference between the policies is the inventory position which is either monitored continuously or periodically. Continuous review policies order as soon as the inventory position is sufficiently low. The order is then delivered after a certain lead time (L), defined as the time between the ordering decision and placing the order in stock. Periodic review policies consider the inventory position only at certain intervals in time, the review period, defined as the time interval between reviews (Silver, Pyke, & Thomas, 2016).

Silver et al. (2016) name four main types of inventory control policies for single-echelon systems. Additionally we introduce a policy from Jansen, Heuts, and De Kok (1998). In these systems, s is the reorder point, Q is the order quantity, S is the order-up-to-level and R is the review period:

- *(s,Q) Policy (continuous review)*: Whenever the inventory position drops to the reorder point s or below, an order is placed for a fixed quantity Q .
- *(s,S) Policy (continuous review)*: Whenever the inventory position drops to the reorder point s or below, an order is placed for a quantity to raise the inventory position to the order-up-to level S.
- *(R,S) Policy (periodic review)*: The inventory position is reviewed at regular intervals T, where an order is placed for a sufficient quantity to raise the inventory position to the order-up-to level S.

- *(R,s,S) Policy (periodic review)*: The inventory position is reviewed at regular intervals T, where if the inventory position is at the reorder point s or below, an order is placed for a sufficient quantity to raise the inventory position to the order-up-to level S or if inventory position is above the reorder point s, no order is placed.
- *(R,s,Q) Policy (periodic review)*: The inventory position is reviewed at regular intervals T, where if the inventory position is at the reorder point s or below, an order is placed for a fixed quantity Q or if inventory position is above the reorder point s, no order is placed.

(s,Q) Policy

The system orders a fixed quantity batch Q as soon as the inventory position drops to the reorder point s or lower. The inventory position also accounts for outstanding orders. The (s,Q) system is also called a two-bin system (Silver et al., 2016). Demand is satisfied from the first bin, as long as units remain there. The amount in the second bin corresponds to the order point. This means that as soon as the first bin is empty, the second bin is opened, and a replenishment is triggered (Silver et al., 2016). Once the replenishment order arrives, the second bin is refilled, and the remainder is put into the first bin. However, the policy only works when no more than one replenishment order is outstanding. Otherwise, no more orders are triggered since no bins are available (Silver et al., 2016). Figure 3.1 a) shows an example of the (s,Q) system.

(s,S) Policy

Comparable to the (s,Q) policy, the (s,S) policy replenishes whenever the inventory position drops to the reorder point s or lower. Unlike the (s,Q) policy, the (s,S) policy uses a variable replenishment quantity, thus orders to raise the inventory position to the order-up-to-level S. Since the inventory position is always between a minimum value of s and a maximum value of S, except for a possible temporary undershoot below the reorder point, this policy is frequently referred to a min-max system. In case that all demand transactions are unit sized, the two systems are identical since the replenishment requisition will always be made when the inventory position is exactly at s. Once the transactions are larger than unit size, the replenishment quantity in the (s,S) policy becomes variable. Figure 3.1 b) illustrates the (s,S) policy. It shows that a variable quantity is ordered to raise the inventory position to the order-up-to-level S (Silver et al., 2016).

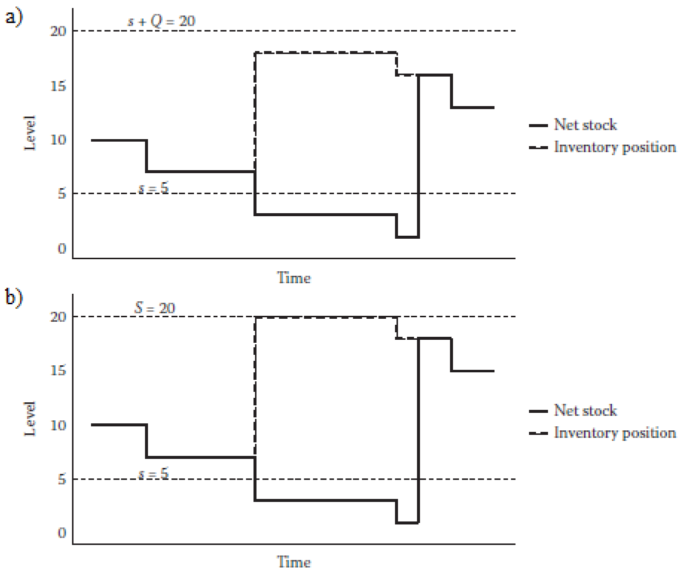


Figure 3.1 - a) (s,Q) Policy and b) (s,S) Policy (Silver et al., 2016)

(R,S) Policy

This system, which is often referred to as replenishment cycle system, orders every R units of time enough items to raise the inventory position to the level S. The (R,S) policy offers a regular opportunity, during the review interval, to adjust the order-up-to-level S. This is especially useful if the demand pattern changes with time (Silver et al., 2016). Figure 3.2 shows an example of a (R,S) policy.

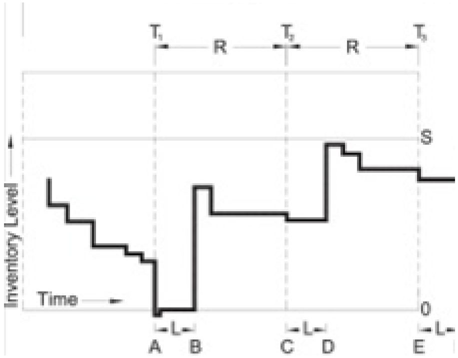


Figure 3.2 - (R, S) policy (Silver et al., 2016)

(R,s,S) Policy

The (R,s,S) policy is a combination of the (s,S) and (R,s) policies. Every R units of time the inventory position is checked. If the inventory position is at or below the reorder point s, an order is placed to raise the inventory position to S. If the position is above s, nothing is done until at least the next review moment. Often, the (R,s,S) policy is referred to as a periodic version of the (s, S) policy (Silver et al., 2016). Figure 3.3 shows an example of a (R,s,S) policy.

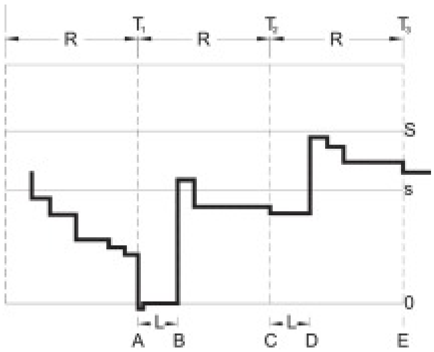


Figure 3.3 - (R,s,S) system (Silver et al., 2016)

(R,s,Q) Policy

The (R,s,Q)policy is similar to the (R,s,S) policy. The main difference is that there is no order up to level, but the Economic Order Quantity (EOQ) raises the inventory position. This policy helps to translate the customer orders to efficient production schedules (Jansen et al., 1998).

3.1.1 Perishable Inventory Models

Perishable products have the characteristic of a limited lifetime. The inventory systems described in Section 3.1, assume that stock items can be stored indefinitely to meet future demands. However, since most food products become unsuitable for consumption as time passes, the perishability of a food product cannot be ignored for certain types of inventories (Lemma, Kitaw, & Gatew, 2014). Lately, food loss has become a problem commonly researched. Since research indicates that 20 to 60 percent from the total production is lost in the food supply chain, researchers such as Lemma et al.

(2014) pay more attention to maximize the availability of food products for the society. The food supply chain differs fundamentally from other supply chains since the quality of the products changes continuously and significantly throughout the entire supply chain up to the point of final consumption (Lemma et al., 2014). It is possible to model perishable goods in an inventory model with a known fixed lifetime or with a random lifetime. Inventory models that consider the known a priori deterministic (fixed) lifetime belong to models for fixed lifetime. All other models with probabilistic distributed lifetime, constant, known, or unknown deterioration rate as models for random lifetime products (Janssen, Claus, & Sauer, 2016).

A fixed lifetime model assumes that units may be stored in stock and satisfy customer demand for some specified fixed time. After this time, the products must be discarded. It is important that companies that have such products use a FIFO policy in their warehouse. This way the earliest produced products, will also be sold the earliest (Nahmias, 1982). Within the fixed life time models, we can differ between deterministic and stochastic demand.

The lifetime of the products at Bolletje is deterministic. Deterministic demand ensures, under fairly general conditions, that orders are placed in such a way that items will never perish (Nahmias, 1982). In the EOQ, the optimal batch size, which minimizes the holding and set-up cast rate, is $Q^* = \sqrt{2K\lambda/h}$, where K is the set-up cost per order, λ is the demand rate and h is the cost of holding one unit for a unit time. If this is the case, the optimal order size that ensures that no units expire is $a = min(Q^*, \lambda m)$ with a lifetime of m. This expression chooses the lowest value of either the lifetime, or the optimal quantity.

3.2 Safety Stock Calculations for Continuous Review

The decision when planners should place a production order is based on the minimum inventory level. Stockouts can only occur during periods when the inventory on hand is low (Silver et al., 2016). Planners should place orders early enough so that the expected number of units that is demanded during the lead time is sufficient to satisfy customer demand. According to Silver et al. (2016), lead time is defined as the time between deciding to place an order and the time it is stored physically on the shelf. Companies hold safety stock to deal with the uncertainty of production and demand, i.e. to prevent stockouts (King, 2011). The decision of how much safety inventory to hold is important since it is a trade-off between two crucial factors. While raising the level of safety stock, the product availability as well as the inventory holding cost increases (Chopra & Meindl, 2007). King (2011) states that a mathematical approach to safety stock balances the conflicting goals of maximizing customer service while minimizing inventory cost. Figure 3.4 shows the usefulness of safety stock.

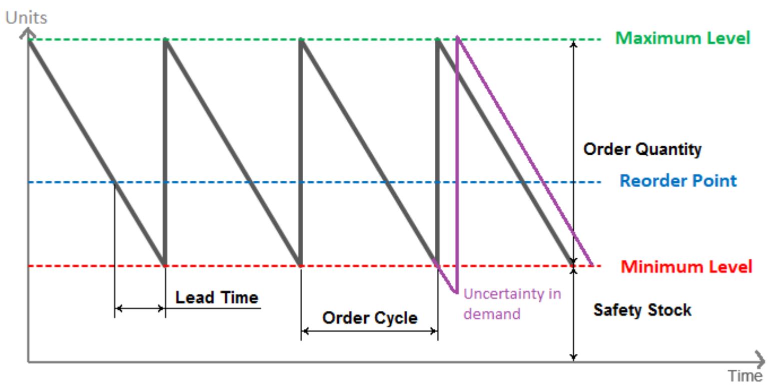


Figure 3.4 - Safety Stock Levels and the associated effects of variability in the supply chain

The main reasons for carrying safety stock is to avoid stockouts and keep customer service and satisfaction levels high. To accomplish this, the safety stock needs to:

1. Protect a company against unforeseen variation in demand.
2. Compensate forecast inaccuracies (in case demand is bigger than the forecast).
3. Protect a company against unforeseen variation in supply.

Most often, companies have a desired level of product availability and the design of safety stock and their replenishment polices is based on this. In these cases, the desired level of product availability is determined by trading off the cost of holding inventory with the cost of a stockout or the level of product availability is set in the contract (Chopra & Meindl, 2007). Equation 3.2 shows the standard safety stock equation for evaluating the safety stock based on the desired service level as formulated by Chopra and Meindl (2007).

Equation 3.2 - Standard Safety Stock (Chopra & Meindl, 2013)

$$SS = F_S^{-1}(Z) * \sigma_D$$

$Safety\ stock = SS$
$Desired\ service\ level = Z$
$Standard\ deviation\ of\ demand = \sigma_D$
$Inverse\ of\ the\ standard\ normal\ cumulative\ distribution = F_S^{-1}$

The standard safety stock only takes the demand uncertainty into account. In many situations, supply uncertainty also plays a significant role. To incorporate this uncertainty Chopra and Meindl (2007) assume that lead time is uncertain and identify the impact of lead time uncertainty on safety inventories.

Equation 3.3 - Safety Stock with Supply Uncertainty (Silver et al., 2016)

$$SS = F_S^{-1}(Z) * \sigma_{(L+R)}$$
$$with: \sigma_L = \sqrt{(L+R) * \sigma^2{}_D + D^{\ 2} * s^2{}_L}$$

$Safety\ stock = SS$
$Desired\ service\ level = Z$
$Average\ lead\ time = L$
$Average\ review\ period = R$
$Average\ demand\ per\ period = D$
$Standard\ deviation\ of\ demand\ during\ lead\ time\ and\ review\ period = \sigma_{(L+R)}$
$Standard\ deviation\ of\ demand = \sigma_D$
$Standard\ deviation\ of\ lead\ time = s_L$
$Inverse\ of\ the\ standard\ normal\ cumulative\ distribution = F_S^{-1}$

3.2.2 Calculating the Parameters for the Continuous Review Policy

There is a well-known method for setting the reorder point to be found in literature. This entails a adding the safety stock and the expected demand during the lead time and review period (Silver et al., 2016). When ordering, the costs of setting up and holding the inventory should be at an optimum. To achieve this, companies often use the Economic Order Quantity (Silver et al., 2016). The order up to level can then be determined by adding the Reorder Point with the Economic Order Quantity. Equation 3.4 shows the equations for these parameters.

Equation 3.4 - Reorder Point, Order-up-to Level and Optimal Production Quantity (Silver et al., 2016)

$$\textbf{Reorder Point} = SS + D_{(L+R)}$$

$$\textbf{Economic Order Quantity} = \sqrt{\frac{2 * A * D}{h * v}}$$

$$\textbf{Order} - \textbf{up} - \textbf{to Level} = \ Reoder\ Point + Economic\ Order\ Quantity$$

$Safety\ Stock\ =\ SS$
$Average\ demand\ during\ lead\ time\ and\ review\ period = D_{(L+R)}$
$Fixed\ Order\ cost\ =\ A$
$Holding\ cost\ charge\ =\ h$
$Unit\ cost\ of\ SKU\ =\ v$

3.3 Stock Keeping Unit Classification

Production companies such as Bolletje often have different SKUs. Production volumes and inventory decisions vary for different SKUs since their sales volume, predictability of demand, product value, and storage requirements might differ (Van Kampen, Akkerman, & Van Donk, 2012). When a company sells a wide variety of SKUs, they often struggle with the production and inventory decisions. Consequently, companies categorize SKUs, based on the characteristics, into a limited number of classes with different importance (Van Kampen et al., 2012). A wide variety of SKU classification methodologies are described in literature.

3.3.1 ABC Analysis

The ABC analysis is based on the well-known Pareto principal, stating that roughly 80% of the effects come from 20% of the causes. The analysis determines which SKUs should be prioritized during inventory management and therefore the SKUs are categorized into the three different classes A>B>C. The grouping is by the means of a single criterion, typically the annual dollar volume. Axsäter (2015) states that “typically 20 percent of the items can account for about 80 percent of the dollar volume” (p.301). The most personalized attentions need to be on the SKUs with very high dollar volume, which are in class A. SKUs with intermediate dollar volume are in class B and finally, all other SKUs are in class C. Since class C SKUs are of least important, employees need to keep time spent on the decisions of these SKUs to a minimum (Axsäter, 2015). Figure 3.5 shows an example of the analysis. Despite the ABC-analysis being the most well-known methodology, it has been frequently criticized for only considering a single criterion (Flores, Olson, & Dorai, 1992; Guvenir & Erel, 1998). Examples of other important criteria are lead-time, obsolescence, inventory cost, and the production reliability (Flores & Whybark, 1986).

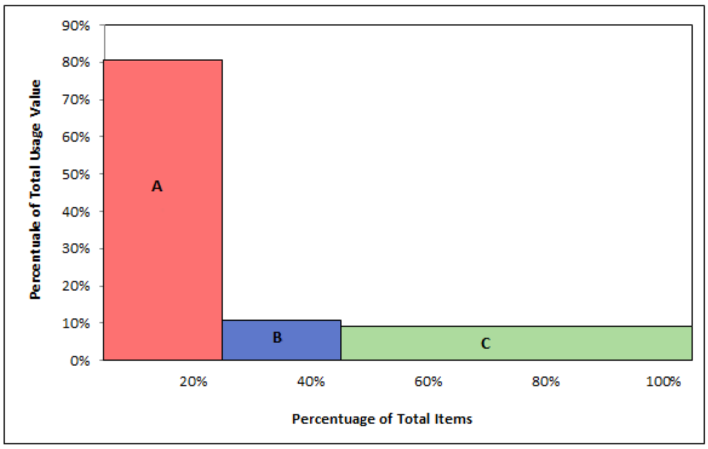


Figure 3.5 - ABC Analysis

3.3.2 Joint Criteria Matrix

Classifying SKUs by using the annual dollar volume as the only criterion may over emphasize the importance of costly SKUs that do not have considerable importance to the company and thus mismanage its inventory assets (Flores et al., 1992).The number of criteria that should be used to manage the inventory vary depending upon the nature and type of the company (Flores et al., 1992).

A method that uses a two criteria analysis is the nine cell joint criteria matrix by Flores and Whybark (1986). Figure 3.6 a) shows this. The disadvantage of this method is that a two criteria joint matrix requires nine different policies to deal with SKUs in the different cells. While establishing nine policies might not be a problem, implementing and managing those will be difficult. It will especially become unmanageable as more criteria are added (Flores et al., 1992).

a)

		Criteria 1		
		A	B	C
Criteria 2	A	AA	BA	CA
	B	AB	BB	CB
	C	AC	BC	CC

b)

		Criticality		
		A	B	C
Dollar usage	A	AA	BA	CA
	B	AB	BB	CB
	C	AC	BC	CC

Figure 3.6 - Joint Criteria Matrix a) for Two Criteria and b) Adapted by Flores and Whybark (1986)

Flores and Whybark (1986) establish an example on how to deal with the nine cells. Figure 3.6 b) shows an example of their joint criteria matrix. Dollar usage and criticality are the criteria in this joint criteria matrix and their objective is to reclassify the SKUs into three categories: AA, BB and CC. The off-diagonal SKUs should then be reclassified, in this example AB and BA are classified as AA, AC and CA as BB, and BC and CB as CC.

3.3.3 Analytical Hierarchy Process

Saaty (1980) developed another multicriteria methodology, the Analytic Hierarchy Process (AHP). This method involves a pairwise comparison and can be used for multiple quantitative, as well as qualitative criteria. To still be able to analyze all criteria simultaneously, Saaty (1980) suggests restricting the number of criteria to seven. The biggest disadvantage of AHP is that much managerial time is needed to gather information and structure the approach when reviewing and classifying all important SKUs (Flores et al., 1992). Moreover, subjectivity is involved during the pairwise comparisons (Guvenir & Erel, 1998).

Flores et al. (1992) summarize AHP for clarity in three simple steps and give an example. Appendix A shows this example. First, the decision maker needs to identify all criteria of importance to the specific decision. Next, the criteria should be arranged in a hierarchy of one or more levels. Finally, a series of pairwise comparisons should be conducted whenever sub elements are found in the hierarchy. Here, the decision-maker's subjective judgement is converted into a set of weights of relative importance. Saaty (1980) has developed a scale to describe the relative importance of each pair. Table 3.1 shows this scale. Importance 2, 4, 6 and 8 are used as intermediate values on this scale.

Table 3.1 - Relative importance according to Saaty (1980)

Scale	Relative importance	Explanation
1	Equal importance	Both factors contribute equally
3	Weak preference	Base factor is slightly more important than second factor
5	Essential preference	Base factor strongly preferred
7	Demonstrable preference	Definite preference for base factor
9	Absolute preference	Base factor preferred at highest possible level

3.4 Improvement of Changeover Times

We first introduce the Root Cause Analysis and techniques to conduct such an analysis in Section 3.4.1. Furthermore, Section 3.4.2 explains the Single Minute Exchange of Dies method. In Section 3.4.3 other factors for changeover time reduction are summarized.

3.4.1 Root Cause Analysis

To improve a problematic situation, correct, eliminate, or prevent a problem from happening, the root cause of the problem needs to be found. According to Vorley (2008), six steps need to be followed when conduction a Root Cause Analysis (RCA). Figure 3.7 describes those steps.

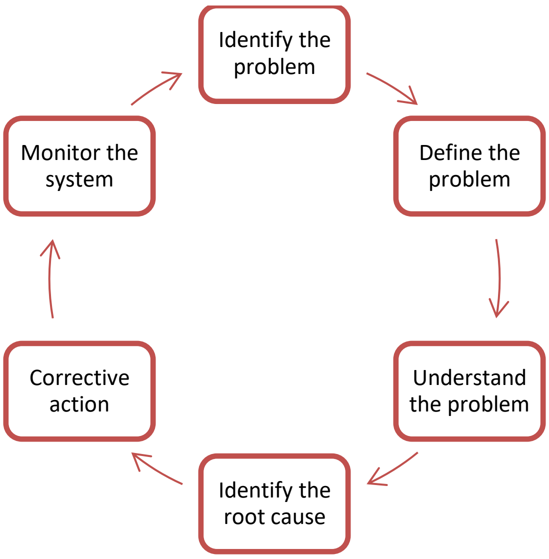


Figure 3.7 - Steps of the Root Cause Analysis

RCAs are important in order to improve a situation efficiently and profitable. While companies often implement short-term fixed, those are not able to ensure an organizations growth, but only maintain the status quo of the situation (Vorley, 2008). Vorley (2008) describes different techniques which can be used.

5 Why's

Decision makers use this technique when solving a simple RCA. This analysis emerged as a result of Taiichi Ohno's observation. He noticed that when mistakes happen in the production or manufacturing environment people would always blame one another. While he knew that mistakes are inevitable, he found out that the best approach towards mistakes is to identify the root causes of the mistakes and act upon it (Murugaiah, Jebaraj, Srikamaladevi, & Muthaiyah, 2010). In the example below, the solution to improving this situation would thus be to install a filter on the pump. This type of analysis usually has a lot of depth and breadth and are not always as simple, straightforward.

1. Why did the robot stop?
   → The circuit is overloaded, causing a fuse to blow.
2. Why is the circuit overloaded?
   → There was insufficient lubrication on the bearings, so they locked up.
3. Why was there insufficient lubrication on the bearings?
   → The oil pump on the robot is not circulating sufficient oil.
4. Why is the pump not circulating sufficient oil?
   → The pump intake is clogged with metal shavings.
5. Why is the intake clogged with metal shavings?
   → Because there is no filter on the pump.

Ishikawa Diagram

Ishikawa diagrams, also fishbone diagrams, help to structure one's thoughts about potential causes and the reasons behind them (Sondermann, 1994). It is a technique that is often used for more complex RCAs. First, the decision maker needs to determine a problem statement. This is the effect the problem has on the process. Then, the major categories of the causes should be chosen. Next, the decision maker brainstorms the potential causes of the problem with his team by asking "Why does this happen?". Causes are sometimes written on several branches if they relate to several categories. The decision maker generates deeper levels and sub-causes by continuing to ask why. Once the causes are captured in the diagram, they need to be prioritized and solutions for the problems they indicate need to be found (Vorley, 2008). The name fishbone is given since, the diagram looks like the bones of a fish when completed. Figure 3.8 shows an example of this diagram.

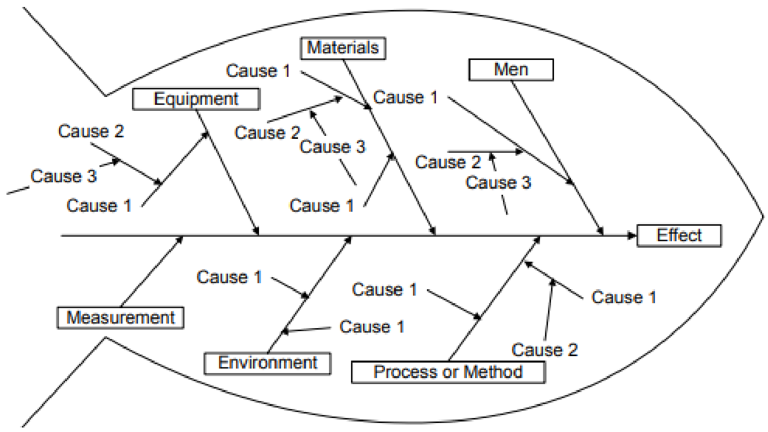


Figure 3.8 - Ishikawa Diagram

Process Mapping

Process maps map the processes and organize the information about a process in a graphical manner. They show clearly what and on which sub process the problem has an influence (Vorley, 2008). Process mapping takes a specific objective and with this it helps to measure and compare it to the entire organization's objectives. This way the problem owner can make sure that all processes are aligned with the company's values and capabilities.

Fault Tree

The fault tree is a graphical technique that provides systematic description and analyzes the combination of possible occurrences within a process that result in undesirable outcome. Mostly it is a top-down, deductive failure analysis (Vorley, 2008). Mainly, it is used in the fields of safety engineering and reliability engineering to understand how and why systems can fail, as well as to identify the best ways to reduce risk.

3.4.2 Single Minute Exchange of Dies

Flexibility and responsiveness to customer demand are an imperative task when running a successful production facility (Ani & Shafei, 2014). One method to realize a quick changeover of setups is Single Minute Exchange of Die (SMED). It is defined as the minimum amount of time necessary to change from one production activity to another. The changeover time is the time between packaging the last piece of the first production run and the first piece of the subsequent production run (Dillon & Shingo, 1985). The ultimate goal is to perform setup operations within a single digit time and thus eliminating waste (Ani & Shafei, 2014).

Within the method, two operations are defined. An operation is either internal, meaning the operation can only be carried out when the machine is stopped, and external operations, which can be carried out while the machine is running (Ani & Shafei, 2014). To achieve a reduction in changeover time four phases are involved (Ani & Shafei, 2014):

1. Preliminary stage
2. Separate internal and external setup
3. Convert internal to external setup
4. Streamlining all aspect of setup

In the first phase it is necessary to have an image of all activities included in the changeover process. This can be done by collecting data about the current setup procedures through interviews with operators along with Production Supervisors. Furthermore, the operations should be decomposed into a series of actions of which a time analysis should be carried out (Almomani, Aladeemy, Abdelhadi, & Mumani, 2013). During the second phase, those activities need to be analyzed and standardized in the third phase. The last phase is meant to improve the process. Here, unnecessary operations are eliminated and internal as well as external activities are improved.

3.4.3 Improvement of Changeover Inefficiencies

Gungor and Evans (2015) identified and categorized 12 influential factors affecting the changeover performance. Knowledge, design, and management were named as root causes and therefore crucial to the improvement of changeover performance. The more transparent branch of the Ishikawa diagram shows manufacturing strategies such as Total Quality Management, Just-in-Time

Manufacturing, Total Productive Maintenance and Lean Manufacturing that could be considered when improving the changeover performance.

Other root causes of changeovers inefficiencies are lack of standardization. According to McIntosh, Culley, Mileham, and Owen (2001) changeover inefficiencies can also be improved by simplifying them in terms of refining and standardizing changeover procedures.

Most of the time, operators do not track the time it takes them to conduct changeovers. Visualizing changeover time can help to provide real-time indications for how long changeovers are taking, compared to the target time. Furthermore, it should also be visual when changeovers take place in order to be prepared and ready in time (Vorne, n.d.).

Improving the changeover times might also mean using the time needed efficiently. Changeover time as well as maintenance activities contribute to the downtime of the machine. The activities often occur entirely separately, contributing to increasing the downtime of the machine. Nevertheless, they have similarities and could be conducted simultaneously. Conducting maintenance and changeover in unison reduces the overall downtime that line equipment experiences (McIntosh et al., 2001). During changeover, access to some machines might be easier since equipment is in a semi-dismantled state (McIntosh et al., 2001). Moreover, whilst the line is stationary, inspections or small maintenance activities can be conducted on machines that are not involved in the changeover procedure (McIntosh et al., 2001).

3.5 Conclusion

In this chapter we reviewed literature and found an answer to the second research question and its sub questions: "*Which methods are available in literature for improving the inventory control policy of production systems?".*

Within the first sub questions, we looked at different inventory control policies which can be used to get more control over the inventory position. Distinction is made between continuous and period review. The five policies described by Silver et al. (2016) and (Jansen et al., 1998) are:

- *(s,Q) System (continuous review);*
- *(s,S) System (continuous review);*
- *(R,S) System (periodic review);*
- *(R,s,S) System (periodic review);*
- *(R,s,Q) System (periodic review).*

For Bolletje it seems like a periodic review is the best option since once a week the production schedule needs to be established. Furthermore, we reviewed literature about the inventory position and safety stock of perishable goods. This is an important aspect since all of Bolletje's products have a limited shelf life. Since the products at Bolletje are deterministic and thus have an expiration date, the life span can be considered during the determination of the order quantity. Furthermore, we reviewed the standard safety stock equations. For Bolletje it is important that they include supply uncertainties during the determination of the safety stock to compensate for lost production time.

For the second sub question we reviewed the methods for SKU classification. There are different methods to determine the importance or production order of the different products.

Moreover, we described different methods to conduct a root cause analysis to answer the third sub question. The Ishikawa diagram seems to be the method which is most appropriate for Bolletje since they can split root causes in categories and sub-causes.

Finally, we found different methods for the improvement of changeovers within the framework of the last sub question. The Single Minute Exchange of Dies method can be helpful at Bolletje to identify the changeover times per activity and find out where time reduction is possible.

4. Improvement of Changeover Process

This chapter revolves around the improvement of the changeover process. The Operational Department believes that reducing the losses due to changeovers will increase the productive value-added time for the production and increase the stability of the production output. First, in Section 4.1, we conduct a Single Minute Exchange of Dies analysis in order to analyze the changeover activities and see if we can reduce the changeover time. Section 4.2 includes a Root Cause Analysis and Section 4.3 describes solution ideas for the root causes found. Then, Section 4.4 comprises the results and gives recommendations for this part of the research. Finally, Section 4.5 concludes the findings from this chapter.

- Section 4.1
  - Single Minute Exchange of Dies
- Section 4.2
  - Root Cause Analysis
- Section 4.3
  - Potential Solutions
- Section 4.4
  - Results
- Section 4.5
  - Conclusion

4.1 Single Minute Exchange of Dies at Bolletje

The goal of SMED is to reduce the changeover time to under a minute. However, depending on the process, changeovers within minutes may not be possible. Nonetheless, if organizations follow the SMED principle they can obtain drastic reductions in changeover time (Dillon & Shingo, 1985). For Bolletje, as for most production companies, a changeover within minutes will be difficult to achieve since most changeover activities still need to be conducted as soon as production stops. However, since Bolletje has a continuous production flow where products need to be thrown away as soon as the line stops for more than a few minutes, changeover times should be as short as possible. Furthermore, changeovers influence the inventory position. If changeovers are long and costly, there is a tendency of having a long batch production or in contrast having a lot of production losses. To continue ensuring a 98.5% service level to their customers, companies need to hold a higher inventory than when ensuring a lower service level (King, 2009). By applying the principle of SMED we try to reduce the changeover time as much as possible.

The reasons behind using SMED to evaluate and analyze the changeover process are the long and costly changeovers at Bolletje. We can apply SMED if the process satisfies the following conditions (Lean Production, n.d.):

- The changeover times are long enough to have significant room for improvement, but not too long as to be overwhelming in scope. A changeover time of one hour presents a good balance.
- There is a large variation in changeover times. They may approximately range from one to three hours.
- There are multiple opportunities to perform the changeover each week in order to test proposed improvements quickly.
- The employees are familiar with the equipment and motivated.
- The equipment is a constraint or bottleneck and will thus bring immediate improvements.

Bolletje suffices on the characteristics mentioned above. Their changeover times are on average approximately one and a half hours with large variations and multiple changeovers per week, as Section **Error! Reference source not found.** described. Furthermore, the processes are familiar to the operators and form a constraint on the production output.

To conduct a SMED analysis we follow five steps. Figure 4.1 shows those steps. Step I involves the process analysis. Here, we list all the changeover steps and measure the time needed for each step. In Step II, we separate the internal and external activities. In the case of Bolletje we defined internal activities as activities that can only be performed when production is shut down and external activities as activities that can be conducted in advance or during production. To reduce the loss in valuable production time it is important to reduce the internal changeover time as much as possible. Therefore, operators should collect tools, equipment, and materials while the machine is still active. They should prepare the changeover before it begins. In Step III we then look how we can (partly) convert the internal activities into external activities. Next, we have a look at how we can optimize the activities. This means looking at the different activities and identifying room for improvement. In the end, we standardize the entire process and develop a manual that clarifies and describes the standardization of the process. Since the long changeover bears the most problems, we carry out this research for this type of changeover. This type includes all steps of the other changeover types and we can derive the reduction for them from this analysis.

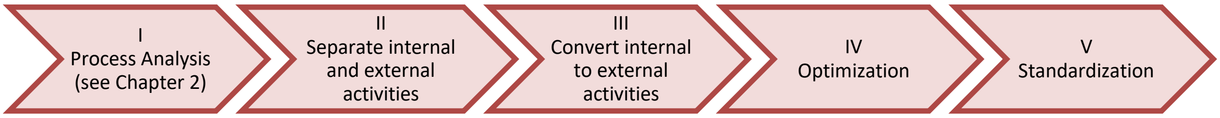


Figure 4.1 - Five Steps of SMED at Bolletje

Step I: Process Analysis

This step deals with an overview of the changeovers. We have already conducted parts of this step in Chapter 2, where we analyzed the changeover process and its steps. However, we have not yet executed the time registration per changeover activity in this chapter. **Error! Reference source not found.** in the confidential appendix shows the different changeover activities and the changeover time per activity. Each activity has a reference number, indicated in the white fields. The light red fields show the time needed for the corresponding changeover activities. The times were measured a couple of times during the changeover and their correctness was discussed with the operators afterwards. For clarity reasons, we use integer numbers. Furthermore, for simplicity, we do not yet take into account if activities happen simultaneously. There are activities that only take a few minutes, but there are also activities that require much time. In total, operators need 142 minutes to perform a changeover.

Step II: Separate Internal and External Activities

The next step is separating internal and external activities. Figure 4.2 shows this second step. The light red fields indicate the time needed for internal changeover activities and the dark red fields indicate the time needed for external changeover activities. To show at which moment operators carry out external activities we place them below the production during which they are executed. Operators working in the dough-room can perform their changeover activities externally before the changeover. However, the operators from the packaging section need to execute their activities while the production is shut down. There are always three operators that conduct changeovers: one operator from the dough-room and two operators from the packaging section. The operators divide the internal changeover tasks and thus two activities can be performed at the same time. In the figure we show this by placing the activities underneath one another. The longest time path determines the total time necessary for the entire changeover. This step paints a realistic picture of how the operators currently conduct changeovers at Bolletje. Regarding this step, we conclude that Bolletje needs to shut down the production for 60 minutes to execute the changeover.

Step II	Product A					1	7	8	9	10	11	12	14	Product B	
	2	3	4	5	6	13								15	
Internal						20	3	10	3	2	2	2	3		45 min
						60									60 min
External	10	5	5	2	10									5	37 min

Figure 4.2 - SMED Bolletje Step II: Separate Internal and External Activities

Step III: Convert internal to external activities

While we described how the operators execute the changeover process in the last step, this step makes assumptions and describes opportunities for converting activities from internal to external. Figure 4.3 shows the results of this step. The key is recognizing that some tasks, normally conducted during changeovers, can be done before the production is stopped or as soon as the process is running successfully. Since activity 13, the adjustment of the HE packaging machine, has the longest registered changeover time, this activity promises the most opportunities for improvement. Therefore, the main idea of this step is to convert activity 13 from towards an external activity[1]. As a result of converting activity 13 to an external activity, we can also convert (the following) activity 14. Because of the extra time we create, the operators will have enough time to conduct this activity before activity 13 is successfully changed over. Since the production run of product A needs to be successfully completed before conducting activity 13, we need to conduct it during the production run of product B. By realizing those changes, we can conduct the other activities with two employees simultaneously. In this case, the production line only needs to be stopped for 32 minutes. We conclude, that we can accomplish an improvement in changeover time of 28 minutes.

Step III	Product A					1	7	9	10	11	12	Product B			
	2	3	4	5	6		8					13	14	15	
Internal						20	3	3	2	2	2				32 min
							10								30 min
External	10	5	5	2	10							60	3	5	100 min

Figure 4.3 – SMED Bolletje Step III: Convert Internal and External Activities

[1] Section 4.3 describes how this activity can be converted.

We will describe the next two steps in Section 4.4 since we determine some optimizations during the root cause analysis. We will evaluate the time reduction these activities can achieve in Step IV of the SMED analysis and discuss an implementation plan in Step V.

4.2 Root Cause Analysis

Identifying potential causes for why the changeover process exceeds the changeover time is one of the objectives of this research. The potential causes, which we identify in this section, are ideas of stakeholders and do not necessarily all need to be relevant for this thesis. The operators, Production Supervisors and employees of Bolletje are the most relevant stakeholders involved in this step of the research. With their input we will create an Ishikawa diagram with which we identify potential factors causing the overall loss in production time caused by changeovers.

We use the Ishikawa diagram as a helping tool to identify, visualize and signify the root causes. Figure 4.4 shows the Ishikawa diagram. It represents the potential causes and their effects. We will identify the main problem at Bolletje as 'changeover process exceeds maximum changeover times'. Since some of the root causes have the same overall theme, we merge them into one group. The colors in the Ishikawa diagram represent those groups. We split the Ishikawa Diagram in Figure 4.4 in six categories that are based on the research of Kern (2008). The groups are:

- *Machinery* - Machines that need to be adjusted during the changeovers;
- *Material* - Material and tools used during the changeovers;
- *Manpower* - Operators (their behaviors, attitudes, as well as work style) involved in the changeover;
- *Methods* - Methodology used during the changeover process;
- *Measurements* Measurements or data gathered during the changeovers;
- *Management* - Coordination and management of the changeover process.

4.2.1 Potential Causes

Before solving a problem, it is important to understand the nature of the problem itself and to define a problem statement for each one separately (Annamalai, Kamaruddin, Abdul Azid, & Yeoh, 2013). We merge similar root causes into one group with one problem statement and solution approach. Table 4.1 enumerates all problem statements of the potential causes at Bolletje. The colors indicate the groups.

Table 4.1 - Potential Cause Subjects

#	Name	Problem Statement
1	Adjustment of packaging machine	Too much time is invested in the adjustment and fine-tuning of the packaging machine.
2	Handles of packaging machine	The handles of the packaging machine are fastened too tightly.
3 5 11	Regulation of oven settings Employees' lack of motivation Lack of skilled workforce	The tasks and responsibilities of operators are not clear.
4	Changeover material	Too much time is invested in searching and allocating changeover material.
6 8	Manuals Changeover matrices	The manuals and changeover matrices are not up-to-date and no review system is implemented.
7	External changeover activity	Internal changeovers cause long changeover times.
9	OEE measurements	OEE measurements are not reliable.
10	Changeover to wrong product	Production teams incorrectly conduct the changeover for the next team.

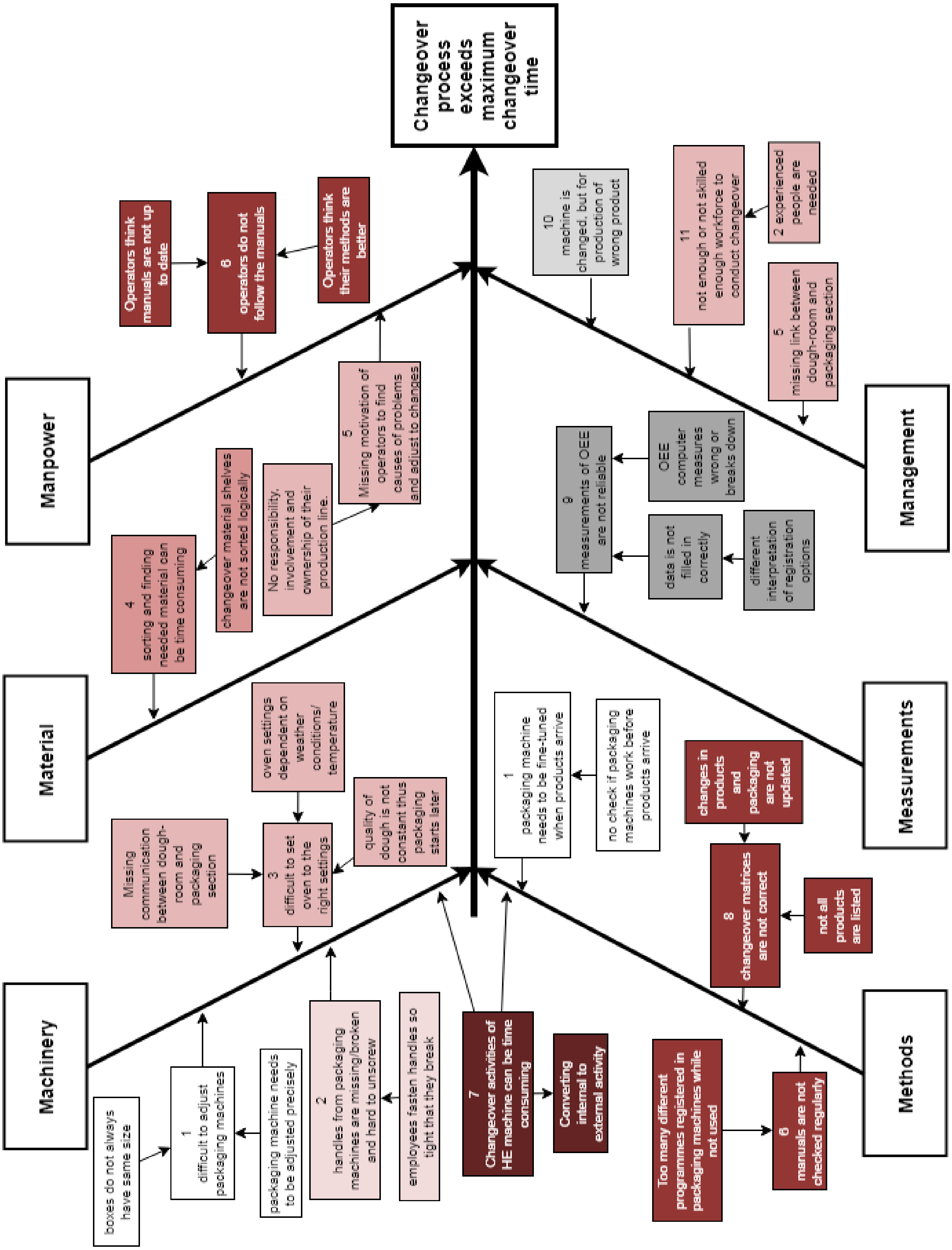


Figure 4.4 – Ishikawa Diagram – Root Cause Analysis Changeovers

1 – Adjustment of Packaging Machine

Each knäckebröd production line has two packaging machines. Bolletje uses the first machine to package the flowpacks into CE boxes and they use the second to compile those CE boxes into HE boxes. Figure 4.5 shows the operation of a packaging machine. The machine's main task is to open the boxes, push the products inside and seal the box with glue.

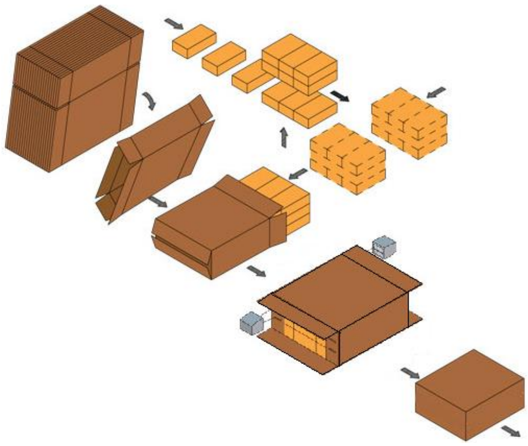


Figure 4.5 - Operation Packaging Machine

The most time-consuming activities during the changeovers is the adjustment of the packaging machines. The adjustments on those machines imply an adjustment of the different box configurations. Different manuals indicate the values to which the different parts of the machine need to be adjusted to. Operators need to carry those adjustments out precisely, otherwise the boxes will not be opened correctly. Furthermore, HE or CE boxes do not always have constant quality. This means that sometimes the boxes are slightly bigger or smaller. The consequence is an adjustment of the machine. Especially after having changed from one product to another, operators often stop the machines for what they call 'fine-tuning'. The time for fine-tuning is also classified as changeover time.

2 – Handles of Packaging Machine

Within the packaging machines there are handles to adjust the different parts of the machine. Some of the handles, especially of the Focke (HE packaging machine of line R156), are missing or broken. The handles of the other packaging machine also show signs of improper usage. Employees use force or aids to loosen the handles. This damages or breaks the handles. The main reason for improper usage is the difference in body strength of the involved employees.

3 – Regulation of Oven Settings

The problem concerning the settings of the oven is twofold. On the one side, setting the oven to the right temperature is a challenge since the oven is not built for the kind of work it does. When Bolletje designed the production line, they decided on a wrong type of oven and this now has a negative impact on the process. On the other side, we noticed that the responsibility for the oven is shifting between the operators of the dough-room and packaging section. The oven of line R156 is approximately 50 meters long. In this oven the knäckebröd first needs to bake at hot temperatures. After 25 meters, the temperature decreases almost exponentially to reduce the chance of burning the knäckebröd. Every product has its own settings since the ingredients and the thickness of the dough influence the baking process. This makes the oven a complex machine. While it is said to be one machine, there are several burners within the oven that operators can adjust separately. The problem of setting those burners to the right temperature has already been known for quite some time. Although there are thermal sensors that operate the burners, operators often need to adjust the temperature manually. There are a range of factors that influence the oven temperature. An example is the outside temperature. In the summer, it is warmer in the factory and thus the burners need to be colder than in the winter. As a cause of this research, this problem has resurfaced and a project team including the Plant Manager and process operator research the opportunities of maintaining this oven or investing in a new one. The settings of the oven itself are not part of this research. On the other side, the communication between the operators and the responsibility for the oven settings is a problem that we want to solve. Due to miscommunication operators sometimes forget to adjust the oven settings. Right now, the responsibility for the oven setting lies between the operators of the dough-room and the packaging section.

4 – Changeover Material

During changeovers, depending on the HE box, operators need to adjust parts of the Focke packaging machine. Based on the configuration of the CE box, they exchange different parts in the machine. An example of the configuration is 2x4, meaning that the packaging machine packages 4 CE boxes next to each other, that each have 1 CE box on top, into one HE box. The parts that the operators need to exchange have positions within the machine. The positions again have numbers in order to match the interchangeable part to the position where it belongs. Table 4.2 shows the three different configurations and the parts that operators need to use for each type of box. The operators need to take the parts out of the machine and insert the new parts. After that, they need to adjust the exact position of the parts within the machine. During a meeting with the operators, they indicated that finding the right part takes a lot of time. The parts are all arranged on a two-sided movable rack. On the rack it is not clear which parts need to be used during which box configuration.

Table 4.2 - Changeover Parts for the Configurations

		Configuration		
		2x4	**2x6**	**3x8**
Positions in the machine	**2.1**	530	531	549
	2.2	138	139	138
	2.3	52	52	53
	2.4	47	47	48
	2.19	-	-	40
	3.1	90	15	102
	3.2	90	15	102
	3.3	171	171	173
	3.4	171	171	173
	3.5	-	49	16
	4.31	129	128	130
	4.32	15	15	17
	5.2	920	915	918
	9.5	9	100	-
	9.6	9	101	130

5 – Employees' Lack of Motivation

The operators at Bolletje are responsible for performing and maintaining the daily activities associated with a production line, thus operating various manual and automated equipment in the production process. It is noticeable that the operators do their jobs well at Bolletje. However, they are not motivated to find causes to the problems at hand. Furthermore, they have difficulties to adjust to changing situations if they do not yet see its usefulness. The manager thinks that the lack of structure and routine in their work process is the underlying reason. Right now the operators often work for both knäckebröd lines interchangeably. Figure 4.6 shows the current work structure of the employees. In the current structure, employees are designated to a production section with designated tasks according to their rank (C being the best). However, the operators do not have one designated production line. This way the operators do not form clear teams since they might be working with different employees each week. The reason behind this is that two different types of shifts are used in the production section ‘Hal 16’. There are two three-shift teams as well as one five-shift team. Everyone works eight-hour shifts. While the three-shift teams rotate each week between early, late, and night shifts, the five-shift team works according to a 60% work and 40% free time rhythm and is not necessarily on the weekend off. Within this rhythm they change between early, late, and night shifts approximately every two days. We conclude that operators do not have a feeling of responsibility, involvement, and ownership of their production line.

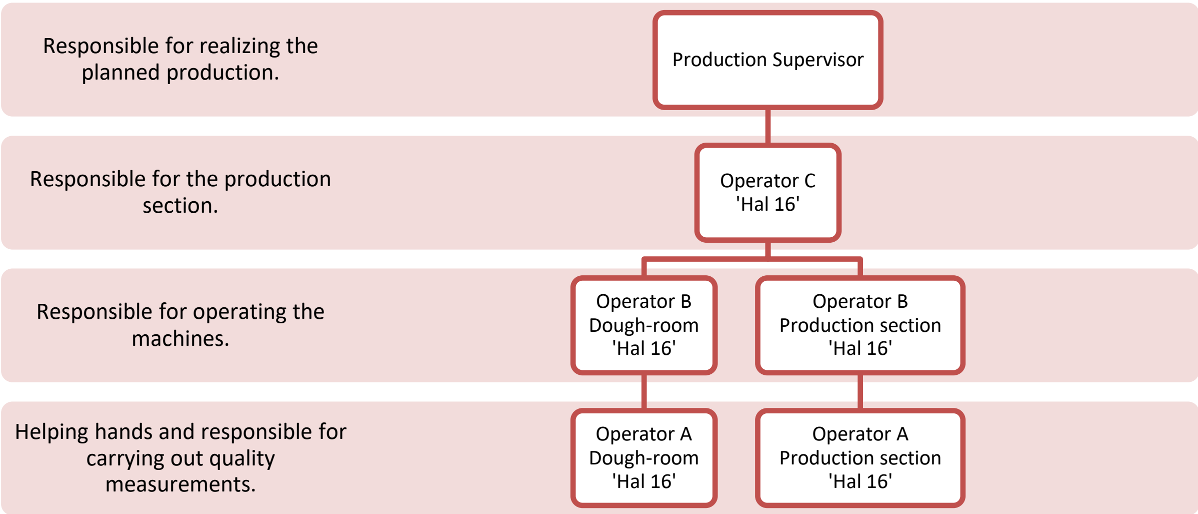


Figure 4.6 – Current Work Structure Knäckebröd Production Lines

6 – Manuals

Changeovers are complex processes since operators need to adjust various machines differently depending on the box configurations. In order to let this process run smoothly Bolletje employees use manuals that include all important information. There are two problems with the manuals. On the one hand, the manuals are not up-to-date and not checked regularly. On the other hand, the operators do not follow the manuals, since they do not believe the information listed is correct. To make the operators follow the manuals, the manuals would need to be checked more frequently. This problem particularly occurs at the packaging machines.

7 –External Changeover Activities

In Step III of the SMED analysis, we detected that converting internal changeover activities towards external activities has a significant impact on the changeover time. The HE (Focke) packaging machine of line R156 has the biggest effect on the changeover time and we will therefore analyze the options for improvement in this production section.

The changeover activities for the HE packaging machine take 60 minutes for each long changeover. there are approximately one to two long changeovers weekly. Operators conduct most of the other activities in a fraction of this time. Right now this activity is an internal changeover activity, meaning the production needs to be shut down during the adjustments. Adapting this activity from internal to external can reduce the changeover time significantly and realize a reduction in production loss.

8 - Changeover Matrices

The changeover matrices give an indication of the time in which operators need to execute the changeovers. Both sides of the matrix list the products that the specific production line can produce. The matrix is symmetric, meaning that changing from product A to B takes as long as from B to A. **Error! Reference source not found.** shows an example of a changeover matrix.

There are two problems that operators face with those matrices. Primarily, the problem is that the matrices do not list all products that can be produced on a specific production line. An example are the products of PL6 in **Error! Reference source not found.**. These products need a different format of the HE box than all other products listed in the matrix. This means that operators need to conduct a long changeover. To keep the long changeovers to a minimum, the planners decided to always produce the two products in a row. Although there is time needed to switch between the dough of the Sesam and Volkoren knäckebröd, the matrix only lists the category PL6. This gives the planners and operators a wrong indication of the changeover time. Another problem is that the matrices are not always up-to-date. Recently, the private labels decided to change the dough and layout of their products. The products now have the same recipe and box format. These changes affect the changeover times. The consequences of these changes are a decrease in the changeover time in between products which need to be indicated in the changeover matrices.

9 – OEE Measurements

The accurate estimation of the equipment utilization is very important since the identification and analysis of hidden time losses are initiated from those estimates (Jeong & Phillips, 2001). At Bolletje, we detected an unreliability of those measurements. During a meeting with the Bolletje employees, the problem of inconsistent and lacking data surfaced. In the data we especially see inconsistency resulting from the different interpretations of the failure options from employees. An example is the registration of data about the failure of the saw machine. The saw can stop working due to several reasons. It can stop because of a technical failure or it can stop because of the quality of the knäckebröd. Operators do not fill in the difference between the two consistently. Right now, Bolletje has divided the options into the categories 'production', 'minor stoppage'[2], 'speed loss', 'downtime', and 'no production planned'. These categories do not clearly indicate the problem and operators need time to find the failure cause within the options on the screen. Moreover, there is not always a clear distinction between the options. Depending on the operators, the same stoppages might have been booked on a product deviation or a machine. Furthermore, the computers on which the OEE program runs often crashes or freezes. The freezing of the computer has the consequence that it continues counting the time of the last chosen activity: if the production line stopped because of a technical problem with the saw and the computer freezes during the failure, it does not start counting the production time as soon as the machine is operational again.

Another problem is the variety of options for the cause of a breakdown between which the operators can choose. The OEE indicates the actual losses from machines related to the production time. As Jeong and Phillips (2001) say, it is apparent that the successful computation of OEE depends on the ability to collect data, since unreliable data does not reflect the real equipment utilization. Bolletje's OEE measurement has different options to register failures. In the past, options were added frequently, meaning that there are now too many options making the OEE confusing.

[2] Minor stoppage = minor interruptions that take less than 45 seconds

However, it is important that the utilization estimates are reliable. Based on those, Bolletje can identify the causes of the time losses and attempt to reduce them. According to Jeong and Phillips (2001), the success of the OEE depends on the quality of data collection. For the changeovers we can conclude by saying that if we are interested in monitoring the actual changeover time continuously, the data collection must improve. Only by observing the time in which the machine is being changed over, we can monitor the progress. Thus it is important that the employees fill in the data correctly.

10 –Changeover to Wrong Product

To reduce the production time loss, it always needs to be clear which product should be produced next. Employees at Bolletje sometimes execute the changeover for another team. When this is done, it has occurred in the past that the team changed the machines for the wrong product or they only conducted half of the changeover. The consequence of this is that the new team does not know if the changeover was conducted cautiously and in order to be sure that everything is correct, the machines need to be checked again. This process delays the production of the next product.

11 – Lack of Skilled Workforce

In complex processes skilled and experienced workforce is important for the efficiency. Bolletje has a lack of skilled workforce and often operators are still in training. To conduct a changeover within the default changeover time, at least two experienced operators need to be present. In the last year, it has gotten more difficult to find machine operators for the production industry. This job is listed at place three for the top 10 vacancies that are difficult to fill (Beentjes, 2016). This makes it difficult to fill the job at Bolletje with a skilled workforce. Furthermore, it is a big problem that the skilled workforce is not always working on days with difficult changeovers.

4.3 Potential Solutions

After investigating all the potential causes, we consider actions for improvement. Table 4.3 gives a description of the actions and a categorization of their importance. We established the importance ranking together with the Plant Manager and Production Supervisor. For the ranking we considered the positive impact for the changeover and the difficulty of implementation. Furthermore, we added a column that indicates whether we will implement the improvement action within the scope of this research.

Table 4.3 - Potential Causes, Improvement Actions, and Importance Categorization

#	Name	Improvement Actions	Ranking	Scope
1	Adjustment of packaging machine	There is a need for the packaging machines to be adjusted more quickly and precisely.	Low	Partly propose and partly implement improvement actions
2	Handles of packaging machine	The handles of the packaging machines need to be loosened and fastened more easily.	High	Propose implementation actions
3 5 11	Regulation of oven settings Employees' lack of motivation Lack of skilled workforce	The tasks and responsibilities of operators need to be established more clearly. Furthermore, a step to more skilled and motivated employees needs to be taken.	Medium	Partly propose and partly implement improvement actions
4	Changeover material	Changeover materials need to be accessible and quickly found.	High	Implement improvements
6 8	Manuals Changeover matrices	Manuals and changeover matrices need to be up-to-date and regularly checked.	High	Implement improvements
7	External changeover activity	An action plan for converting the internal changeover steps to external ones.	Medium	Propose implementation actions
9	OEE measurements	Improve the structure for the data registration in the OEE toolkit.	Medium	Implement improvements
10	Changeover to wrong product	Better agreements on planning and executing changeovers.	High	Propose implementation actions

1 – Adjustment of Packaging Machine

For significant improvement of this potential cause, we advise a full automation of the packaging machine. This automation would include that the machine can adjust itself to the kind of boxes that Bolletje uses. Such technology is still in development and entails great investment and risk. Right now, this is not part of Bolletje's vision and therefore we searched for a solution with lesser costs and noteworthy impact.

To reduce the time needed for fine-tuning after a changeover, we advise Bolletje to check if the packaging machine works before the products arrive. The process of testing a machine addresses the problem of finding the bottleneck in a procedure. During the changeover procedure, testing can help to find problems with the machines or settings before the products arrive and it thus improves the effective production time. On the other hand, testing might increase the changeover time. However, the management team at Bolletje would rather have a good changeover with hardly any fine-tuning, than a fast changeover with fine-tuning.

Methods to implement testing in the changeover procedure are either the usage of dummies[3] or the usage of knäckebröd flowpacks from earlier production runs. With both we can test the readiness of the machine for operation. Table 4.4 describes the advantages and disadvantages of both methods.

[3] Mockup products from plastic or another material.

Table 4.4 - Advantages and Disadvantages for Options Packaging Machine Test

Option	Advantage	Disadvantage
I: Dummies *Mockup products from plastic or another material.*	Dummies can be made specifically per product since different products have different heights and weights and thus test the machine optimally for each box configuration.	Dummies ideally do not break easily, however, this means that the machine could break down or get damaged as a result of using them. If dummies do break easily, they would need to be renewed frequently. There are costs involved in the creation of each dummy.
II: Flowpacks *Products of earlier production runs.*	If the settings are not correct and the Knäckebröd breaks within the machine, no damage is done. The costs of the flowpacks can be neglected.	Using flowpacks from the earlier production run means that those products are missing output that also could have been packaged and sold. Furthermore, for convenience reasons, the flowpacks of the production run before would be used that might have distinctive characteristics.

After a discussion with the Operational Department they choose to follow our advice and implement option II. The reason for using this option is that the costs are lower, and it is easier to realize. For the production process this means that before a changeover, flowpacks should be kept apart during the previous production run. Therefore, operators gather flowpacks for the test in crates. Since those products do not contain the knäckebröd indicated on the CE boxes, it is important that the products will be gathered after the tests and are not palletized and given to the customer. To simplify this process, the conveyor belt that moves the products to the palletizer could be temporarily stopped. However, since those boxes would have a different product and batch number it would not be a problem to retrace the products at any moment in time.

2 – Handles of Packaging Machine

Concerning the handles of the packaging machine, we contacted the company who built the machines. This problem was not yet known to them. Together with them, we developed two ideas for improvement options. Table 4.5 shows the advantages and disadvantages for both options. Option I involves the use of a leverage to loosen the handles. Option II concerns the usage of a torque wrench as handle.

Table 4.5 - Advantages and Disadvantages for Options Handles Packaging Machines

Option	Advantage	Disadvantage
I: leverage to unscrew 	The leverage could be attached to the handle if needed. The Technical Department can create one themselves and the costs can then be neglected. During the implementation of this option, no downtime is needed.	It would be possible for operators to use the leverage to tighten the handles even more. This leaves the problem unsolved.
II: torque wrench as handle 	Every operator can tighten and unscrew the handles with the same power.	Onetime costs of approximately 200 euros for each torque handle need to be considered. Additionally, all bolts need to be switched out (extra costs). Moreover, planned downtime is needed for the implementation.

We advised Bolletje to implement option II. However, after consideration they decided to implement option I for the near future since this option promises a quick fix situation at low costs. For the disadvantages of this option to be minimal, a sticker needs to be attached to the leverage stating clearly that it is only to be used to unscrew the handles. The Production Supervisor should monitor the process to ensure that everyone uses the leverage correctly. For the future, the Operational Department follows our advice and wants to invest in the implementation of Option II. Eventually, this option promises a more assuring solution since it fits better to the values of the organization, the work procedures and the machine. For this, we summarized the costs and benefits in an investment proposal. Appendix B shows the investment proposal we designed.

3 – Regulation of Oven Settings, 5 – Employees' Lack of Motivation, 11 – Skilled Workforce

A combined solution for the three potential causes is having a link between the dough-room and the packaging section to control and regulate the oven settings. Therefore, we propose a new work structure.

While right now the operators work interchangeably on both lines, it is important that in the future operators have one designated line on which they work. The advantage of such a structure is that they have more specific knowledge about their line and hopefully get a feeling of responsibility towards it. However, this influences the workforce planning negatively since operators cannot be used interchangeably anymore. Since the operators work in either the 3- or 5-shift team, we conclude that we can disregard the effects of this disadvantage. Figure 4.7 shows the new work structure for the knäckebröd production lines. In this structure Operator C acts as link between dough-room and production section and should therefore be responsible for the oven settings. In his position operator C will receive input from both sides about the quality of the product. We furthermore choose this structure since the feeling of responsibility and structure gives operators new motivation. They can now be trained on one specific production line and they can improve their skills level more quickly. Moreover, Bolletje started to use Training within Industry (TWI). TWI is a well proven methodology that uses hands-on learning and practicing experiences to teach essential skills to supervisors, team leaders, and anyone who executes the work. This method is known to motivate operators and create an environment with skilled workforce (Huntzinger, 2006).

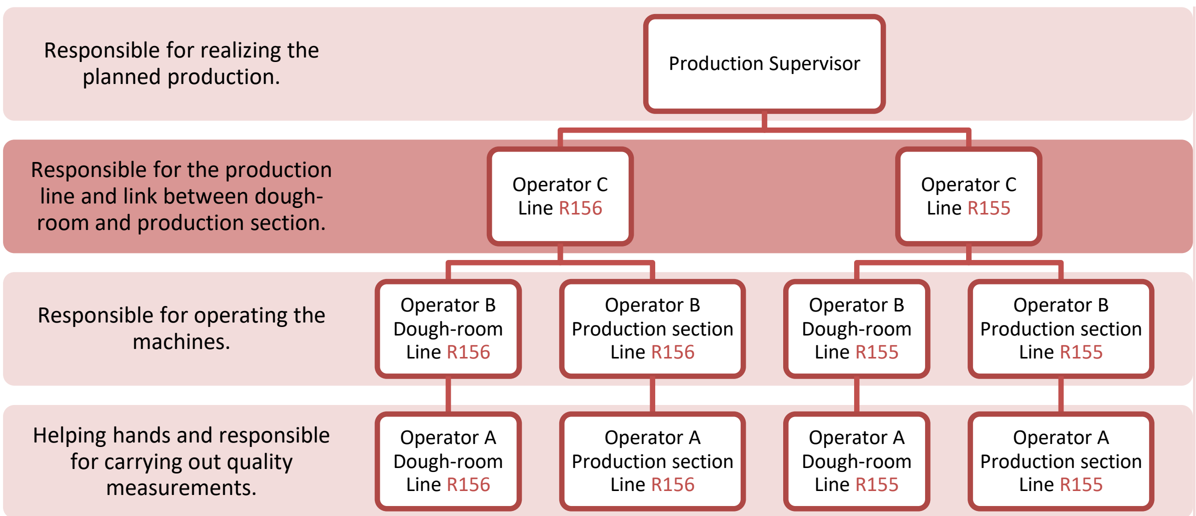


Figure 4.7 - Proposed Work Structure Knäckebröd Production Lines

4 – Changeover Material

For visibility and clearness, we carried out a restructuring of the material rack. Because of the improvement it is now clear which material belongs to which configuration. Figure 4.8 shows the rack before and after the improvements[4]. We conducted the improvement of the rack based on the configurations in Table 4.2. In the previous situation the parts were clustered on one side, which made the rack seem crowded and the structure unclear. Furthermore, the part list needed to be studied closely to find the needed part. In the new structure, we decided to cluster two configurations on one side. For clarity, we decided to have configuration '2x4' and '2x6' on the same side of the rack since the configurations share five parts. For visual clearness we attached different kinds of stickers. The stickers differ in color since the human brain can best identifying an objects identity by its color (Swain & Ballard, 1991). The different stickers and color are:

- Yellow stickers attached on the green blocks to indicate where which part should be placed.
- White stickers attached on the parts itself to indicate which part it is.
- Red(2x6), blue(3x8) and green(2x4) stickers attached in order to indicate to which configuration a part belongs.

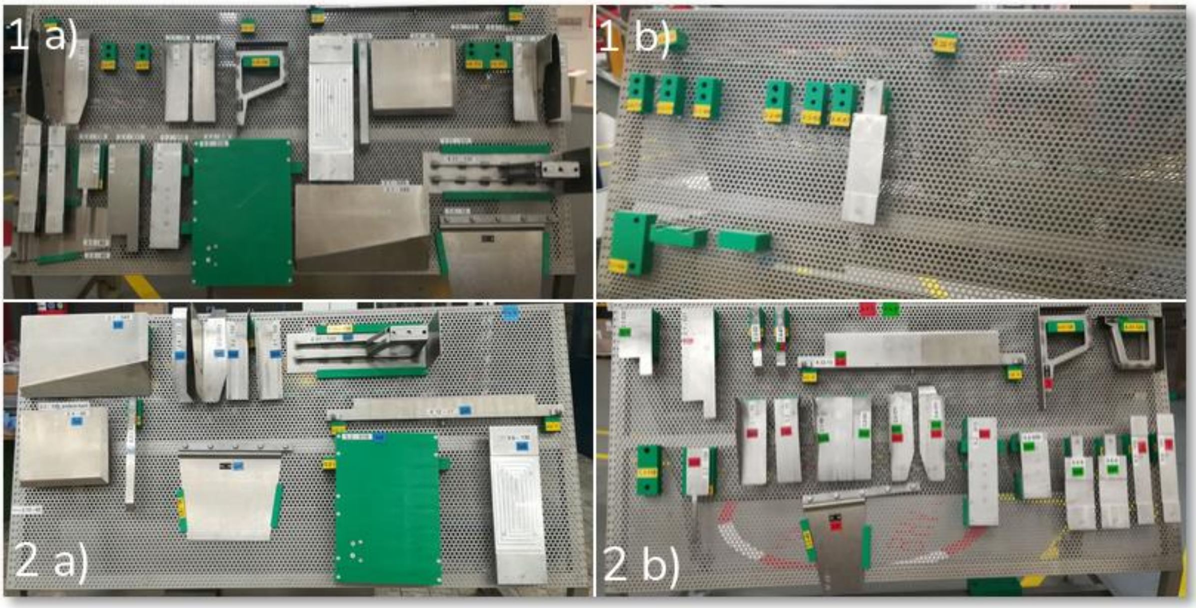


Figure 4.8 - Changeover Material Rack 1) Before and 2) After

6 – Manuals, 8 - Changeover Matrices

The best approach to ensure the correctness of information in the manuals and changeover matrices is to implement a method that checks the status frequently. To ensure this, we introduce a deviation form. Appendix C shows this form. Operators should use this form to record the deviations of the machines and products. On this form operators need to indicate:

- the code of the part or product;
- the number for the CE or HE configuration;
- the original value;
- the new value;
- the reason for deviation.

[4] In 1) not all parts are located on the rack since some parts were in the machine at the time of the picture.

Furthermore, we designed a checklist for the changeover supervision together with operator C. Appendix **Error! Reference source not found.** shows this list. Operator C should check if the operators executed all steps of the changeover and make a note if activities take longer than expected. The checklist should be handed in to the Production Supervisor after each medium or long changeover in order to monitor the changeovers and its time more closely.

We furthermore developed new changeover matrices. As soon as we implemented the different improvements, described in this section, the time needed for the different changeovers was measured and documented. The new matrices include the updated changeover time. Further it is important that those matrices are updated as soon as there are product or machine changes. To do so, Bolletje will use the deviation form in the future. Appendix **Error! Reference source not found.** shows the new changeover matrix for production line R156.

7 – External Changeover Activity

For the adaption of the Focke packaging machine we developed an improvement idea. The main aspect of this idea is a buffer to collect the CE packages before they enter the HE packaging machine while employees can conduct the changeover without any interruption. Hence, the buffer enables the operators to conduct the changeover of this machine during production. Figure 4.9 shows the layout of the packaging section. The red x indicates where we would want to place a buffer. The buffer could be a person or a robot that collects the CE boxes from the conveyor belt and puts them on a pallet. There is enough space for those activities between the packaging machines. After the machine is changed over, the boxes need to be put back on the conveyor belt so that they can continue their way through production.

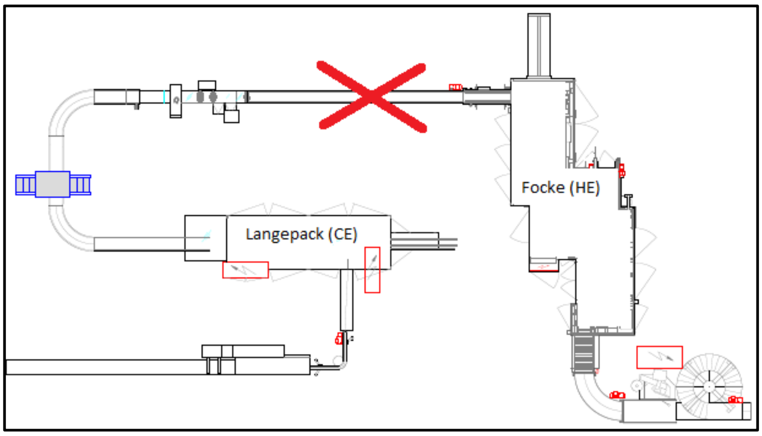


Figure 4.9 - Buffer Placement Line R156

Bolletje has a continuous production and HE boxes of different kinds are not allowed to be collected on the same pallet. Therefore, we need to calculate if the products from the buffer can be packaged before the end of the production run and without delaying the next production run. Figure 4.10 shows an example calculation for this. For confidentiality reasons, we do not use the real output of the system. For the calculation we need to know the capacity of the HE packaging machine as well as the number of CE boxes that arrive at the buffer. Furthermore, we need to make a distinction between the different configurations. With this data, we can give an indication of how long it takes before the products in the buffer can re-enter the production. When the products re-enter, we also need to consider that the machine is running, and normal production quantities are arriving at the machine at the same time as the boxes re-enter.

$\# \boldsymbol{HE} = Capacity\ of\ HE\ packaging\ machine\ per\ hour = 100$
$\# \boldsymbol{CE} = Amount\ of\ CE\ boxes\ that\ arrive\ hourly\ at\ the\ HE\ packaging\ machine = 500$

$\# \boldsymbol{CE\ in\ HE} =$ # of CE boxes in a HE box
$\# \boldsymbol{possible\ HE} = HE\ boxes\ that\ can\ actually\ be\ packaged\ per\ hour$
$\# \mathbf{h} =$ Number of hours needed to let the CE boxes re − enter the process

Configuration	# CE in HE	# possible HE	# h
	given	$\frac{\# \boldsymbol{CE}}{\# \boldsymbol{CE\ in\ HE}}$	$\frac{\# \boldsymbol{possible\ HE}}{(\# \boldsymbol{HE} - \# \boldsymbol{possible\ HE})}$
2x4	8	$\frac{500}{8} = 62.5\ HEs$	$\frac{62.5}{(100-62.5)} \approx 2\ hours$
2x6	12	$\frac{500}{12} = 41.67\ HEs$	$\frac{41.67}{(100-41.67)} \approx 1\ hours$
3x8	24	$\frac{500}{24} = 20.83\ HEs$	$\frac{20.83}{(100-20.83)} \approx 1\ hours$

Figure 4.10 - Example of HE Box Calculation

9 – OEE Measurements

We propose a new structure of the OEE options to make the OEE more systematic. The OEE options describe the cause for a stop of the production line. An example is that the CE packaging machine stops because the knäckebröd is too high and does not fit in the box. The OEE structure is subdivided into six main categories. Production is not counted as a category since this is the default option of the machine. Each category summarizes the theme of the options that belong to the category. Table 4.6 displays the categories and describes them.

Table 4.6 - OEE Categories Explained

Name	Description
Production *(automatically)*	
(1) Minor stoppage *(automatically)*	For stops less than 45 seconds.
(2) No production planned	For planned downtime.
(3) Malfunction of a machine	In case there is unplanned downtime due to a malfunction or failure of a machine. All machines of the production line are listed. The category is again split up into dough-room and packaging section.
(4) Product deviation	Chosen if products have a deviating quality (e.g. too dry). The product is then grinded.
(5) Changeover	In case a changeover takes place. This option also includes ‘fine-tuning after changeover’ and ‘setup’.
(6) Stoppage due to unforeseen circumstances	In case an unplanned stoppage occurs that is not due to machine failure (e.g. no packaging material).

Figure 4.11 shows the new structure for line R156. We first established a structure, then suggested it to the operators in order for them to adjust it. Finally, together with the operators we developed the structure below. During the meetings we furthermore emphasized that it is important to look for the cause of a failure. Next to the new categories, we agreed on two rules in order to ensure the correctness of the data:

1. If Plantapps (program to control the quality) is within the green area (the product meets the standards), nothing may be booked on product deviation. However, the machine that caused the stoppage needs to be selected for the interruption of the production.
2. Do not use 'fine-tuning after changeover' in case the machine has run without problems for approximately an hour.

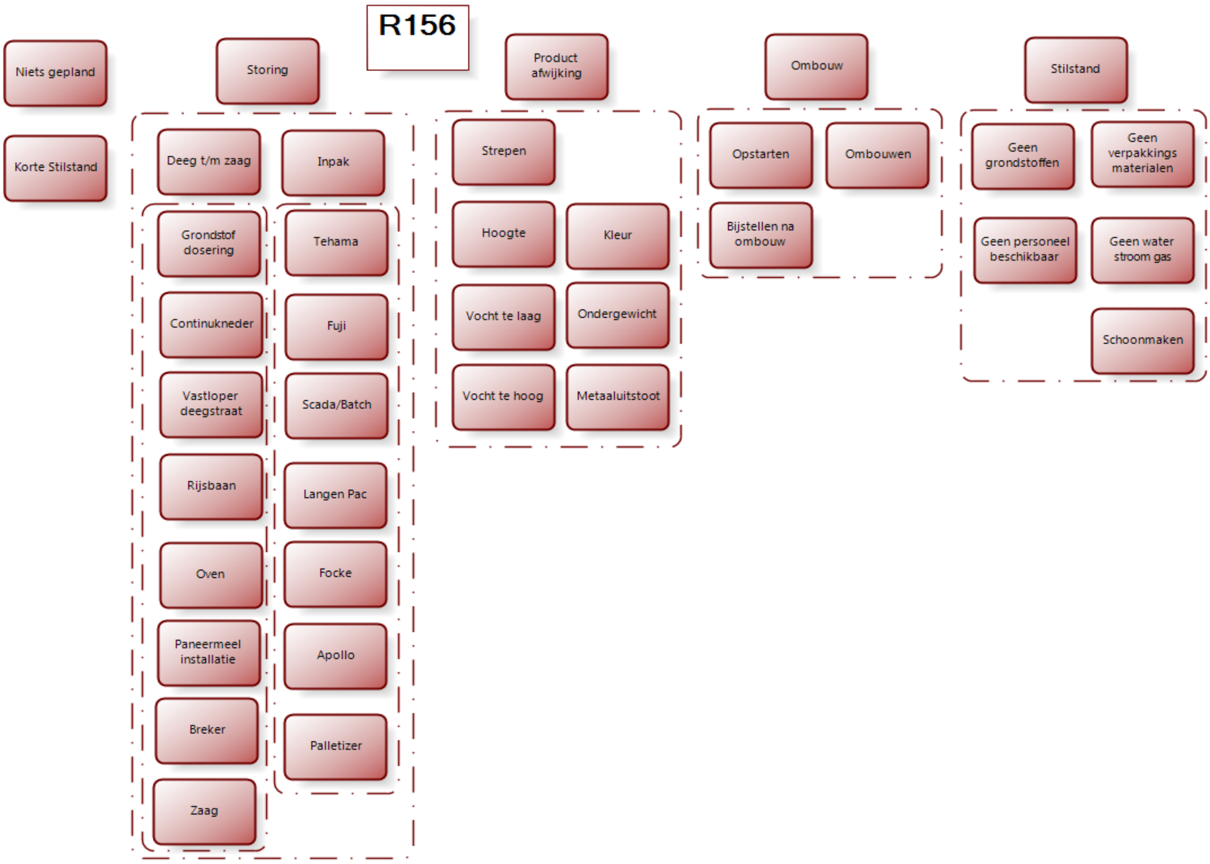


Figure 4.11 - Structure OEE Line R156

10 – Changeover to Wrong Product

Within the Operational Department, better agreements about the planning and conduction of the changeovers should be made. To establish this, we propose a couple of agreements:

1. To avoid confusion and miscommunications, changeovers should be conducted during a shift and not at the end of a shift. This way the next team can take over a running production line. For a running production order this means that if this scenario arises the Production Supervisor and production planners decide whether the production should stop and changeover before the shift switch or after. In either case the production order quantity can either be increased or decreased at the end of a shift.
2. Since long changeovers are more complex than other changeovers, they should be performed during the daytime shift. During the day, mechanics are available to help if a bigger problem arises and additional staff is available to help.

4.4 Results

After we have conducted the root cause analysis and have implemented some of the improvements, we continue with step IV and V of the SMED analysis.

Step IV: Optimization

We described several optimization activities such as the new handles of the Focke packaging machine and an improved work structure on the production lines, in the Section 4.3. By implementing them we reduce the changeover time and production losses caused by changeovers. We split the optimization into two scenarios. Scenario 1 describes the situation if the Operational Department places a buffer before the Focke packaging machine, while scenario 2 describes the situation as it is now. Figure 4.12 shows the analysis for both scenarios. The orange fields indicate that the changeover time of an activity decreased.

Scenario 1 (with buffer)

Step III	Product A					1	7	9	10	11	12	Product B			
	2	3	4	5	6		8					13	14	15	
Internal						↓15	3	3	2	2	2				27 min
							10								25 min
External	10	5	5	2	↓5							↓45	3	5	80 min

Scenario 2 (without buffer)

Step II	Product A					1	7	8	9	10	11	12	14	Product B	
	2	3	4	5	6	13								15	
Internal						↓15	3	10	3	2	2	2	3		40 min
						↓45									45 min
External	10	5	5	2	↓5									5	32 min

Figure 4.12 - SMED Bolletje Step IV: Optimization

The biggest optimizations are:

1. By optimizing the work structure of the operators, the operators communicate more and form a better team. Furthermore, operator C is now responsible for the oven settings. This change results in a decrease in changeover time for two activities. Activity 6 decreased from 10 to 5 minutes and activity 1 from 20 to 15 minutes.
2. Because of the reorganization of the material rack, operators need less time to find the needed parts. Furthermore, by optimizing the handles of the packaging machines operators can adjust the machine more easily. Therefore, the changeover time from activity 13 decreased from 60 to 45 minutes.

We conclude that with scenario 1 we can reduce the internal changeover time to 27 minutes. For scenario 2 we can reduce the changeover time to 45 minutes. For scenario 1 this means that the changeover time is reduced to half the time and for scenario 2 to 3/4th. We carried out the analysis for the long changeover, but the same time reduction also applies for the medium changeover. Because of the improvement of activity 6, the medium changeover will now take approximately 15 minutes instead of 20 minutes.

Step V: Standardization

For the standardization we designed a better changeover manual. This describes the changeover activities in more detail. Appendix **Error! Reference source not found.** shows this manual.

Furthermore, we advise Bolletje to visualize the changeover time in the factory. Often, operators do not know if they are on pace during a changeover. When Bolletje provides real-time plant floor indication for how long changeovers are taking compared to the default time, operators have an indication of their progress (Vorne, n.d.). Operator C needs to ensure that the employees do not get stressed when the changeover takes longer than the target time but encourage them to give their best effort. A longer changeover without fine-tuning is favored over a quick changeover with fine-tuning. It is also possible to break the changeover into elements with a visual timer for each step.

4.4.1 Recommendations

From the analysis we provide some recommendations for the Operational Department of Bolletje Almelo, to further improve the management and structure of the changeovers. Since there are many recommendations within this part, these are already discussed here and not only in Chapter 8. We include summary of the recommendations in Chapter 8.

- Implement a torque wrench handle for the packaging machine.
- Emphasize the importance of focusing on one production line towards the operators. Furthermore, let operator C fulfill the role as link between dough-room and production section. This change should be closely monitored and evaluated.
- Ensure that manuals and changeover matrices stay up-to-date. Indicate towards the operators that changes need to be documented in the deviation form. The Production Supervisor should be responsible for the updates.
- A project team should be established in order to look into the conversion of the internal process of the HE packaging machine towards an external process. Employees should create an investment proposal including a cost-benefits analysis. This investment proposal is outside the scope of this research.
- Clear agreements about the planning of products, changeovers and personnel should be made between the Production Department and the Logistic Department. The Production Supervisor should be the link between the two parties.

4.5 Conclusions

Within this chapter we solve the third research questions: "*What are the root causes for the inconsistencies and unexpected duration of changeovers and how can those be improved?*"

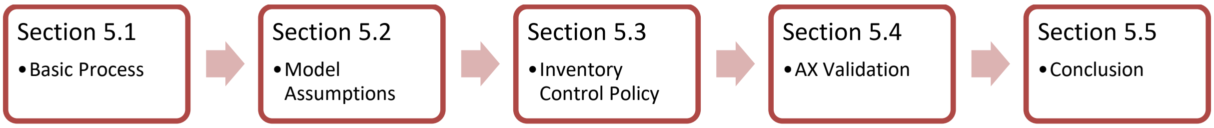
We conclude that there are multiple reasons for the inconsistencies and unexpected duration of changeovers. During the root cause analysis, we found eleven potential causes and improvement options for these. Examples of improvements are the reorganization of the material rack, the exchange of the handles and the reorganization of the work structure. The new structure of the OEE is also an important improvement. Now, the operators can indicate more precisely what the cause for interruptions is. For the eleven potential causes we partly implemented the improvement actions and we partly proposed improvement actions.

Furthermore, the SMED analysis shows that changeovers mainly cause production interruptions since operators need to carry out changeover tasks while the production run is stopped. Converting the longest internal activity to an external activity can increase the valuable production time.

The results we obtained are based on the improvement actions. In order to draw a conclusion, we split the improvement actions into two scenarios. Scenario 1 describes the situation if the Operational Department places a buffer before the Focke packaging machine, while scenario 2 describes the situation as it is now. We conclude, that we can improve the internal changeover time. During the baseline measurement we measured that the changeover time for the long changeover is 60 minutes. With scenario 1 we can reduce the internal changeover time to 27 minutes. For scenario 2 we can reduce the changeover time to 45 minutes. The time reduction also applies for the medium changeover. Medium changeovers will now take approximately 15 minutes instead of 20 minutes.

5. Solution Design - Planning within AX

This chapter starts by introducing Bolletje's basic planning process and the desired future situation in Section 5.1. Section 5.2 describes our assumptions for the inventory planning and control model. Next in Section 5.3, we look at the possibilities of implementing Bolletje's planning in their ERP system, Microsoft AX. In Section 5.4 we validate the model and compare the safety stock equations from the theory to the equations available in the ERP system. We finish this chapter with a conclusion in Section 5.5.



5.1 Basic Process

Figure 5.1 gives a short recap of the current planning process. Every Wednesday the planners check the inventory level of the finished products and adjust the MPS by means of the supply schedule from the products for the next 13 weeks. They adjust the MPS and plan production orders in such a way that there is enough inventory for one week of demand plus two weeks of safety stock. If there is not enough capacity to produce all products, they discuss with the manager which products will be pushed to the next week. Next, they create a proposal for coming week's DP. According to this proposal and the planned production orders, they order raw materials if needed. However, the inventory levels of raw materials are outside the scope of this research. On Wednesday, the Production Supervisor reviews the DP and afterwards the planners send the final version to the operators. 24 hours before the production starts, the planners release the production orders and monitor if enough raw materials are at the production location. If not, the warehouse workers bring the raw materials to the location and the production starts. After the production, the operators report the actual raw material usage and production output back to the planners to complete the production order.

In the improved, automated situation we want to establish that AX takes over many of the planners' tasks. The idea of this research is finding an inventory control policy for finished products that is implementable in AX. We furthermore determine the optimal values of the corresponding inventory policy in AX. The goal is to automate the replenishment of finished goods inventory by using the prosed policy and implementing it in AX. This means that in the future AX proposes a supply schedule for each product and proposes the moments when planners should place raw material purchase orders. These purchase orders are outside of the scope of this research and we only focus on the ability of AX to place such an order on time. Implementing the planning in AX means that the planners no longer need to do all the work themselves but are mainly responsible for monitoring the proposals, adjusting them if necessary, and finally approving them.

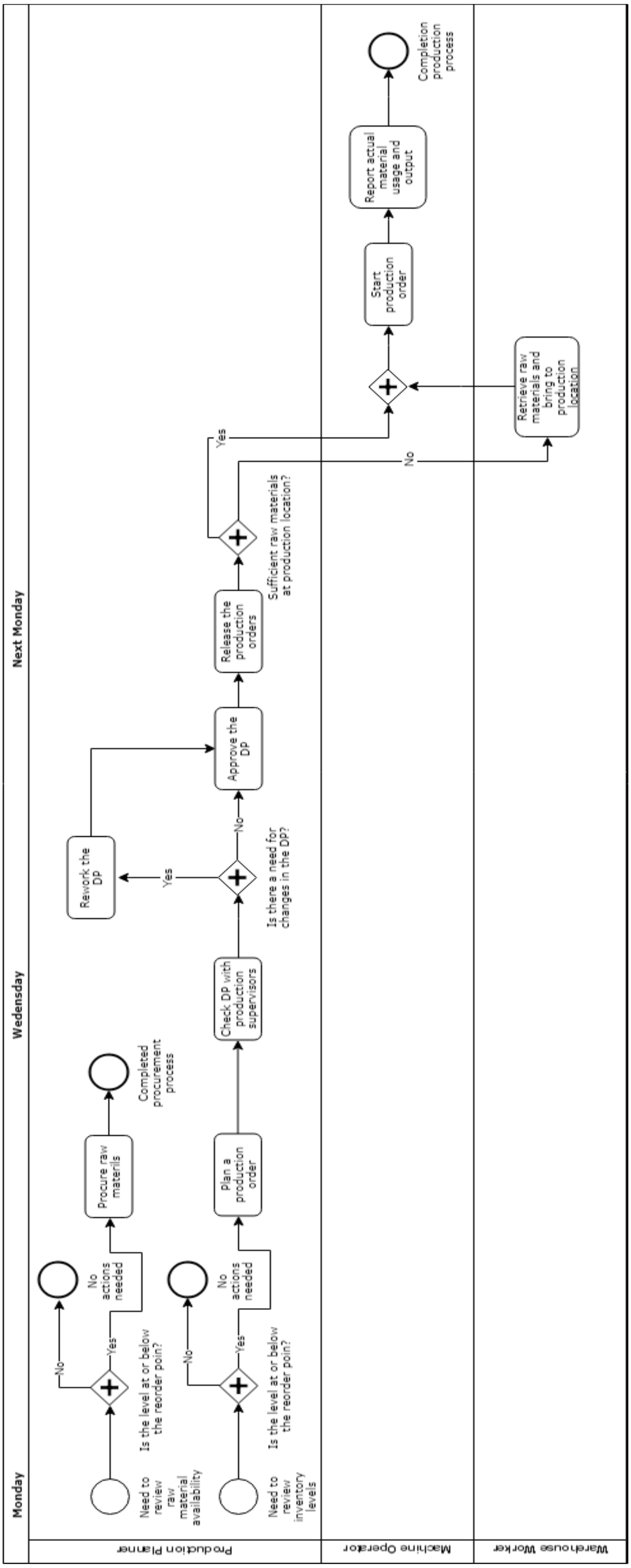


Figure 5.1 - Process Chart of Planning and Production

5.2 Model Assumptions

We start constructing our inventory model by setting the following model assumptions:

- *Single-item*: Each item is produced independently and after one another. They have changeover time and capacity relations. The products' demand distributions are assumed to be independent.
- *Length of a production run and Production Order Quantity*: Since the quality of the knäckebröd increases with longer production runs, Bolletje decided that the minimum production run length is 8 hours (one shift). Hence, the minimum production order quantity is at least the output of one shift.
- *Service Level Constraints*: We focus on achieving the service level of 98.5% (Bolletje's service-level) with a low on-hand inventory level. The service level measure is the fill rate.
- *Production Sequence*: Because of the oven temperatures and dough-making, the production sequence '*Goudbros* → *Sesam* → *Volkoren*' should be established (if possible).
- *Periodic Review Period*: Since Bolletje's current planning and production is based on a periodic review, we decide to work with such a model, too. Each Wednesday Bolletje's planners review the MPS and decide which products should be on the DP for the next week (Monday-Friday). Therefore, Bolletje has a review period of one week.
- *Production Capacity*: Production is conducted each week during the working days. Hence, the production capacity is 120 (24*5) hours.
- *Constant Lead Times*: The DP includes all production orders for the next week. Bolletje produces products between Mondays and Fridays. Immediately after the production, they are available to fulfil demand. During the MPS creation, the planners assume that the products planned in the current week are already in stock to fulfil the demand of the next week. All products, no matter on which day they are produced, have a constant lead time. We determine the lead time in Section 5.3.1.
- *Demand*: Weekly demand is seen as demand from Monday until Friday. On the weekend, no products are delivered to customers.
- *Setup*: In our model we do not account for setups and downtime due to maintenance.
- *Changeover Times*: Changeover times depend on the two products produced in a row.
- *Inventory Units*: Inventory units are expressed in HE boxes.
- *Working week*: For simplicity, we disregard the weekend and assume that a week has only working days, i.e. 5 days.

5.3 Inventory Control Policy

At Bolletje the planning activities require much time. Four Production Planners and one Demand Planner are responsible for forecasting, planning of the production and for purchasing raw materials. These activities are complex because of the high number of different SKUs. Moreover, mistakes have a great negative effect on the company. To minimize the mistakes made, Bolletje wants to automate this process and let their ERP system automatically generate production and procurement orders in their MTS environment. The aim is to integrate an efficient inventory control policy for finished products that spreads information across the enterprise and minimizes complex situations and expensive mistakes. An efficient inventory control policy is important since not having enough inventory means there is risk of losing sales and stockouts. Having too much inventory is costly on the other hand.

There is a close link between the inventory system and production system. While the inventory system plans the production orders, the production system produces and delivers them to the warehouse. In simple terms, inventory control involves having a better overview of the products and quantities produced. Within the production system, uncertainty is part of Bolletje's processes. Uncertainty arises because of increasing product (group) complexity, the complexity of the production lines, and an increasing emphasis on low costs and high efficiency. When starting to plan the production, an adequate model must incorporate these uncertainties into a realistic representation of the production process. Since Bolletje wants to become a more efficient business, it is important to understand how much inventory they have, where it is, and at what moments raw materials are going in, products are produced, and finished goods go out (Silver et al., 2016). Introducing the planning in AX gives Bolletje the possibility of having this understanding and a better overview.

Inventory Control Policy

Bolletje works with a production schedule of one week. Therefore, a periodic review policy seems most appropriate since it reviews the inventory in regular intervals. Based on the description in the literature, the (R,s,S) policy is a good fit for Bolletje. The literature describes the (R,s,S) policy as the best possibility especially if holding costs are low (Axsäter, 2015; Jansen et al., 1998; Silver et al., 2016). The idea behind the inventory control policies is to check the inventory position at previously determined review moments. Planners review the inventory and place corresponding production orders every Wednesday. Based on the current process, Bolletje should implement a review period of one week. Changing the review period is not possible because it would affect the current production planning and the production system too much. At the review moments on Wednesdays, the system determines whether it needs to place a new production order. It only places the production order if the inventory level is at or below the reorder point s. Depending on the option, the system determines the size of the production order. A major advantage of the periodic review is that the Operational Department can place production orders in the same interval as they currently do. Currently the actions are clustered at the review point and not spread continuously. However, a disadvantage of periodic systems is that companies (in general) need larger inventories since there needs to be enough inventory for the period between reviews as well as the lead time (ConnectUS, n.d.). We have two options to implement this policy in AX:

Option A: A (R,s,S) policy where the review period is pre-determined with a fixed reorder point (minimum) and an order-up-to level (maximum). When on-hand inventory is estimated to fall below the minimum, it generates a planned production order to get back to and maintain the maximum. The maximum and minimum can be chosen freely in AX, but do not change with fluctuating demand.

Option B: A (R,s,S) policy where the review period is pre-determined with a flexible reorder point and an order up to level. The reorder point is based on the demand and standard deviation during lead time and review period. The order-up-to level is the reorder point plus the minimum order quantity. The last is based on the economic order quantity. The parameters for the policy fluctuate with the demand.

The AX software can conduct the actions of the inventory control policy. With the master planning it determines the future need for raw materials and production quantities to meet customer demand.

This is equivalent to Bolletje's current MPS. According to the demand, inventory and capacity, AX determines the future production orders. Hence, AX is able to:

- run forecast scheduling to calculate production order quantities for forecasted demand;
- calculate the requirement quantities of raw materials;
- recalculate and adjust production order quantities to fulfill actual demand.

Each week on Wednesday, the planners should run the master planning for all products. Since the planners review the inventory position within the MPS for 13 weeks, we also set the master planning length to 13 weeks. AX then reviews the inventory levels and places or adjusts production orders according to the forecasted and, if available, actual demand. Accordingly, if the inventory position is at or below the reorder point the system places a production order to raise the inventory position. AX calls the reorder point the minimum inventory level, this is equivalent to the safety stock plus the demand during the review period. AX also considers fluctuations in demand. By increasing or decreasing the minimum inventory level AX deals with seasonal fluctuations or promotions. It is even possible to let the inventory gradually increase before the season. The supply schedule shows the demand, inventory position and production order quantities for a specific product. Figure 5.2 shows the supply schedule for a product from the end of week 34 until week 36. The inventory at the start of week 34 is 14726 units. In week 35 there is a demand of 4441 units. 4418 units are forecasted demand and 23 units are already ordered. The required minimum inventory is 6662 units. Furthermore, a planned production order is set to raise the inventory level with 5500 units in week 36 since the inventory position would otherwise fall to 5631 (9802-4441) units.

	Achterstallig	Week 34	Week 35	Week 36
Periode voorraad starten	10029	14726	14243	9802
[-] Vraag		7145	4441	4441
Prognose			4418	4441
Verkoop		483	23	
Minimumvoorraad		6662		
[-] Leveren				5500
[-] Productie				5500
Productieorders				
[+] Geplande batchorder				5500

Figure 5.2 - AX Supply Schedule

In case of option A, we can apply the order-up-to level as the maximum inventory level. Then, the system plans production orders to increase the inventory position up to this maximum level. However, AX is not able to adjust or calculate the maximum level. Planners would need to calculate and set the maximum manually.

In case of option B, the system creates a production order with a specific order quantity. However, since AX is not able to calculate the economic order quantity it instead bases the production order quantity on the capacity, the demand of the coming weeks and the minimum order quantity. To ensure that the production order quantities are large enough for the effort of switching to a product, we set the minimum order quantity to the output of one shift.

Figure 5.3 shows an example of the inventory behavior of the inventory control policies in AX. The blue arrows indicate the demand for the corresponding week. Option A produces enough inventory to fulfill the maximum inventory level. Every time the inventory position, inventory on hand minus the demand, is lower than the minimum inventory level, AX places an order to increase the inventory up to the maximum. Option B estimates the demand for the upcoming week and produces enough to fulfill the forecasted demand with the inventory on hand. This policy tries to avoid undershooting. Undershooting is the situation when the actual inventory level is below the minimum inventory level. However, since there is uncertainty in the demand, undershooting is not eliminated.

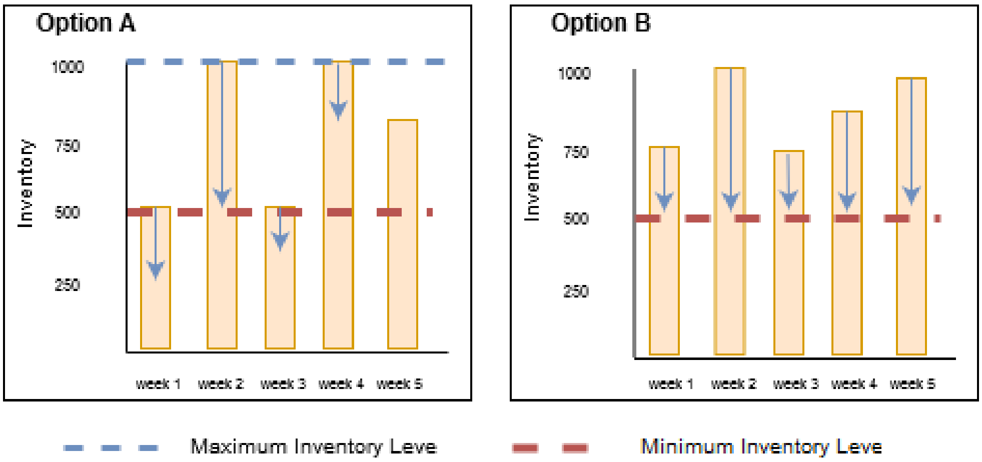


Figure 5.3 - Inventory Control Policies AX

Reorder Point, Order-up-to Level and Optimal Production Quantity

Chopra and Meindl (2007) determine the reorder point as the sum of the consumption during lead time and the safety stock and the order-up-to level as the sum of the demand and the product of standard deviation of the demand times the safety factor. For Bolletje it is useful to account for uncertainties in the safety stock. The safety stock should especially consider the supply uncertainty. Supply uncertainty arises at Bolletje because of unplanned machine maintenance and varying production output. The optimal production quantity depends on multiple factors such as the setup cost, demand, production rate and holding cost and can be calculated with the EOQ equation.

Lead Time and Review Period

To ensure that stockouts do not happen, we want to advise Bolletje to assume the worst situation. Figure 5.4 shown the scenario we draw. In this scenario, the inventory level is not yet under the minimum inventory level, thus the planners do not place a new production in week 2. In this case, the minimum inventory level should be big enough to cope with the demand until the new production order arrives. This is the demand until the next review period in week 3 (5 days) and the lead time. In this case we would need to assume a lead time until the last possible moment of possible delivery, which is on Friday. Therefore, the lead time should be between Wednesday in week 3 until Friday in week 4 (7 days). We assume that production in the next week is always possible. If this is not the case, AX tries to increase the order quantities of earlier orders where not all capacity is used yet. Knowing this, the sum of the review period and lead time is 12 days (5+7).

Figure 5.4 - Explanation Lead Time

Demand Forecast

The demand forecast established in AX is based on the baseline sales of the last four years. AX shows the demand per week. Furthermore, the Demand Planner adds the promotions, which were set in the beginning of the year, to the baseline forecast. Bolletje's forecast has proven to be reliable in the past and the Demand Planner reviews it regularly.

Minimum Inventory Level and Customer Service Level

During the review period, Bolletje should maintain a minimum inventory level to cope with the uncertainty in supply and demand. The minimum inventory level also considers reservations and markings. Those are products that are already promised to fulfill the customer's demand in a given week. These can trigger minimum inventory replenishment before the physical quantity goes below the specified minimum level. Hence, in AX, the minimum inventory level is used as buffer stock in case sales orders come in and the Operational Department is unable to serve the customer from the regular stock. Using parts of the minimum inventory to fulfill a sales order means that AX reduces the inventory level below this level. The minimum inventory level functions as reorder point in AX.

For the determination of the minimum inventory level, AX has a function called *safety stock journal*. The safety stock journal provides statistics for an item which help to calculate a new minimum inventory level based on reliable metrics. It further offers a possibility to cope with changing conditions. To use this method efficiently and have a meaningful calculation, at least three months of historical data needs to be available or past data from the same period should be used. Figure 5.5 shows a screenshot of the safety stock journal for a product within AX. According to this journal, the new minimum should be 5139 units. Within the journal the planners can create journal lines for product groups. The system controls the historical demand for each item in each site or warehouse and calculates the average demand quantity per month, including a standard deviation. The standard deviation indicates how measurements, in this case the average demand of an item per month, are spread out from the average. Furthermore, it calculates the average demand during lead time.

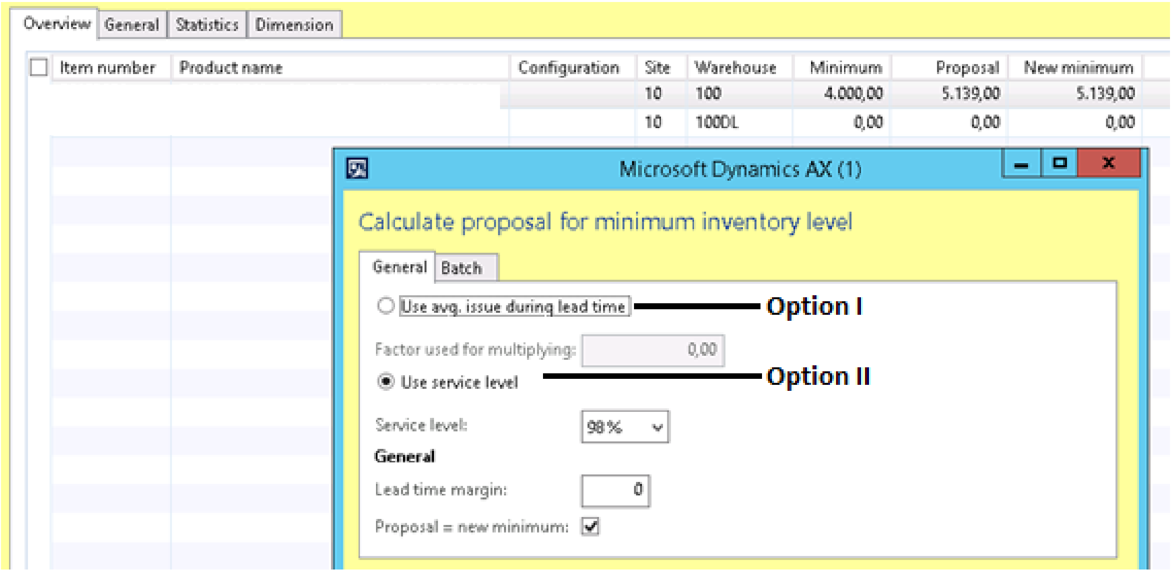


Figure 5.5 - AX Safety Stock

The system offers two options to calculate the minimum inventory level:

- Option I: Use average issue during lead time
- Option II: Use service level

Equation 5.1 shows the equations for the two options. The main difference between the options is that option I uses a multiplying factor, which manages the fluctuations in demand and needs to be determined according to a balance between stockouts and costs, and the average demand. Option II uses the service level and the standard deviation of the demand. The service level factor is derived from Bolletje's service level. AX can review and update the safety stock in a regular interval. Both equations consider the lead time and convert it to working days by multiplying it with $\frac{5}{7}$. The lead time margin accounts for the days that are used for internal administration of the order process and can be disregarded in Bolletje's case, since we account for this in the arrival margin. The review period cannot be indicated in the equations that AX uses. However, since they use the demand and standard deviation per month, the review period is accounted for in the equations.

Equation 5.1 - Minimum Inventory Calculations AX

$$Option\ I: \quad D * \left(\frac{\left(L * \frac{5}{7}\right) + L_m}{30}\right) * M$$

$$Option\ II: \quad Z * \sigma * \sqrt{\frac{\left(L * \frac{5}{7}\right) + L_m}{30}}$$

$Avg.demand\ per\ month = D$
$Lead\ time = L$
$Lead\ time\ margin = L_m$
$Multiplying\ factor = M$
$Service\ level\ factor = Z$
$Std.deviation\ of\ demand\ per\ month = \sigma$

Availability of Production Line and Stability of Production Output

In order to take the availability of the production line into account, AX has a calendar in which employees can enter holidays or planned downtime. In the calendar the planners can also indicate if a production line is running on the weekend. In the capacity calculations AX takes this downtime, or even extra uptime (because of production on the weekend), into account.

Furthermore, there is a possibility to adjust the efficiency of a resource from the production line. This represents the real world since if a machine is scheduled to work 24 hours, the system would otherwise assume that the machine works without interruptions. Natural downtime must be considered. The system uses this percentage to decrease the capacity by increasing the individual production time in case a machine is not able to run at 100% efficiency. The OEE is a good representation of the efficiency. We use the average OEE from the last quarter to represent the efficiency of the production line. This is 75.13% for line R156 in Q1 2018. Although the machine is theoretically capable of producing 360 CE boxes of knäckebröd in a 24-hour day, the line can only produce 270 products (360 x 75.13%) during a 24-hour period. By reducing the efficiency of this production line in AX, the system increases the time needed to produce an item.

Shelf life

Within the product information in AX we enter the shelf life for each product individually. Most of the knäckebröd products have a shelf life of two months. AX considers this during master planning by considering the expiration date and not producing more products than forecasted during the shelf life. Furthermore, AX also gives an alert as soon as a finished product expires in the warehouse. To minimize the number of products that expire, AX can ensure that the inventory units with the latest expiration date will be used for safety stock. This ensures that they fulfil demand with the First Expired First Out (FEFO) principle. When planers run the MPS, AX will cover the first sales order from the existing on-hand inventory, the inventory which will expire first. As soon as a new production run is scheduled, AX registers the new items as safety stock and the older items as on-hand inventory. This ensures no delays for real transactions and helps to prevent over-replenishment and early-replenishment of safety stock.

Procurement

Before the planners can schedule production orders, they have to make sure that they have the needed raw materials to produce the products. As soon as a raw material is no longer in stock, it needs to be replenished before the next production. AX offers the option of entering a bill of material with which the system calculates the exact amount of raw materials for a specific order quantity volume. In order to receive the raw materials on time, each resource has its own purchase lead time. This is the time between placing an order and receiving the raw material in the warehouse. This time has no margin for the administrative and transportation tasks within the warehouse. To avoid that a raw material arrives on the same day as the production starts, AX has the option to implement a receipt margin (in days). Similar to the lead time margin, it accounts for the administrative time. The receipt margin is a safety margin that is added to the requirement date of the receipt during master scheduling. We advise Bolletje to use a receipt margin of two days. This gives enough room for possible delay and transaction within the warehouse. Accordingly, the raw materials will arrive two days before the production date. The system also takes into account that a delivery on the weekend or holiday is not possible. In case this should be necessary, it plans the delivery on the working day before the weekend or holiday.

AX provides an overview of the availability of raw materials in the requirement profile. This shows the net requirements for production orders, the on-hand inventory and at what point new inventory becomes available. Figure 5.6 demonstrates this for the HE box. Right now, 12,680 units of this resource are on hand. The planners planned another purchase order for 27th of April. Furthermore, the planners have released two production orders (production line) and planned seven production orders (formula lines). AX advises the planners to order new boxes before the planned production on the 25th of May. After AX runs the master planning, the net requirements profile from the planned orders is available.

Overview | General | Action | Futures | Period

Update ▾ Inquiries ▾ Sorting ▾

D	Reference	Reference	Number	Item number	Requireme...	Expiration date	Req. quantity	Accumulated
		On-hand					12.680,00	12.680,00
		Purchase order			27-4-2018		6.480,00	19.160,00
		Production line			8-5-2018		-1.566,00	17.594,00
		Production line			14-5-2018		-2.045,00	15.549,00
		Formula line			15-5-2018		-340,00	15.209,00
		Formula line			15-5-2018		-583,00	14.626,00
		Formula line			15-5-2018		-631,00	13.995,00
		Formula line			22-5-2018		-728,00	13.267,00
		Formula line			22-5-2018		-340,00	12.927,00
		Formula line			22-5-2018		-583,00	12.344,00
		Formula line			22-5-2018		-631,00	11.713,00
		Planned purchase orders			24-5-2018		6.480,00	18.193,00
		Formula line			24-5-2018		-3.333,00	14.860,00

Figure 5.6 - AX Requirement Profile

Classification of Importance

Recently, the problem of reduced efficiency on the production lines started occurring. This problem effects and reduces the capacity of the production lines. Bolletje is sometimes not able to produce enough products to meet customer demand. Because of this situation Bolletje needs to decide which products to produce, which customers to supply with finished products as well as how to determine the production quantities in such cases.

To determine the importance of products, we advise a SKU classification. With a SKU classification Bolletje can see the importance of the different SKUs and reduce the time spent on planning since not all SKUs need to be produced in case of capacity problems. Hence, products with a higher importance score get priority during capacity shortages (Van Kampen et al., 2012). The characteristics as well as the differences in annual sales volume and product value influence the inventory control policy and can be leading when deciding on the importance of an SKU (Van Kampen et al., 2012). Together with the employees responsible for demand planning, we choose three important characteristics for the SKU classification, namely:

- *Sales volume*: important since products with higher volumes have a greater market demand.
- *Product Importance*: important since some products are in the hierarchy above others and their production is thus more important.
- *Line boundedness*: important since some products are easier produced on this line than others, for example products which must be produced on one line and cannot be switched between lines.

Since we decided on more than two characteristics, the AHP method is most suitable. Advantages of AHP are that it builds alignment around criteria priorities and validates their consistency (Saaty, 1980). Part of this method is the establishment of a pairwise comparison matrix in which the importance of the criteria is established.

Table 5.1 shows this matrix. Together with the employees from Bolletje we tried to let the matrix reflect the current importance classification. Currently, there is no clear process for the classification. By choosing the criteria the Demand Planner wanted to emphasize and bring his subconscious decision-making forward.

Table 5.1 - Pairwise Comparison

	Sales volume	Product importance	Line boundedness
Sales volume	1	1/9	1/6
Product importance	9	1	2
Line boundedness	6	1/2	1

When Bolletje needs to decide which products to produce in case of low capacity, their first criterion is the product importance. To determine the importance, we let the Demand Planner choose the importance in relation to the other criteria. The Demand Planner can choose from as important as (score 1) up to 10 times more or less important than (score 10) the other criteria. Bolletje's own products are most important, while the individual private labels have lower importance. For the Demand Planner the product importance is nine times more important than the sales volume and the line boundedness six times as important as the sales volume. We follow the same procedure for the other criteria.

From the weights in the pairwise comparison matrix we can derive an equation which describes the importance of each characteristic. The inconsistency index measures the consistency of our importance ranking. Since the inconsistency index is smaller than 10%, the inconsistency is acceptable (Saaty, 1980).

$$0.0614\, Sales\ volume\ +\ 0.6049\, Product\ importance +\ 0.3337\, Line\ Boundedness$$
$$Inconsistency\ Index :\ 0.01$$

With this distribution we are now able to score the products per criteria. For the criteria product importance and line boundedness, the products can receive a score between 5 (important product/high line boundedness) and 1 (less important product/low line boundedness). For the criteria monthly sales volume, we only show the rank the products achieve in comparison to the other products for confidentiality reasons. Having established the scores and criteria weights, we split the products into three categories based on their final score. The final score is the sum of the weight times the score. Class A involves all products that lay within 70 to 100%, class B products within 40 to 70% and finally class C all products below 40%. **Error! Reference source not found.** in the confidential appendix shows the default products of line R156, their scores within the AHP classification and the category in which they belong. Appendix D explains the steps of the shown AHP method in more detail. The products from Bolletje itself score best within the classification and are thus the products line R156 should focus on the most.

5.3.1 Production Scheduling

After the master planning and the procurement, AX needs to schedule the production orders of the DP. Figure 5.7 shows an example of such a production schedule. To schedule, AX differentiates between job scheduling and operations scheduling. Operation scheduling is a general estimate of the production process over time, while job scheduling returns a detailed schedule that considers the current capacity. We make use of job scheduling since Bolletje wants to consider the available capacity and receive a DP at the end of the scheduling process. Furthermore, AX can plan with finite or infinite capacity. By selecting finite capacity, we present AX with a capacity constraint.

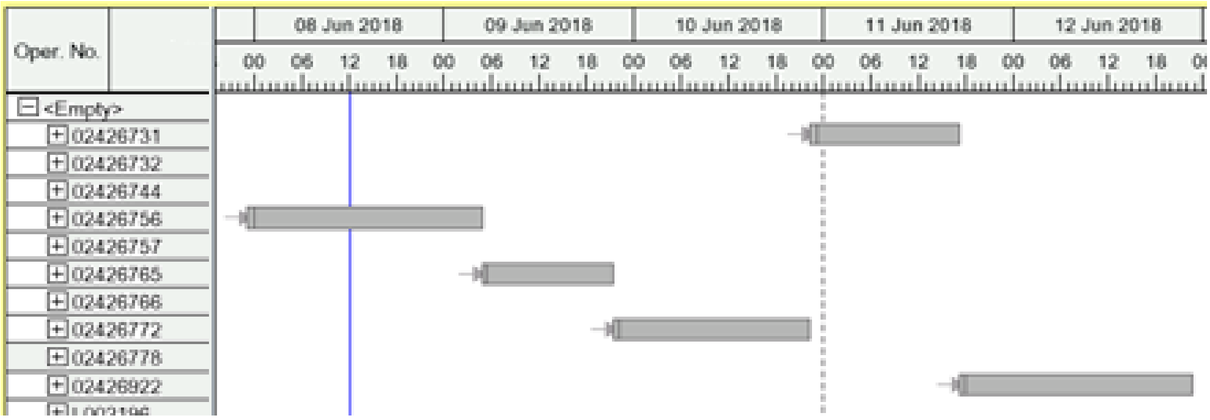


Figure 5.7 - AX Production Schedule

There are natural groupings of products in manufacturing, meaning that major changeover costs might be incurred for one product combination while minor changeover costs are required for another (Hax & Meal, 1973). As already indicated in Chapter 4, changeover losses are a problem at Bolletje. By scheduling the products with similar characteristics together, the batch sizes increase and by grouping the products, the changeover costs are substantially reduced in comparison to independent scheduling since costs are not for the individual product but spread over the group. Hence, the scheduling decisions for the products within one family are strongly coupled (Hax & Meal, 1973). In the case of Bolletje, we see that products with related packaging material and doughs can be grouped in a family. Moreover, they can then be scheduled jointly to reduce changeovers. Since embedding the changeover matrices is not an option, we calculated the average changeover time as standard setup time for each product. We determine the average changeover time to be 25 minutes, this is 2 medium and one long changeover per week[5]. We create this family grouping in AX by assigning product sequences. Sequencing means that the items are ordered according to their group during scheduling. For the sequence, we specify the required order in which we schedule jobs during production. For example, we can create a sequence to produce Bolletje's own products in the order Goudbros, Sesam, Volkoren. Since Bolletje Goudbros is scheduled before Bolletje Sesam, we assign a lower rank (0) to the Bolletje Goudbros and assign a higher rank (1) to Bolletje Sesam. Moreover, we can assign sequence groups. This is useful if we also want to produce private label products next to Bolletje´s own products. Bolletje wants to produce their products first. Therefore, Bolletje products receive the highest rank. Since the changeover from Bolletje to the private labels is faster than from Bolletje to PL6, most private labels receive rank 1 while PL6 receives rank 2. In the confidential appendix, **Error! Reference source not found.** shows how we

[5] $\frac{(2*15 \text{ minutes} + 45 \text{ minutes})}{3} = 25 \text{ minutes}$

indicated the sequences in AX. AX now schedules according to those sequences. The system schedules all products of one group according to their sequence values and after that starts with the next group. With this method, we can reduce the changeover time to a minimum.

5.3.2 From Practice to Theory

The implementation of two different inventory control policy options is possible in AX. While reviewing the possibilities, we conclude that option B is a better fit for the system and Bolletje. We give this recommendation on account of the ease of use and implementation. Option B is easier to implement and monitor in AX because in the system this method is more responsive to change in demand. While the maximum inventory level for option A is a parameter that needs to be calculated and adjusted manually, the production order quantity from option B is automatically adjusted according to the fluctuations in demand and capacity. Hence, option A would increase the workload of the planners since they need to be alert if the parameter needs to be adjusted.

From Silver et al. (2016) we can derive a formula from the theory that reflects the inventory control policy of option B. This formula is based on a heuristic procedure in case of a fill rate constraint.

Equation 5.2 - Option B of the (R,s,S) policy (Silver et al., 2016)

We select the minimum inventory to satisfy:

$$minimum\ stock = S - \widehat{X_R}$$

With reorder point and order-up to level that satisfy,

$$s = x_{R+L} + k * \sigma_{R+L}$$

$$S = s + Q$$

$$\sigma^2_{(R+L)} * J_u(k) = 2(1 - P_2) * \hat{x}_R * \left[S - s + \frac{\sigma_R^2 + \hat{x}_R^2}{2\hat{x}_R} \right]$$

By using the table of Ju(k) versus k from Silver et al. (2016) the parameter can be found.

According to this, we can derive the minimum inventory level to be:

$$S - \widehat{X_R} = x_{R+L} + k * \sigma_{R+L} + Q - X_R$$
$$= x_L + k * \sigma_{R+L} + Q$$

$Order\ up\ to\ level = S$
$Demand\ during\ review\ period\ and\ lead\ time = x_{R+L}$
$Special\ parameter\ of\ the\ normal\ distribution = k$
$Economic\ Order\ Qantity = Q$

5.4 AX Model Validation

During the process of modelling the planning in the ERP system earlier, we were constantly concerned with how closely the model reflects the theory. According to the literature, this can be described as part of the model validation process (Neelamkavil, 1987). Model validation is the process of determining the degree to which the ERP system accurately represents the theory (ProModel Cooperation, 2010). Gathering evidence to determine model validity is largely accomplished by examining the structure of the ERP model to see how closely it corresponds to the theory we found and to the model currently used. Moreover, proving validity also includes analyzing the results to see if those appear to be reasonable. In the theory it is also advised to compare the model to the actual system to see how it corresponds if the circumstances permit to do so (Neelamkavil, 1987; ProModel Cooperation, 2010). The inventory control model that we established within AX is comparable to the theory we found. The biggest difference is the calculation of the safety stock. Before we implement one of the equations of AX, we need to find out if they can give a reliable safety stock level. Furthermore, we need to decide which of AX options is best for Bolletje. In Bolletje's situation we validate the system in two ways. First, we compare the safety stock equations in AX to those mentioned in the literature to see if the equations in AX represent the theory. Furthermore, we are going to compare the current planning system and its results with the ERP planning in Chapter 6. If we perform this procedure without encountering a discrepancy between the real system and the model, the model is said to have validity (ProModel Cooperation, 2010).

We compare the performance of five equations mentioned in this report. The first two are the safety stock equations from the literature review in Chapter 3. We will further refer to Equation 3.2, the standard safety stock equation as 'Theory Standard (TS)' and to Equation 3.3, the safety stock equation that takes the supply uncertainty into account, as 'Theory Supply Uncertainty (TSU)'. Furthermore, we use the equation which we derived from Silver et al. (2016), denotes with 'Theory Fill-rate (TF)'. Moreover in Equation 5.1, we introduced the safety stock equation that AX uses to calculate the minimum inventory level. Those will be further referred to as 'AX 1' and 'AX 2'. We assume that TS scores the worst since this equation does not account for uncertainty and does not consider the review period or lead time. Furthermore, TSU might have a higher minimum inventory than the others since all uncertainties are considered. Equation (TF) should reflect the behavior of AX2 since both use the fill rate. The behavior from AX 1 shall be dependent on the multiplicity factor.

For the comparison we use a Monte Carlo simulation. We choose this method above a calculation method since the complexity is easiest to describe and reflect on in such a system. With this method, we generate a large number of samples with random demand and standard deviation of the demand according to the uniform distribution. The values for the uniform distribution are from last year's demand of one of the products produced at Bolletje. For confidentiality reasons we will not reveal the identity of the product. We disregard seasonality and promotions for the pure purpose of testing the model. We regard those aspects and their effects in Chapter 6. Since AX only expresses the standard deviation per month, we converted the standard deviation to weeks. Equation 5.3 shows the equation for this confirmation.

Equation 5.3 - Standard Deviation Confirmation

$$\sigma(week) = \frac{\sigma(month)}{\sqrt{4}}$$

5.4.1 Simulation and Model Design

Monte Carlo is a proven, widely used and much appreciated method for simulation. The analysis is a computerized mathematical technique that produces a sequence of numbers from certain random distribution and uses these as an input variable sequence to perform experiments (Jiao & Du, 2010). Van der Aalst (1995) finds it a very much reliable and valid method to compare the different equations since simulation can create insights on performance of the system in certain scenarios that are too risky or expensive to test in the real system. In our model we perceive the dynamics of the real inventory as a black box. Recent studies have been using Monte Carlo simulation for inventory management problems (Cáceres-Cruz, Juan, Bektas, Grasman, & Faulin, 2012; Jiao & Du, 2010). However, little effort has been spent in using Monte Carlo simulation specifically to explore optimal safety stock levels.

The model's main objective is to calculate the safety stock realistically for the five different methods. The production and its output as well as efficiency is not simulated. For simplicity we assume that the production system is seen as a black box and it is believed that enough products can be produced unless there is a capacity constraint within a week. The safety stock of the equations is based on a service level of 98.5% and on the randomly generated demand according to the uniform distribution as well as pre-determined settings. Furthermore, a capacity factor is added. This factor simulates that in some weeks production is not possible due to unforeseen events and is therefore a random variable that occurs approximately in 5% of the weeks. Based on the safety stock level and the capacity factor, the model can determine if a stockout will occur. We evaluate the performance of the model based on the average safety stock level, the number of stockouts per year and the total costs incurred per year. We build the model in Microsoft Excel. For the simulation we used an add-in from RiskAMP.

Since Bolletje is not aware of their holding cost, we decided to base the total costs on two factors: the inventory value and the penalty costs. We base the inventory value on the value of one HE box which is the sum of the consumer purchase price of the CE boxes within a HE box. For the product we choose this price is € 9.20. The penalty costs are the estimate costs associated with a stockout. Together with the Financial Department of Bolletje we agreed to a penalty cost of € 100,000.00 per stockout. Within the EOQ we also consider the ordering costs. The costs connected to ordering are the costs setup and changeover cost. To reflect these costs, we calculate the production loss by multiplying the average changeover time (25 minutes), the throughput (approximately 4 HE boxes per minute) and the price of the HE boxes (€ 9.20). This means that the ordering cost is approximately € 828.00. However, the EOQ of the product we choose is with 9650 units too high to be realizable at Bolletje right now. Because of capacity problems Bolletje produces smaller batches to be able to fulfill all customer's demand as good as possible. To have a more realistic situation we decrease the EOQ to half the size. This is comparable to the current minimum order quantity of this product (4480 units). For the future, Bolletje should try to consider the EOQs of the different products as the minimum order quantities.

As results, we choose to evaluate the average safety sock, the number of stockouts and the costs per equation. All safety stock equation methods use the same random demand and standard deviation. The demand is based on the uniform distribution with a minimum of 1996 and a maximum of 3457 units per week. The Demand Planner approved this distribution. It is comparable to the uniform distribution he uses in AX. However, this distribution does not account for seasonality. The minimum and maximum of the standard deviation per month is 1895 and 4125 units respectively, which includes promotions. The distribution is derived from two years of historic data in AX. The sum of the lead time and review period is set to be a constant twelve days. Furthermore, the service level is set to 98.5% with a corresponding service factor of 2.17.

The AX equations also have equation dependent factors. This is the average demand per month[6] and the multiplicity factor for AX 1. To determine the right multiplying factor, we test several factors. In a general analysis we saw that the factors 9, 10 and 11 had the best safety stock. Therefore, we decided to further test the performance of this equation with all 3 factors.

The Excel cells calculate the safety stock per week per equation. To register the stockouts, Excel indicates whether there would be a stockout within a week. A stockout occurs if the safety stock cannot account for the demand and standard deviation. In case there is a capacity constraint, the demand and standard deviation of the current and following week is added up. The capacity constraint is applied on average 2.5 times a year. We discussed this factor the Maintenance Engineer. It accounts for the longer maintenance stops during which no production is possible. Equation 5.4 shows the used equations.

[6] AX does not calculate it per week.

Equation 5.4 - Stockout Determination

$$Stockout = \begin{cases} 1 \;\; if \;\; Safety\,Stock_x < ((Demand_x + Standard\ deviation_x) + Capacity\ Constrsint * \\ \qquad (Demand_{x+1} + Standard\ deviation_{x+1})) * Service\ Level \\ 0 \quad otherwise \end{cases}$$

5.4.2 Execution and Model Assumptions

The simulation models the safety stock for the different equations within the period of one year. The run-length of one year is chosen since this is the period of the budget year at Bolletje. This way Bolletje can understand the effect of the inventory level and the stockouts over the period of one year. For simplicity reasons the simulation assumes that a month has four weeks (a year 48 week).

The number of replications were determined for 100 independent years. We determine the replications with the traditional confidence interval method of Robinson (2004) and an equation of Winston (2004), which Equation 5.5 shows. The number of replications is based on a 95% confidence interval and a relative error of 0.05.

Equation 5.5 - Number of Replications

$$n = [\, z_C * S \,/\, E \,]^2$$

$Number\ of\ replications\ needed = n$
$Estimated\ standard\ deviation\ of\ the\ output = S$
$Desired\ margin\ of\ error = E$
$Confidence\ coefficient = z_C$
$Confidence\ level = C$

Figure 5.8 shows the results of the number of replication calculations. Since the total cost and number of stockouts are dependent on the average safety stock level, we decide to take the safety stock level as the determining factor. Based on the results, we see that TSU indicated the highest number of iterations. Based on this, we choose to round the number op to 20,000 iterations.

	# iterations	Final # iterations
AX 1 (MF=9)	5835	
AX 1 (MF=10)	7203	
AX 1 (MF=11)	8716	
AX 2	8528	15991
Theory Standard	1599	
Theory Supply Uncertainty	15991	
Theory Fill-rate	1217	

Figure 5.8 - Number of Replications

5.4.3 Results

Figure 5.9 presents the results of the simulation. Comparing the results, we see that equation TS, which does not account for any uncertainties, has in general the lowest minimum inventory, the most stockouts and also the highest costs. When using TSU, the chance of having a stockout is slim. However, this equation has the second highest costs since more inventory than in the other equations is being used. Equation TF shows results in between the other equations. The performance of the AX 1 equations is similar. The best performance in number of stockouts as well as costs, is with a multiplicity factor of ten. AX 2 shows the lowest total costs but has yearly on average 2 stockouts. The results of this equation are as expected similar to TF. However, TF has a higher level of the minimum inventory but the same number of stockouts as AX 2.

	Average MinInventory	Standard Deviation MinInventory	Average Stockouts	Standard Deviation Stockouts	Average TotalCosts	Standard Deviation TotalCosts
AX 1 (MF=9)	7014	160	2	1	€ 3.315.972,30	€ 155.218,91
AX 1 (MF=10)	7793	178	2	1	€ 3.615.608,11	€ 145.477,86
AX 1 (MF=11)	8572	196	1	1	€ 3.867.143,93	€ 118.468,62
AX 2	6979	216	2	1	€ 2.870.402,73	€ 159.020,68
Theory Standard	3264	101	45	2	€ 5.959.488,26	€ 155.078,58
Theory Supply Uncertainty	9557	296	1	1	€ 4.286.691,89	€ 144.008,17
Theory Fill-rate	7415	95	2	1	€ 3.488.019,75	€ 145.414,69

Figure 5.9 – Simulation Results

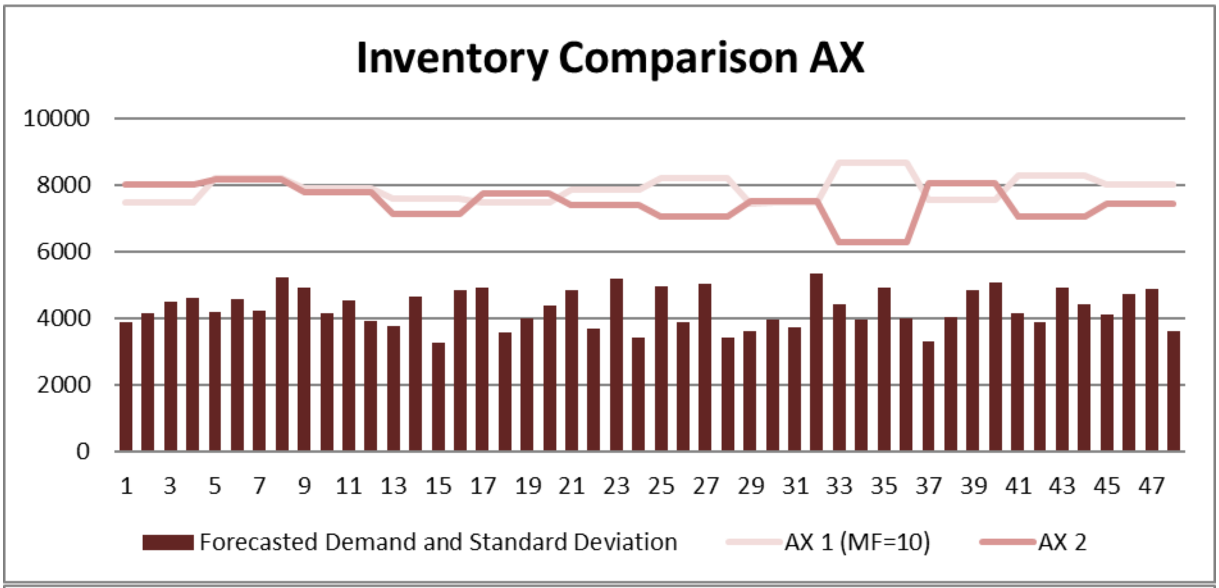
To visualize the comparison, we compare the forecasted demand and standard deviation according to a 98.5 % service level to the safety stock levels of the different equations. Figure 5.10 shows the charts. The needed inventory level, which the bats illustrate, is the level at which no stockout occurs, without taking into account that the production could be stopped for a week. The lines indicate the minimum inventory level according to the different equation. The simulation shows that AX 1 and AX 2 are both able to generate a minimum inventory level with a low chance of stockouts.

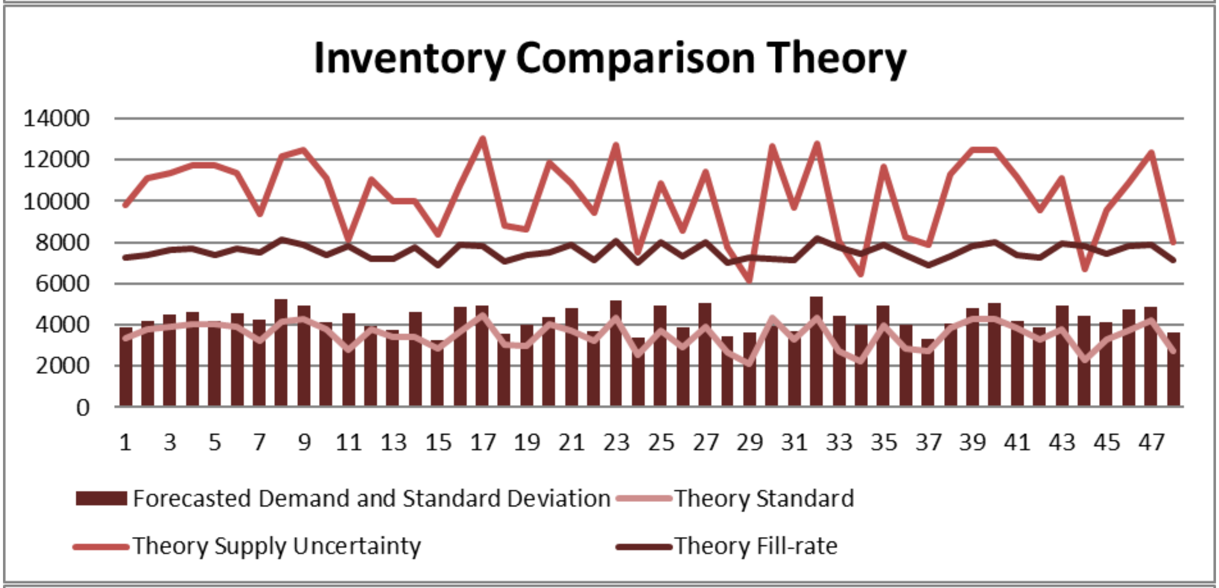
The last chart shows the comparison of equation AX 2 and TF. The minimum inventory level of AX 2 has one moment in which it decreases considerably under the minimum inventory of TF (33 until 36). During this moment the demand for this period (4 weeks) is lower than the average demand. The contrary happens as soon as the demand is higher (weeks 36 until 39). This shows that equation AX 2 reacts to the fluctuations in demand forecast. The two equations have quite some similarities. However, equation TF calculates the demand on weekly basis, while the AX equations consider the period (4 weeks) demand divided by 4 weeks.

Shelf Life and Seasonality

An important factor in the model design is the shelf life of the products since it needs to be ensured that products do not perish in the warehouse. The shelf life of knäckebröd is a few months. In the results we see that the stock leaves the warehouse in under a month when we use equation AX 2. Therefore, the shelf life is no longer a critical factor.

The seasonality is not yet included in the normal baseline demand in this situation. However, the seasonality is seen as an increase of the baseline demand in specific weeks of a period. Since we see that the equations increase the minimum inventory in case of higher demand forecast, we do not see that the inclusion of the seasonality would lead to any problems.





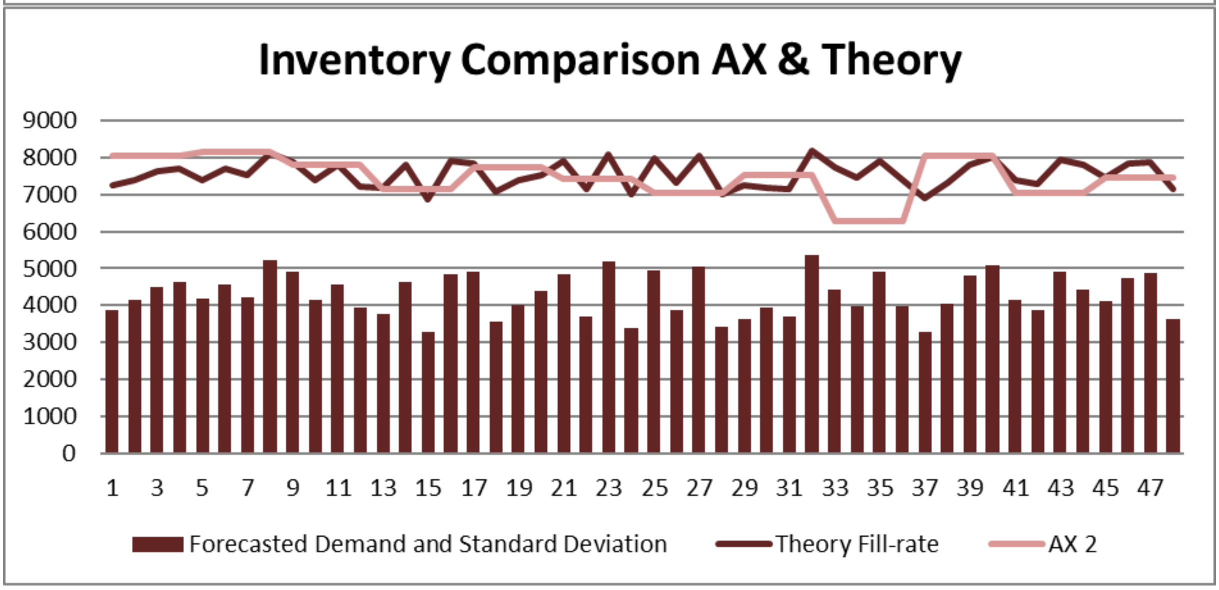


Figure 5.10 - Inventory Comparison

5.5 Conclusion

With the results from this chapter we answer the fourth research question: *Which finished products inventory control policy is suitable for Bolletje and the ERP system and how can it be implemented?*

We conclude that an implementation of the inventory control policy in AX is possible. Within AX it is possible to implement two different versions of a (R,s,S) policy. While option A has a fixed reorder point (minimum) and an order up to level (maximum), the parameters fluctuate in option B with the demand. At this moment, option B seems to be the best fit since it is more responsive to change in demand and copes with the uncertainties. AX can then first plan the production orders in the long-term. Because the MPS can be conducted in AX in the new situation, the planners see the raw material demand for the planned production orders on time and can place new purchase orders. This means that there should be enough raw materials for the planned production orders at all times. Finally, AX schedules the production runs in an order that minimizes changeover time and according to their importance.

Furthermore, we compared the different safety stock equations from the theory to the ones in AX. Although AX 2 does not have the lowest number of stockouts, it seems like it is the most appropriate choice for Bolletje because of its low costs and its adaptability to fluctuations. While the multiplicity factors of AX 1 need to be checked and controlled for each product, equation AX 2 uses the service level which is set. Equation AX 2 gives promising results in which we see that a balance between service level and inventory value has been found. Moreover, the shelf life and seasonality are no critical factor when using this equation and the AX planning.

6. Solution Test – Planning within AX

Within this chapter we do an experimental study on the model we described in Chapter 5. In Section 6.1 we describe the model test. We split the test into the validation and comparison of the AX model to the current model. In Section 0 we evaluate the model and its performance. Finally, in Section 6.2 we come to a conclusion regarding the performance of the model.

Section 6.1
- AX Model Test

Section 6.2
- Evaluation AX

Section 4.3
- Conclusion

6.1 AX Model Test

The second step of validating and testing the model is a comparison of the AX planning with the current planning. Since the start of this research, the performance of the production line R156 has decreased drastically. This is due to unknown factors and the determination of those is not part of this research. However, the performance decrease has a significant effect on the planning since the capacity of the production line decreases with a decrease in efficiency. Since this situation has just emerged, we decided to first validate the AX planning with the assumption that the line is able to run with 100% efficiency. This way we see if a planning in AX is possible. After assuring that AX is able to plan the production we test the model with the current efficiency percentage of 75.13%. We compare the MPS planning from AX to the MPS plan from the planners. In the test we implement the (R,s,S) policy for option B, the minimum inventory level according to equation AX 2 and the parameters/variables described in Chapter 5. Evaluation AX

In the following we evaluate the model and describe the advantages, disadvantages and future research needs.

Advantages

Planners need to spend less time. While updating the MPS and making a production schedule is typically a task that takes two days, AX can do it in a fraction of this time. To increase the time that planners can work on the schedule, the master scheduling should be run Tuesday night in order for the planners to control and adjust the MPS and DP. Furthermore, the planners have much more time for analysis.

Furthermore, while the current MPS planning does not take the planned downtime for maintenance stops into account, AX does so if the working time calendar is filled in per line. This way planners notice inventory shortages that arise because of planned maintenance tasks beforehand.

Disadvantages

AX does not stop a production order before the weekend. This means that on Monday the production needs to start and produce a fraction of the total production. This is not a desired situation for the operators of the production since they prefer long production runs. However, AX does not have a function that regards this. Moreover, the changeover matrices cannot be set in AX. Changeover time in AX is the same for each product. However, at Bolletje the time is dependent on the products before and after the changeovers. To minimize the effect of the disadvantages and to have a realistic DP the planners should manually adjust the DP.

Further research

Right now, there is a difference in the capacity load registration. The manual Excel planning and AX do not use the same production time for the same production quantities. In AX the possible maximum output is set. By adjusting the efficiency in AX, this maximum output changes. The origin of the differences is unknown. However, we assume that it has to do with the maximum output. To be able to work with AX, the origin of the difference in the capacity load registration should be researched and a standard should be agreed on. This means that the maximum output per product needs to be checked and updated.

6.2 Conclusion

With the results of this chapter we are able to answer the fifth research question: *What is the effect and improvement of the automatized inventory control policy and safety stock levels on the processes within Bolletje?*

The (R,s,Q) policy is implemented nicely in AX. The safety stock is large enough to cope with uncertainties and the capacity restrictions are considered during the planning. The inventory level of finished products rises to about four weeks, while in the current situation three weeks of inventory is in the warehouse at most. However, during the planning in AX some problems arose which need attention before the definite implementation. The scheduling ranking is sometimes disregarded, and production orders are paused during the weekends. These are minor problems.

Implementing the planning within AX has a positive effect on the workload of planners. While all planners have high workloads, AX can take over some of their tasks. Therefore, a shift of the tasks of the production planners arises. There tasks will shift from executing the planning to checking and verifying the planning. Another advantage of the planning in AX that there is more assurance that raw materials arrive on time. Furthermore, AX detects future bottlenecks faster than the planners.

7. Conclusion & Recommendations

This final chapter concludes this research by answering the main research question in Section 7.1. In Section 7.2 we list the recommendations for Bolletje that follow from this research. Furthermore, this chapter includes an implementation plan.

Section 7.2
- Conclusion

Section 6.2
- Recommendations

7.1 Conclusion

With its wide variety of products, Bolletje needs to ensure that their customers and consumers are always able to buy their products. To fulfill this aim, it is important that Bolletje uses an efficient inventory control policy that allows them to ensure a high service level to their customers. Hence, the policy needs to ensure that the planners place production orders at the right time and that there is enough safety stock for critical moments. Many employees within Bolletje criticize the current, manual planning. The management team would like to create a new, automated, and efficient planning. Instead of manually determining plans, Bolletje's ERP system, should relieve planners and avoid human mistakes. Moreover, for the successful implementation of a new inventory control policy, Bolletje should improve their changeover process. Right now, changeover times are inconsistent, and changeovers often have unexpected long durations. However, for the inventory control policy and production planning, planners need to assume constant changeover times in order to level the production order quantity that the planners order and the output the Production Department delivers. Within this research we are eager to answer the main research question:

How can the finished products inventory control policy of Bolletje be improved and implemented in Bolletje's ERP system while keeping in mind the right balance between customer service level and inventory investment? Furthermore, how much finished products safety stock should be held and how can the changeover procedure be improved?

There are multiple reasons and improvements for the inconsistencies and unexpected duration of changeovers. The changeover duration and the interruptions between production runs are long since operators need to stop it while carrying out changeover activities. However, external changeover activities, which operators can execute during production - before or after the changeover- can increase the value-adding production time. The changeover process on line R156 includes different activities. Bolletje should consider converting the longest internal changeover activity, which is the adjustment of the Focke packaging machine, to an external task by buffering the products before they reach this production step. Moreover, we found ten other potential causes that can improve the changeover process. While we partly implemented the improvement actions, there are also actions where we only propose improvements. To draw a conclusion, we split the improvement actions into two scenarios. Scenario 1 describes the situation if the Operational Department places a buffer before the Focke packaging machine, while scenario 2 describes the situation as it is now. In conclusion, we can say that we can improve the changeover time. During the baseline measurement we measured that the changeover time for the long changeover is 60 minutes. With scenario 1 we can reduce the internal changeover time to 27 minutes. For scenario 2 we can reach a reduction to 45 minutes. The time reduction also applies to the medium changeover. The operators can conduct the medium changeover now in approximately 15 minutes instead of 20 minutes. Thus, we conclude that Bolletje can improve the changeover procedure by implementing the improvements and by enforcing a more standardized process.

Furthermore, we showed that it is possible for Bolletje to implement an inventory control policy and planning within AX. For Bolletje the implementation of AX results in a more interconnected company and a reduction in the workload of the planners. It is easy to access the detailed information about the inventory, demand, and production. Bolletje needs a periodic inventory control policy to keep their current process structure. After reviewing the literature, we advise a (R,s,S) policy for Bolletje that is able to adapt to the fluctuations on demand. Bolletje should start using AX as soon as possible and set it up such that it can control the procurement, MPS and DP tasks for the planners. Therefore, AX should first design the MPS and thus plan the production orders for the following 13 weeks. Next, based on the planned production orders from the MPs AX should propose procurement orders for the raw materials needed. Finally, AX should design the DP and thus schedule the production runs in an order that minimizes changeover time. The minimum inventory level that AX calculates is similar to the level the theory determines. By using equation AX 2 with a customer service level of 98.5%, Bolletje can ensure that the inventory can deal with uncertainties in demand and supply. We furthermore see that the new minimum inventory level increases by 15%, still offering a good balance between Bolletje's desired customer service level and the inventory investment and stock levels. The inventory level which should be held is based on the service level and differs per product since it is based on the demand and standard deviation of this demand. The advantage of AX is that it ensures a real time solution concerning the state and availability of inventory, blocked quantities, customer demand quantities, customer reserved quantities, raw material purchasing quantities and expired batches. During future research, Bolletje can also investigate of the implementation of minimum inventory levels with equation AX2 for other products like raw materials is possible.

Because of the recent efficiency reduction of one of the production lines, AX shows that it is no longer possible to produce all 12 default products on this production line. It is however possible to produce more products on the other production line, since this line has more available capacity at the moment. For the planning of production and raw materials, this does not have negative consequences for the planning as long as the planners or AX clearly indicate on which production line they want to produce the products.

However, AX also has its drawbacks and more research needs to be done before the full implementation can start. A disadvantage is that AX pauses production orders over the weekend. This means that on Monday a fraction of the total production order still needs to be produced and thus two smaller batches (one on Friday and one on Monday) arise. Moreover, a huge disadvantage is that the changeover matrices cannot be set in AX since changeover time in AX is product dependent. There is also a difference in the capacity load registration. Nevertheless, these are not reasons to stop the implementation of AX. The benefits of the system outweigh the disadvantages. However, the planners need to invest more time and patience in the beginning since they need to check the sequence, times and add the changeover times.

While we only tested the methods for the knäckebröd production line, we can say with confidence that AX can handle the other production sections as well. However, the project team should have a closer look at the shelf-life of the other products. With setting a low minimum or maximum production order quantity, the planners can assure that the products do not expire. It might also be a better idea to start the implementation of AX with a more constant and reliable production line.

We finally conclude that the implementation of the planning in AX, even with some disadvantages of the system, will improve the business process for Bolletje. A correct and detailed implementation is important for the system to work efficiently. Problems such as forgetting to order a raw material or capacity problems are detected and corrected more easily.

7.2 Recommendations

To conclude this research, we provide some recommendations for the Operational Department of Bolletje Almelo. These recommendations, based on the thesis results and the limitations we found in the system, should help Bolletje to take actions, improve the planning and make good choices.

- An ERP planning implementation aims at the automation of many basic processes with the goal of integrating information across the company and eliminating complex, expensive interfaces between computer systems as well as errors made in the manual planning. Since there are a lot of problems with the efficiency of the production line R156 we recommend that Bolletje implements the AX planning on one of the more stable production lines first.
- Bolletje should ensure that products have historic data. If a product changes, they should use the historic data of the last product. This way they can calculate the minimum inventory level with equation AX2. If products are new, the planners should manually add a minimum inventory level.
- Bolletje should implement a live, online planning connected to the production performance. This way employees can see when the changeover takes place. The benefits are that planners and operators can better plan changeovers. Moreover, earlier decisions about cancelling a production run or adding a different one can help to minimize stockouts and expired batches. With such a planning Bolletje can even be established that mechanics carry out maintenance during changeovers. Currently this is not possible because the timings of changeovers are unknown.
- The Operational Department should start monitoring the quality within the OEE. Currently the OEE gives an incorrect picture of the performance. Products that are blocked due to quality issues, should be counted in the OEE.
- We recommend Bolletje to start using AX with the proposed inventory control policy and safety stock. However, if Bolletje decides not to implement the planning, they should increase their safety stock by 15% according to this research. This is a conclusion based on the analysis in Section **Error! Reference source not found.**5.4.3.
- Because Bolletje experiences capacity problems on line R156, they should look into rearranging the products. It might even be an option to produce products interchangeably on the line to make optimal use of the capacity. Bolletje should only interchange products within the production facility in Almelo, since it is possible to use production material interchangeably on those lines.
- For the future, Bolletje should try to consider the EOQs of the different products as the minimum order quantities. Right now the batch sizes do not have an optimal size since there is a shortage in capacity. The EOQ calculation within Chapter 5 shows that Bolletje can save costs by producing bigger batches.

Recommendations from Chapter 4:

- Implement a torque wrench handle for the packaging machine.
- Emphasize the importance of focusing on one production line towards the operators. Furthermore, let operator C fulfill the role as link between dough-room and production section. This change should be closely monitored and evaluated.
- Ensure that manuals and changeover matrices stay up-to-date. Indicate towards the operators that changes need to be documented in the deviation form. The Production Supervisor should be responsible for the updates.
- A project team should be established in order to look into the conversion of the internal process of the HE packaging machine towards an external process. Employees should create an investment proposal including a cost-benefits analysis. This investment proposal is outside the scope of this research.
- Clear agreements about the planning of products, changeovers and personnel should be made between the Production Department and the Logistic Department. The Production Supervisor should be the link between the two parties.

7.2.2 Implementation Plan

In this chapter, we recommend how Bolletje can implement the planning within AX. The idea behind the implementation of the planning within the ERP system is that it will link order management, production and distribution with external suppliers and customers into a tightly integrated system with shared data and visibility (Chen, 2001). Chen (2001) describes one of the potential benefits of this implementation as drastic decline in inventory. This is however not the case at Bolletje due to the high supply uncertainty.

To reach the benefits of an ERP system, a successful implementation is important. Most ERP implementations fail because companies start with automation and forget about the understanding of its business implications and simplifying or reengineering their processes (Chen, 2001). For the implementation of the ERP planning at Bolletje it is important to look on how the planning is done currently and to fit this situation to the ERP system. For the planners this means that they should be ready to change their manner of working. Furthermore, the work is not completed once they implemented the planning in the system. The most significant benefits will not be realized until sometime after the implementation as people in organizations will continue to learn and improve the system (Chen, 2001).

For the implementation, Bolletje needs to establish a project team with employees from different departments (Kumar, Malik, & Sharma, 2012). To smoothen this process, consistent and tough support from top management, excellent project planning, and teamwork is of high importance (Berchet & Habchi, 2005). The following steps should be followed thoroughly in order to ensure that everything is prepared for the final implementation (Berchet & Habchi, 2005; Kumar et al., 2012):

1. *Identify processes:* Evaluate which processes the ERP system should execute. Hence, which manual processes should be automated, and which should be continued to be done manually by the planners.
2. *Develop standard operating procedures (SOPs)*: Develop and document SOPs for all sections of the process. When the SOPs change, the planners should modify the document.

3. *Pre-test the database*: The project team should practice in the test database (accept-environment) to confirm that all information is accurate, and the processes and SOPs work correctly. Furthermore, the planners should test real life scenarios.
4. *User training*: Since not all employees that will work with the new planning are involved in the project team, all users should receive a training by one of the project team members.
5. *Step-for-Step implementation*: After the tests in the accept-environment turned out successfully, the planers should implement the planning procedures within AX step-by-step.

While we already executed some of those implementation steps within the context of this thesis, the project team at Bolletje needs to review and verify those steps and add the needed details. During the last implementation step, it is indeed important that the planners implement everything step-by-step to ensure that AX does all tasks correctly. Figure 7.1 shows the thee steps in which the implementation should take place and one step that evaluates the implementation. The operators should start the implementation of the planning in AX by implementing the procurement tasks. This means that based on the production orders, which the planners still add manually in AX, the planners should let AX make planned procurement orders for all raw materials. The planners should check the orders for their correctness and approve the orders once everything seems to be right. After the procurement is successfully implemented, the planners should start implementing the MPS. They should let AX propose the supply schedule for the different products for the next 13 weeks. The planners should make sure that the planned production orders and production order quantities are correct and approve the orders once everything seems to be right. Next, AX should start to arrange the DP. During this step the operators' cautiousness is of utmost importance since some of the production lines (not line R156) have products with allergens. For these products the scheduling sequence is important since allergens need to be scheduled last and an extensive cleaning must be scheduled afterwards. Once the planners implemented those three processes, AX is able to conduct all key planning processes. However, the process does not stop here. The last step is the evaluation. During the coming month and years, the key users need to detect and improve difficulties and problems.

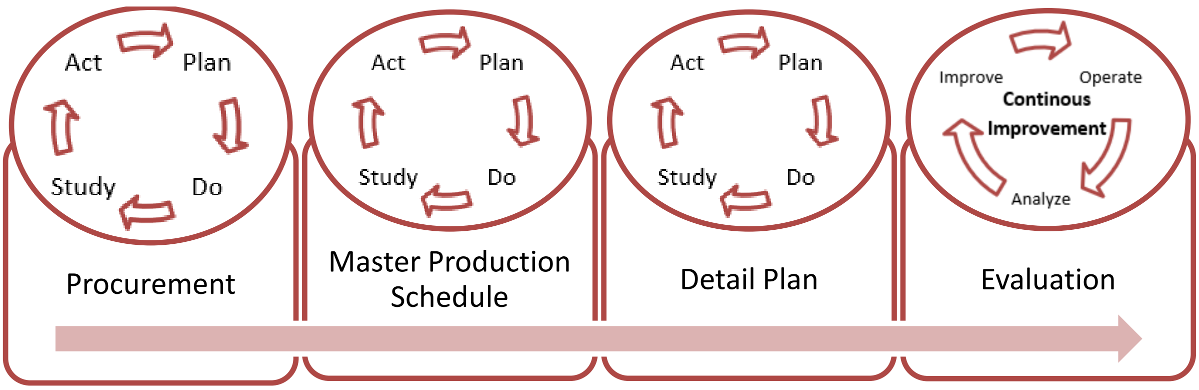


Figure 7.1 - AX Planning Implementation Plan

For the first three implementation steps, the planners need to follow the Plan-Do-Study-Act (PDSA) circle. This is a cyclic learning approach to adapt changes aimed at improvement (Taylor et al., 2014). After the implementation of each step, the planners follow the PDSA circle. In the first stage (plan) of the circle, the planners need to identify the problems and errors within AX and decide which changes they want to execute. During the second stage (do), the planners test those changes. The planners examine the success of the change during the third stage (study) and finally identify the last adaptations and improvements during the last stage (act) (Taylor et al., 2014). The cycle is followed until the planners are satisfied and ready to start with the next implementation step. During the last stage of the implementation, the planners should follow a different circle, namely the continuous improvement circle. This circle enables, as the name says, the continuous improvement of the process by operating, analyzing and improving (Slack, Chambers, & Johnston, 2010).

During the implementation process, the planners need to adapt to the new way of working. AX is not a custom ERP solution but was built for a variety of industries. This means that it might be necessary to change some parts of AX in order to be able to use it efficiently at Bolletje. However, customized solutions are time consuming to implement and add unnecessary cost (Kumar et al., 2012). Hence, Bolletje should try to keep the customized solutions to a minimum and focus on adjusting their manner of working to the system.

During the implementation it is also important to encounter the barriers that employees first named towards the implementation of the planning in AX. It is important to spend time on training the employees to use the ERP system. Some of the employees might be new to such a system and they should have time and training to get used to it. The project team should also have enough free time during the work day to fulfill their tasks within the team. Other employees should take over their tasks during the implementation phase. We assume that the employees will get more confidence regarding the skills of AX during the implementation and testing phase.

Conclusion

With the information in this chapter we are able to answer the sixth research question: *How should Bolletje implement the inventory control policy in the ERP system?*

Bolletje can improve their processes with the implementation of AX. With AX the planning processes are more structured and can deal with change and uncertainties. Problems such as forgetting to order a raw material or capacity problems are detected and corrected more easily.

It is important that Bolletje implements the planning in AX with much patience in order to eliminate the chance of mistakes. Furthermore, the project team needs to embrace the barriers the employees named for the implementation of the planning. While the implementation in AX is time consuming for the planners and the project team, the planner will have a smaller workload and a more efficient system in the end have. It is important that they implement the system step-by-step to ensure the correctness and monitor the processes. Employees should use the PDSA circle to ensure this.

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Appendix

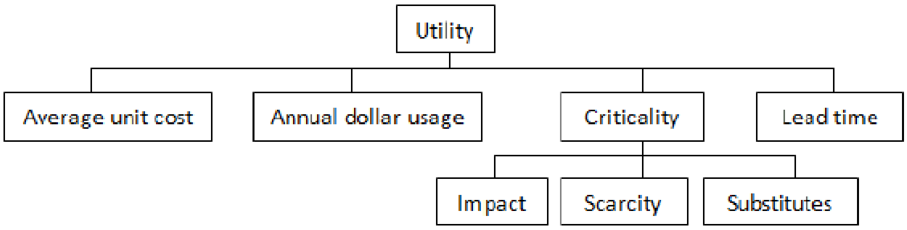
A. Example AHP Classification

First step: *Identify criteria*

Criteria: average unit cost, annual dollar usage, criticality, and lead time.

Second step: *Arrange in a Hierarchy*

Flores et al. (1992) choose to combine the criteria under the single variable utility. The definition of the variables continues at lower levels and criticality is split into the factors impact, scarcity and substitutes.



Third step: *Pairwise Comparisons*

Below the pairwise comparison for *utility* is shown. From this table one can see that *average unit cost* is considered equivalent in importance to *annual dollar usage* and much less important than *criticality*.

	Average unit cost	**Annual dollar usage**	**Criticality**	**Lead time**
Average unit cost	1	1	1/8	1/4
Annual dollar usage		1	1/3	1/6
Criticality			1	1
Lead time				1

A variety of software products can derive the implicit weights for this pairwise comparison matrix:

$$0.0782\ Average\ Unit\ Cost + 0.09161\ Annual\ Dollar\ Usage + 0.41969\ Criticality \\ + 0.40999\ Lead\ time\ (\text{Inconsistency Index} = 0.04)$$

It can thus be concluded that for this example *average unit cost* contributes to approximately 8 percent, *annual dollar usage* to 9 percent, *criticality* approximately 42 percent, and *lead time* for 41 percent to *utility.*

B. Investment Proposal: Adjustment Focke Packaging Machine

Memo of Justification

Projectnaam	: Aanpassing handles van de Focke verpakkings machine
Auteur	: Nina Rusch
Datum	: 1.6.2018

1 Huidige situatie (probleemomschrijving / nadelen huidige situatie)

In de huidige situatie hebben operators lang nodig om de Focke om te bouwen. Een groot probleem zijn de handles die niet makkelijk open en dicht gedraaid kunnen worden. Aangezien deze vaak heel erg vast zitten, nemen operators gereedschap als hulpmiddel. Hierdoor zijn veel handles stuk of beschadigd.

2 Gewenste situatie (voorstel):

Het gewenste voorstel is dat een momentsleutel gebruikt wordt voor het open en dicht draaien. Hiervoor zullen alle handles uitgewisseld worden voor imbus schroeven en een draaimoment-handle gekocht worden.

3 HSE-aspecten:

Deze verandering is voor het welzijn van de operators ter voordeel. Verder verwachten wij dat het ombouwen 5 tot 10 minuten sneller kan worden doorgevoerd.

4 Alternatieven (onderbouwing keuze):

En alternatieve zou zijn om een verlengstuk te implementeren met die de handles geopend kunnen worden. Echter zou deze net zo goed gebruikt worden om de handles vast te draaien. Als dit gebeurt, ontstaat hetzelfde probleem als nu.

5 Financiën:

2 draaimoment-handles: 125,82 € per stuk (http://www.dkmtools.nl/products/gedore-763.momentsleutel-dremometer-t-fs/684576)

100 Cilinderkop imbusbout: 45,86 €

Totaal: 171,48 €

6 Planning:

Deze aanpassing kan tijdens een van de TD stops doorgevoerd worden. Het gaat ongeveer 2 uur duren als 2 monteurs werken.

C. Deviation Form

Afwijkformulier Inpakmachines

Inpakmachine:			Datum:	
Code	**CE nummer**	**Orgineele waarde**	**Afwijkende waarde**	**Rede van afwijken indien bekend**

Afwijkformulier Wisselmatrix

Inpakmachine:			Datum:	
Product 1	**Product 2**	**Orgineele waarde**	**Afwijkende waarde**	**Rede van afwijken indien bekend**

D. AHP Classification

Pairwise Comparison Matrix	nthly Sales Volu	Product Importance	Line Boundedness
Monthly Sales Volume	1	1/9	1/6
Product Importance	9	1	2
Line Boundedness	6	1/2	1

Pairwise Comparison Matrix	nthly Sales Volu	Product Importance	Line Boundedness
Monthly Sales Volume	1	1/9	1/6
Product Importance	9	1	2
Line Boundedness	6	1/2	1
Total	16	1.61	3.166666667

Normalized matrix				Total	MMULT	
Monthly Sales Volume	0.0625	0.068965517	0.052631579	0.184097	0.552593769	1.00054768
Product Importance	0.5625	0.620689655	0.631578947	1.814769	5.473911071	1.00543784
Line Boundedness	0.375	0.310344828	0.315789474	1.001134	3.01310118	1.0032291
Total				3		3.00921462

	Weight
Sales Volume	6.14%
Customer Relationship	60.49%
Ease of Production	33.37%

CI	0.004607309
RI	0.58
CR	**0.007943636**