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Determination of Batch-Sizes

A case-study in the process industry.

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Abstract

Title

Optimization of batch sizes, A case-study in the process industry.

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Background and Research question

The company have a complex product portfolio and production facility. Currently, the batch sizes in production are based on experience and is not based on any cost analysis. The central organization have recently put more emphasis on the batch sizes, especially in a context of increasing the efficiency of the packaging lines. The company wishes to investigate the batch sizes and analyze the consequences of implementing a method to calculate batch sizes from a cost perspective.

Methodology

The chosen research method is a balanced approach which incorporates both qualitative- and quantitative research. Interviews and archive analysis was used to develop an understanding of the problem and obtaining data for a quantitative analysis. The research took place at the company and the data was collected from the company's IT systems.

Theoretical Framework

Theory relevant to the problem at hand was first studied and is presented in the report. This theory is well-established in operations research and is used as both a foundation to analyze the current situation as well as a base for suggestions of how to solve the company's problems.

Conclusion

The EOQ model was chosen as a suitable theoretical model for the company. During the analysis, several findings were made regarding the current approach of determining costs and managing the inventory. The current approach of determining batch sizes encourages a reactionary way of thinking for operational planners where the most important SKUs are shown most regard due to pressure from top management. The current way of calculating safety stock have also been shown to greatly discourage an increase in batch sizes, even though an increase could both be cost-effective and increase efficiency in production. Hence, a new theoretically sound method to calculate safety stock s suggested.

The report presents an approach that takes cost, the perishability of products and operational constraints into account and provides the company with an Excel based decision making tool.

Keywords

Lotsizing, Changeover cost, Holding cost, Safety stock, EOQ, Process industry.

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1 Introduction

During the introduction the reader will be introduced to the company and their current situation. The problem will be described, a clear purpose of this thesis, and its delimitations, will be stated.

1.1 Background

The beverage industry has ancient roots. For example, the procedure of refining water, malt, hops and yeast into beer, called Brewing is a complicated process that have been developed by humans for more than 7000 years. (Nelson, 2005)

The project was performed at the request of a company that manufactures beverages, at their production facility in Sweden. The facility produces a multitude of different beverages and packages them to be sold. The company possesses a vast array of brand that are both internationally and locally known. The company wishes to remain anonymous, and shall in this thesis be referred to as "The company". The names of the production lines and the articles have also been altered in this thesis.

This thesis concerns the manufacturing unit in Sweden which produce drinks for the Swedish market. In total, around 400 unique products are produced in the facility at this time.

1.2 Problem Description

The company currently experience difficulties in the decision-making process regarding ordering quantities along their supply chain. The planning department is responsible for determining the produced batch sizes, but the decisions affect the various departments throughout the supply chain in different ways depending on which KPIs (Key Performance Indicators) the department is evaluated upon. Therefore, the batch sizes in the production are a topic of much interest for the entities in the supply chain and various opinions related to them exist.

Several problematic areas that might be affected by the batch sizes exist. The warehouse management team brings attention to the fact that 40-60% of the company's finished goods inventory is stored at expensive external warehouses, to which inventory must be transported. In turn, the production management highlights the low equipment efficiency shown on the production lines and the resulting cost of sourcing goods that cannot be produced on site due to lack of capacity. Sourcing of finished goods and the cost of external warehouses are considered by the departments to be major unnecessary cost drivers.

The planning department currently have an ambition to decrease the total stock and to create good conditions for the production team, to increase their equipment efficiency by reducing the number of change overs. They think this can be done by enhancing the procedure of determining batch sizes in production, an effort that is complicated by the complexity of the company's large product portfolio and constraints in their production process, as well as the

perishability of the finished goods. The planning team is currently guided by SAP to handle the production scheduling of the production lines. SAP suggests a preliminary production schedule with batches that aim to satisfy the demand from the customers, but does not take the costs driven by the batches, into account.

To support the planning team in the batch size determination, as well as in negotiations with the different functions, a model that quantifies the costs associated with the batch sizes have been requested. To increase the understanding of the impacts of decisions, the model is requested to be capable of evaluating the effect of changes to the finished goods inventory and the production

1.3 Purpose

The purpose of this project is to create a quantitative model that takes relevant costs and variables into account when determining the production batch sizes. The objective is also to evaluate the impact the model would have on finished goods inventory and the production capacity.

1.4 Delimitations

To be able to perform the project in the limited time frame, the scope is narrowed down. Firstly, only one of the company's production facilities is included. Therefore, the scope of the project has been limited to the supply chain and the operations related to this production unit. The ambition to create a model which can be used in the planning process for most products have because of the limited time frame been tested on four of the production lines.

2 Methodology

Appropriate research methodology is crucial to clarify how the project will be carried out and for the quality assurance. However, the purpose of the methodology is not to dictate how the work will be executed but rather guide the process of acquiring knowledge from the problem formulation. (Höst, et al., 2006). In this chapter, several key aspects of the methodology will be presented. Motivations are given for the chosen methodology and how quality is assured.

2.1 Research purpose

A methodology can have different purposes depending on the goals and characteristics of the project (Höst, et al., 2006). Four different types of purposes are presented by Runesson and Höst (2009), namely exploratory, descriptive, explanatory and improving. The research purpose depends on the knowledge of the studied phenomenon. Exploratory research aims to explore and develop an understanding of the phenomenon. With greater knowledge of the phenomenon, a descriptive research purpose aspires to describe what is happening. Explanatory research intends to explain the phenomenon. An improving research purpose develop a solution which solves a problem. Thus, the different purposes represent the level of understanding of the problem which increases from little knowledge in an exploratory research purpose to profound knowledge in an improving research purpose (Runesson & Höst, 2009).

2.2 Research Design

A suitable research design must be aligned with the research purpose. Examples of ways to design a research study are through case studies and modelling (Höst, et al., 2006). Kotzab and Westhaus (2005) use the phrase research strategy and outline case studies and modelling from a supply chain perspective. Christer Karlsson (2016) also explains these strategies from an operations management perspective.

2.2.1 Company case study

Projects which are set out to solve a problem experienced in a manufacturing industry are by its nature a study of a particular case and thus the design of the methods are considered flexible. (Höst, et al., 2006) In this context, flexible means that the questions asked, and the alignment of the study can be altered during the project itself. These studies can include both quantitative and qualitative evidence. They also benefit from multiple sources for these evidence, as well as from a previously set theoretical framework. (Yin, 2014)

2.2.2 Modelling

A model is an abstraction of the reality where un-relevant aspects of the phenomenon are disregarded (Höst, et al., 2006). Modelling of supply chains can relate to quantitative methods such as systems dynamics, agent-based simulation, object-oriented modelling, discrete event simulation, stochastic modelling, optimization problems and queuing networks (Kotzab & Westhaus, 2005). These methods are applied to study how uncertainty and inventory quantities affect the performance of the supply chain (Kotzab & Westhaus, 2005).

2.3 Research Techniques

There are several different techniques that can be used for collecting data when studying a particular case. Höst, Regnell and Runesson (2006) especially mention three common techniques, which can be conducted in several ways. These are Interviews, Observations and Archive analysis.

2.4 Problem Description

The company currently experience difficulties in the decision-making process regarding order quantities along their supply chain. The planning department is responsible for determining the batch sizes used in production, but the decisions affect the various departments throughout the supply chain in different ways depending on which KPIs (Key Performance Indicators) the department is evaluated upon. Therefore, the batch sizes in the production facility is a topic of much interest for all the different entities in the supply chain.

Several problematic areas that might be affected by the batch sizes exist. The warehouse management team brings attention to the fact that 40-60% of the company's finished goods inventory is stored at expensive external warehouses, to which inventory must be transported. In turn, the production management highlights the low equipment efficiency seen in some of the production lines and the resulting cost of sourcing goods that cannot be produced on site due to lack of capacity. Sourcing of finished goods and the cost of external warehouses are considered by the departments to be major "unnecessary" cost drivers.

The planning department currently have an ambition to decrease the total stock and to create good conditions for the production team, to increase their equipment efficiency by reducing the number of change overs. They think this can be done by enhancing the procedure of determining batch sizes in production, an effort that is complicated by the complexity of the company's large product portfolio and constraints in their production process, as well as the perishability of the finished goods. The planning team is currently guided by SAP to handle the production scheduling of the production lines. SAP suggests a preliminary production schedule with batches that aim to satisfy the demand from the customers, but does not take the costs driven by the batches, into account.

To support the planning team in the batch size determination, as well as in negotiations with the different functions, a model that quantifies the costs associated with the batch sizes have been requested. To increase the understanding of the impacts of decisions, the model is requested to be capable of evaluating the effect of changes to the finished goods inventory and the production.

2.4.1 Interviews

Interviews can be a powerful tool to gain a person's knowledge from the current setup and configuration of the system. An interview can be conducted in several ways, the number of which is different in various literature. Cohen, Manion and Morrison (2000) specifies four distinct types of interviews, each with their strengths and weaknesses.

An *Informal conversational interview* is similar to a natural conversation between the participating parties and follows no beforehand set agenda. The strength of this is that it is flexible in its nature and the topic emerges and evolves as the interview progresses. On the other hand, it has the weakness of being unreliable as the chance for unbiased answers and leading questions increase.

Interviews conducted with a *guided approach* or with *standardized questions* are both more systematically done and makes the data collection more efficient and robust. It is also easier to review the plan of the interviews. The negative side of these approaches are that take a lot of resources to conduct. The *guide approach* is presented by Yin (2013) as a *semi structured interview*.

Lastly, *closed quantitative interviews* are essentially questionnaires with fixed answers, suitable for quick interviews and analysis. The primary weakness is that the interviewer is essentially forcing the participant to provide the “least wrong” alternative.

2.4.2 Observations

Cohen, Manion and Morrison (2000) argue that observations are conducted on a continuous spectrum ranging from a *highly structured* to a *semi-structured* ending in an *unstructured approach*. Simplified, a structured approach is based on a hypothesis and uses the observation to either reject or confirm it while an unstructured approach aims to be exploratory (Cohen, et al., 2000).

2.4.3 Archive analysis

Archive analysis is the activity of examining historical data gathered for other purposes than those in the actual project (Höst, et al., 2006). *Historical research* is also introduced by Cohen, Manion and Morrison (2000), saying that “Historical research has been defined as the systematic and objective location, evaluation and synthesis of evidence in order to establish facts and draw conclusions about past events”, originally stated by Borg (1963). The definition of Archive analysis from Höst, Regnell and Runesson (2006) is closely in line with what in research commonly is called secondary data. In contrast to secondary data, primary data is information collected for the specific research project and its defined purpose (Bryman & Bell, 2011). As a result primary data is generally resistant to uncontrollable bias.

As with the other research methods, historical data has strengths and weaknesses. The main strength is that current problems can be solved by using data from former events that have already been recorded (Cohen, et al., 2000).

Cohen, Manion and Morrison (2000) argue that the weakness of using historical data is the vulnerability to vague problem descriptions. It is important to define the problem precisely and to avoid using broad descriptions. As support to this statement they use a quote from Best (1970) saying that “The experienced historian realizes that research must be a penetrating analysis of a limited problem, rather than the superficial examination of a broad area. The weapon of research is the rifle not the shotgun”. The conclusion is that for relevant analysis of historical data, the starting point or the problem description must be explicit and precise.

Related to this project, data from former events have been obtained from the company's IT-systems.

2.5 Research Approach

Deductive research and inductive research represent two perspectives of how the research are conducted (Bryman & Bell, 2011). The deductive perspective sees the relationship between theory and research praxis as testing of ideas developed from theory. The inductive perspective is the other way around, where theory is generated from the research praxis. A third way to conduct research is called the abductive approach which suggests an iterative process between deductive and inductive research (Freytag & Young, 2018).

2.6 Research Strategy

Traditionally in a business context, there has been a distinction between qualitative- and quantitative research. The most obvious difference is the associations between qualitative research and words, and the association between quantitative research and numbers (Bryman & Bell, 2011). Quantitative research puts effort into analysing procedures and descriptions of the studied phenomenon. Questionnaires, interviews and or documents are common ways to conduct qualitative research. Quantitative research use mathematical or statistical methods to analyse the gathered data. Field studies associated with quantitative research include surveys or experiments (Bryman & Bell, 2011).

Kotzab & Westhaus (2005) point out that historically, research in the context of logistics and supply chain management mainly has been deductive and typically been using quantitative methods. Therefore, the need for inductive research, especially the need for qualitative methods is identified in this environment. A suggested strategy to solve this is the balanced approach which incorporates both qualitative and quantitative research in an iterative way. The strategy is illustrated in Figure 1 below.

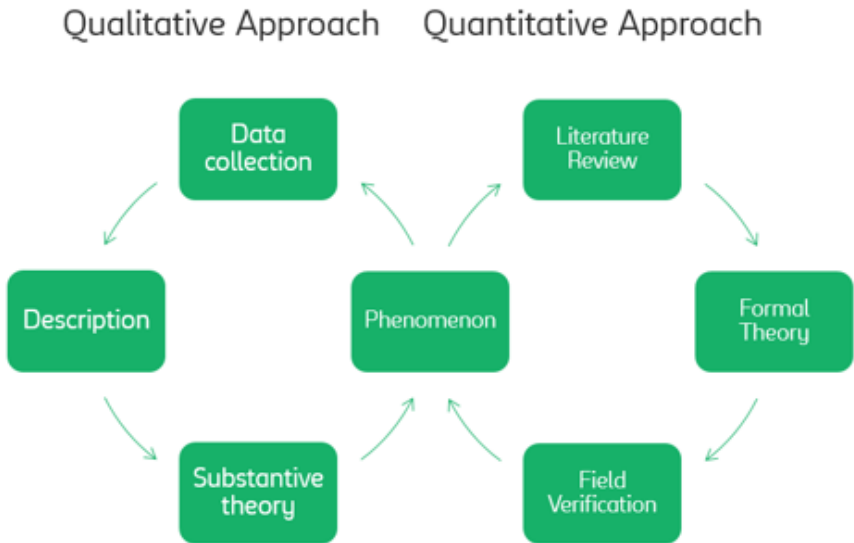


Figure 1: The balanced approach to research strategy (Kotzab & Westhaus, 2005, p.20)

Kotzab and Westhaus (2005) explain that the applicability of the balanced approach depends on the initial understanding of the problem. If the level of understanding is low, the suggested approach is to start with qualitative methods and further on use the established knowledge to develop relevant quantitative approaches. If a well-known phenomenon is studied, the suggested approach is to start with the quantitative approach to gain a deeper understanding of the more complex aspects of the problem, from where a qualitative approach could be used to explain it.

2.7 Quality Assurance

Several components need to be accounted for to achieve a trustworthy quality assurance of a thesis. Höst, Regnell and Runesson (2006) accounts for three categories:

2.7.1 Reliability

Reliability can in quantitative research be said to be equivalent to consistency and reproducibility over time, over instruments and over groups of correspondents. (Cohen, et al., 2000) Three different types of reliability are stability, equivalence and internal consistency.

2.7.2 Validity

Cohen, Manion and Morrison (2000) state that validity should not be absolute but rather as “a matter of degree”. Thus, perfection in validity is not achievable but aiming for a high degree of validity in a thesis is important. Höst, Regnell and Runesson (2006) further comments that validity is a matter of how well the data gathered is connected to what is intended to be measured.

2.7.3 Representativeness

Representativeness refers to the possibility to generalize the research material. Höst, Regnell and Runesson argue that strictly speaking, case studies are not generalizable in a broader context but can with the help of coinciding parameters of different cases be applicable in similar studies. Therefore, a pronounced description of the situation for the investigated case can increase the representativeness of the thesis. (Höst, et al., 2006)

2.8 Chosen methodology

This section summarises the chapter by presenting the chosen methodology and arguing for its quality.

2.8.1 Used Methodology

As previously mentioned, different types of research purposes are associated with different levels of understanding of the problem. Therefore, the purpose of the earlier stages of the project are exploratory while the purpose of the later stages are descriptive, explanatory and even in some respects improving since the purpose is to create a model to guide future decisions. To enable such outcome, one first need to understand the problem, which is the purpose of explanatory research. The purpose of developing a model which represent the

reality is closely in line with descriptive and explanatory research. Since the project's purpose is to develop a quantitative model which evaluates effects of changes, the most heavily emphasised research purpose is explanatory and improving.

The project take place in a business environment. Therefore, one used research design in the project is a study of a particular case. Every organisation operates under its specific conditions which limits the general representativeness. By presenting the specific conditions in this study, the representativeness is improved and argued to be high for organisations with similar circumstances.

The other used design is modelling, since one of the main tasks in the project is to develop a quantitative model. The process of developing the model is described in the next section, working procedure.

The chosen strategy is the balanced approach which incorporates both qualitative- and quantitative research strategies. The project starts with qualitative methods such as informal and formal interviews, to develop a deeper understanding of the problem. The knowledge is then extended by quantitative research. In this way the validity of the quantitative research is argued to be high, since the qualitative interviews and observations have pointed out relevant data to use. In the balanced approach both inductive and deductive research approaches are used. For that reason, an abductive research approach is taken where ideas are developed and tested in an iterative way.

Suitable research techniques to gather data and information for this project include Interviews, Observations and Archive analysis. These are used to build a solid understanding of the problem, as well as for validation, which is especially important in a complex environment where a holistic view is needed. Both informal conversations and guided interviews have been conducted. The informal interviews are used to gather relevant information to understand the nature of the problem, without affecting the interviewee with formal questions. The guided interviews are used to test and validate the information. Also, data from the company's IT-systems are used to test and validate the information, by confirming or contradicting the given information. To rely on established methods improves the validity in the study. The data from the archive analysis is argued to be of high validity since relevant and accurate data are obtained from the company's IT-systems. The data in the IT-systems have not been modified and are thus considered to be unbiased data with high reliability and validity.

As the work is made in an ever-changing organisation, consistent results cannot be guaranteed after time have passed. This is partly circumvented in the data gathering part of the thesis by delimiting data recorded prior to major changes in the company's operation. For example, a substantial change in the process of a line will result in the removal of the data from before that change in the analysis.

2.9 Working procedure

Hillier and Lieberman (2010) suggest a working procedure that can be divided into the six steps presented below.

1. Defining the Problem and Gathering Data
2. Formulating a Mathematical Model
3. Deriving Solutions from the Model
4. Testing the Model
5. Preparing to Apply the Model
6. Implementation

The procedure has been modified to fit this project and broken down to sub-steps to further guide the work. Because of the time-limitations of the project, the mathematical model is less comprehensive than those mentioned in Hillier and Liebermann (2010). Therefore step 2, 3 and 4 are merged into one step: step 2. Developing a quantitative model. The model is continuously built, validated and tested which suggest an iterative process of the three sub-steps. Giving the time constraints for this project no implementation of the results and little effort will be put into preparing the model for continuous use for the employees. The updated procedure is structured according to the steps below.

1. Defining the Problem and Gathering Data
 - 1.1. Mapping the supply chain.
 - 1.2. Evaluate and validate the process map.
 - 1.3. Identify crucial variables to include in the model.
 - 1.4. Identify data required to build framework of the model
 - 1.5. Collect, clean and validate data.
2. Formulating a mathematical model
 - 2.1. Developing the model and deriving solutions
 - 2.2. Validate the model and its solutions
 - 2.3. Test the model

3 Theoretical Framework

To provide a sufficient base of knowledge for the reader to follow the later chapters in the report, this chapter is dedicated to present relevant theory.

The chapter starts by presenting theory related to management of business and business processes to provide knowledge for the context of the problem. Thereafter, the theory used to develop the quantitative model is presented.

3.1 Strategic levels of organisations

Literature often refer to three strategic levels of a business plan, namely strategic, tactical and operational which represent different hierarchical levels in the organisation (Johnson, et al., 2015). The strategic level is the long-range business plan which include questions such as what we do and who we do it for. A tactical plan includes actions for how a specific department contributes to the strategic plan. An operational plan ties to the tactical plan by converting the plan to activities in the department (Johnson, et al., 2015). Hill and Hill (2009) use the terminology Corporate-level, Business unit-level and Functional-level to describe levels of strategy. They highlight the importance of the linkage between functional strategies and business unit strategy. The authors emphasise that the functional strategies should be developed together towards the same goals defined by the business unit strategy (Hill & Hill, 2009). They further explain that for many businesses the strategic collaboration between the marketing department and production is especially troublesome. A marketing department's purpose is to provide high customer service for criterions such as customization of products, volume and lead times since it generates sales. While performing high on these parameters is equivalent with costs for the operations which therefore has a conflicting attitude to such decisions. The discussion is shaped by strategic decisions such as investments in resources and priority of future revenues of growth (Hill & Hill, 2009).

3.2 Sales and Operations Planning

Sales and operations planning (S&OP) is a tactical business process which links the corporate strategy with the daily operative processes by balancing the supply with the demand (Grimson & Pyke, 2007). The S&OP process is typically based around the five steps; Data Gathering, Demand Planning, Supply Planning, Preparation-meeting, Executive Meeting (Wallace & Stahl, 2008).

Essential for the result is the cross-functional collaboration between the departments. To reach a balance, it is necessary to coordinate the functions' activities (Grimson & Pyke, 2007). To do so, functional silos must be broken down and managers must work towards a common goal (Grimson & Pyke, 2007).

Grimson and Pyke (2007) pointed out that so far, the development of the S&OP-method are shaped by the industry rather than the academia, although academia are constantly working to fill the gap. Noroozi and Wikner (2017) have pointed out that particularly the implementation of S&OP in the process industry has not received much attention in the literature, compared to the discrete manufacturing industry. Grimson and Pyke (2007)

addressed the gap by providing a framework to determine the maturity level of the S&OP-process in the company.

3.3 Enterprise Resource Planning

Enterprise Resource Planning (ERP) is the current embodiment of the material requirements planning (MRP) system that was introduced in the 1960s and then popularized 1972 when the American Production and Inventory Control Society launched their “MRP Crusade” campaign (Hopp & Spearman, 2001). The basic function of MRP is to plan material requirements by coordinating orders within the plant with orders outside the plant (Hopp & Spearman, 2001). MRP’s main task is therefore to schedule jobs and purchase orders to satisfy material requirements downstream, generated by an external demand. Manufacturing resource planning (MRP II) is an extension of MRP that include demand management, forecasting, capacity planning, master production scheduling, rough-cut capacity planning, capacity requirements planning, dispatching, and input/output control. The functions are explained in a hierarchy illustrated in Figure 2 below.

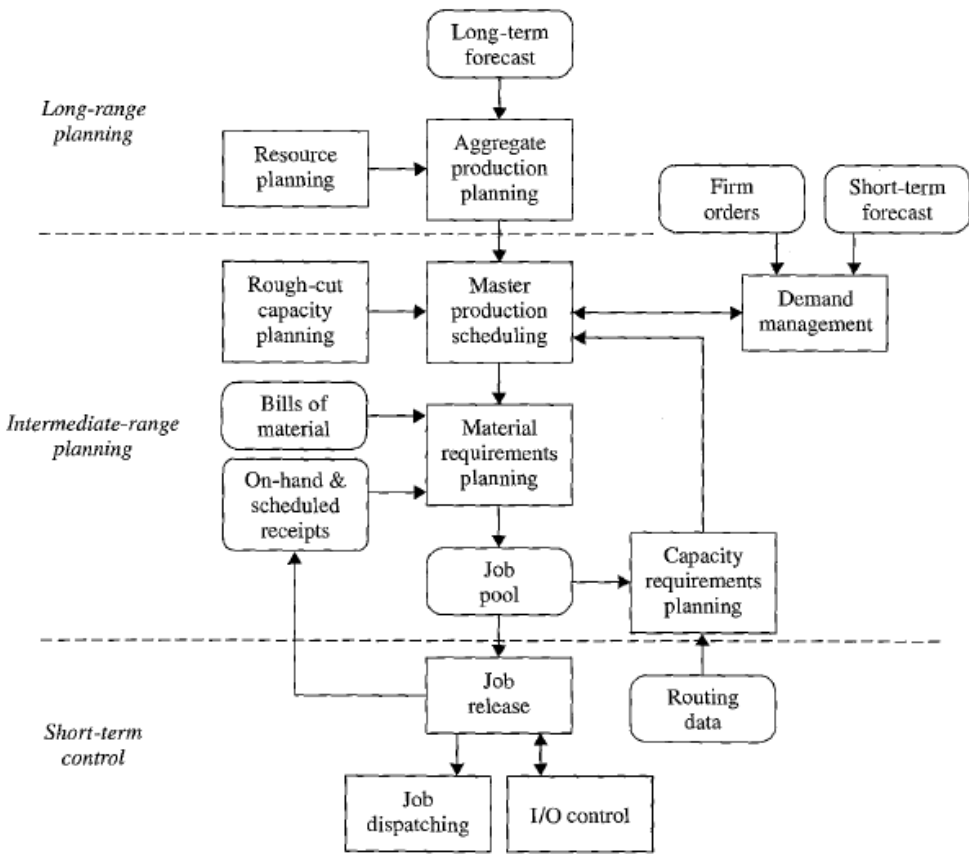


Figure 2: The MRP2 hierarchy (Hopp & Spearman, 2001, p.136).

The long-range production planning has a time range from around six months to, two to four years and the aggregated production planning are typically made for part families. (Hopp & Spearman, 2001)

At the intermediate-range planning, the master production scheduler takes the demand and the available capacity into account to create an anticipated production schedule at the highest level of planning detail. The material requirement planning coordinates the requirements of material for the orders to create a job pool from where jobs could be released into production in the short-term control (Hopp & Spearman, 2001).

3.4 Lot Sizing

Lot sizing is a major driver for both costs and customer service in a supply chain and the topic have been extensively studied during the last century. (Hosang, et al., 2007) The problem has been found to be difficult to solve and Arkin et al (1989) showed that the problem is NP-hard for a general network topology which makes it especially complex to solve for larger supply-chains.

This have made researchers move away from trying to solve the lot sizing problem generally and instead much focus is being put on restricted models as well as heuristic methods. (Hosang, et al., 2007)

This section will present some of these models and heuristics (showing assumptions and limitations) for analysis in later chapters.

3.4.1 The Economic Order Quantity

As one of the earliest and most well-known approaches to inventory management, the economic order quantity (EOQ) is one of the simplest way to determine a cost minimum for operations. (Harris, 1913) (Hopp & Spearman, 2001)

The EOQ model rest on assumptions that concern most parts of the supply chain. The production rate is assumed to be instantaneous, delivery is immediate and demand is assumed to be deterministic and constant over time demand. A changeover induces a fixed cost and keeping inventory in stock brings a constant holding cost. (Hopp & Spearman, 2001)

A consequence of these assumptions is that the average stock is the maximum stock Q divided by two. This implies, as visualised in Figure 3, that the average stock level is $\frac{Q}{2}$.

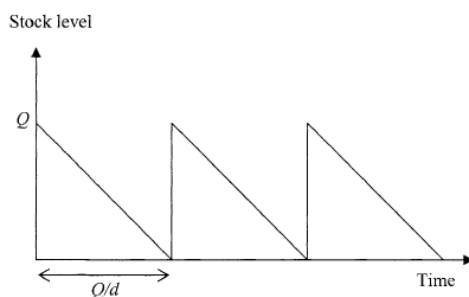


Figure 3: Level of stock in the system as assumed in EOQ-model (Axäter, 2006)

Following Axsäter (2006, page 52) a quick derivation of the EOQ-formula is presented below. For a more extensive derivation, deeper understanding and proof of convexity we refer to Hopp & Spearman (2001, page 49).

Using the following notations:

C = Cost per time unit
 h = holding cost per unit and time unit,
 A = ordering or changeover cost,
 d = demand per time unit,
 Q = batch quantity

The relevant costs related to the ordering cost are the holding cost and the changeover costs. The average holding cost per time unit is approximated to the average stock times the holding cost per unit. The average changeover cost per time unit is simply the number of changeovers per time unit, times the fixed cost of changeover. This gives:

$$C = \frac{Q}{2} * h + \frac{d}{Q} * A \quad (1)$$

To find the optimal batch quantity, the cost function is differentiated with regards to Q and set equal 0.

$$\frac{dC}{dQ} = \frac{h}{2} - \frac{d}{Q^2} * A = 0 \quad (2)$$

Solving for Q the optimal order quantity is obtained.

$$Q^* = \sqrt{\frac{2 * A * d}{h}} \quad (3)$$

Inserting the optimal order quantity in the cost function the following results are obtained:

$$C^* = \sqrt{\frac{Adh}{2}} + \sqrt{\frac{Adh}{2}} = \sqrt{2Adh} \quad (4)$$

Combining equation 1 and 4 we obtain

$$\frac{C}{C^*} = \frac{Q}{2} \sqrt{\frac{h}{2Ad}} + \frac{1}{2Q} \sqrt{\frac{2Ad}{h}} = \frac{1}{2} \left(\frac{Q}{Q^*} + \frac{Q^*}{Q} \right) \quad (5)$$

From (5), Axsäter (2006) concludes that a 50% increase or decrease from the optimal order quantity only increase the cost by about 8%. Axsäter (2006) also notes that the cost parameters are even less sensitive. Using an ordering cost 50% higher than the real cost only impacts the final cost with 2%.

3.4.2 Wagner-Whitin

Another, more complicated, way to incorporate the time-varying demand in the calculation is the usage of the Wagner-Whitin algorithm. Again, time is not modelled as continuous and infinite but rather as a finite number of discrete time periods. The holding cost and changeover cost is still constant over time. The same notations as Axsäter (2006) is used.

T = Number of periods

d_i = Demand in period i

A = Ordering cost

h = holding cost per time unit

Wagner-Whitins optimal solution hold two properties, as presented by Axsäter (2006, page 63):

1. A replenishment must always cover the demand in an integer number of consecutive periods.
2. The holding costs for a period demand should never exceed the ordering cost.

The objective of the algorithm is to minimize the total cost of the ordering cost and holding cost for all periods T . Since the demand is no longer constant during all periods neither is the optimal ordering quantity. Axsäter (2006) give an example, shown in Figure 4, of how this computation is made for $A = 300$ and $h = 1$ per unit of time with a timeframe of 10 periods.

Period t	1	2	3	4	5	6	7	8	9	10
d_t	50	60	90	70	30	100	60	40	80	20
$k=t$	300	<u>600</u>	660	840	1030	1090	1370	1450	1530	1770
$k=t+1$	<u>360</u>	690	730	870	1130	1150	1410	1530	1550	
$k=t+2$	540	830	790	1070	1250	1230	1570	1570		
$k=t+3$	750	920	1090	1250	1370	1470	1630			
$k=t+4$	870		1330	1410		1550				
$k=t+5$			1530							

Figure 4: Example of the wagner-whitin algorithm at work (Axäter, 2006, p.65).

As shown, every feasible solution, following the two optimal solution properties have been computed for each time period. The algorithm then selects the solution with the least total cost as the optimal solution.

3.4.3 Silver-Meal

A well-known method is to use the Silver-Meal heuristic. (Silver & Meal, 1973). In this heuristic, a new delivery is chosen the time period where the average cost per period increase for the first time. Using the same example as before, Axäters (2006, 66) explain how the heuristic work. Below the period cost for deliveries that cover 2, 3... periods are presented.

2 periods $(300+60)/2 = 180 < 300,$

3 periods $(300 + 60 + 2 * 90)/3 = 180 < 180,$

4 periods $(300 + 60 + 2 \cdot 90 + 3 \cdot 70)/4 = 187.5 > 180$, which means a new delivery in period 4.

For a full through explanation of the heuristic we refer to Axäter (2006, 66).

3.5 Critical Variables

The above models are all subject to limitations, and all require calculation of input parameters **A** (changeover cost), **h** (holding cost for period t) and **d** (demand over period t).

Vital to observe when using the holding cost and changeover cost to calculate an optimal ordering quantity is to only include costs that are directly affected by the ordering quantity decision. (Axäter, 2006)

3.5.1 Holding Cost

The holding cost, *h*, is the cost for keeping one unit in stock, one unit of time. According to Berling (2005), the holding cost can be divided in four main cost components.

- Capital cost
- Inventory service cost
- Storage space cost
- Inventory risk cost

The capital cost is essentially tied up to the expectations of the company's stakeholders. While the capital is tied up in inventory, the chance is high that it will not grow in value at the same rate as if it were invested elsewhere. Stakeholders often accept lower return on invested capital when the risk is low and consequently require a higher return of high risks investments. Berling (2005) compare this to the stock market where it is commonly accepted that high return stocks carry higher risks, while for example index funds generally generate lower returns while also carrying a reduced risk.

The Inventory service cost, the Storage space cost and the Inventory risk cost can often be consolidated and are then referred to as out-of-pocket costs. (Berling, 2005). Particularly when outsourcing storage to a third-party firm. Observe that the inventory risk cost is the cost associated to physical risk of keeping the goods in stock and not the financial risk of doing so.

In short, the out-of-pocket holding cost consists of costs connected to the physical storing of the units such as rent and transportation, tax and insurance together with the cost of risk (i.e. the risk that the goods cannot be sold at full price due to circumstances connected to the time stored).

3.5.2 Activity Based Costing

The method of Activity Based Costing originated from price calculations for products, based on the cost of producing them (Skärvad & Olsson, 2005). Costs related to the price are of both direct- and indirect nature. One example of a direct costs are material cost to produce the product. Examples of indirect cost are cost such as planning the production (Skärvad & Olsson, 2005).

The essential in the ABC-method is how the indirect costs are allocated to certain activities. The costs related to the activity are allocated based on specific cost drivers. Berling (2005) concludes that the holding cost can be derived from the used amount of the resource which is derived from the cost driver λ_k , and the activity cost κ which is the marginal increase of the average cost with respect to the mean output level.

$$h_k = \lambda_k * \kappa \quad (6)$$

3.5.3 Changeover Cost

The changeover cost (A), also consist of different elements. According to Berling (2005) these often include personnel and equipment costs, as well as the reduction in capacity associated with smaller batches. It can be concluded that the changeover cost is dependent on several company and machinery specific factors that will be further discussed later in the report.

Changeover costs can increase significantly if an expensive, capacity constrained, machine needs to pause during the setup. (Axäter, 2006)

3.5.4 Shortage Cost

The shortage cost is the cost associated with not being able to meet the demand from a customer in the supply chain on time. A customer can be the end-customer but also for example another step in the production process.

Shortage costs can in the short range be easily quantified, as an incoming customer order that is rejected is a direct loss in sales. In the long run however, a dissatisfied customer might bring their business elsewhere or affect other customers, leading to lost future sales, this is harder to quantify (Berling, 2005).

3.6 (R, Q) Policy

Simple inventory policies to control the inventory have been developed to decide when and how much to order. One of the most widely used policies is the (R, Q) Policy. Inventory systems can be designed so that the inventory position is continuously monitored, denoted *continuous review*. They can also be reviewed at certain times, denoted *periodic review* (Axäter, 2006).

Crucial variables are:

L = Lead time

T = review period, i. e., the time interval between reviews

The decision of when and how much to order should be based on the stock situation, demand and cost parameters (Axäter, 2006). Notations used by Axäter (2006) are:

- *outstanding orders*, defined as orders made that have not yet arrived
- *backorders*, defined as units that have been demanded but not yet delivered

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

$inventory\ level = stock\ on\ hand - backorders$

In an (R,Q) Policy, an order of Q units will be triggered when the inventory position declines to R or below. The maximum inventory position for this system are thus R+Q (Axäter, 2006). How a periodically reviewed (R,Q) policy operates are presented below in Figure 5.

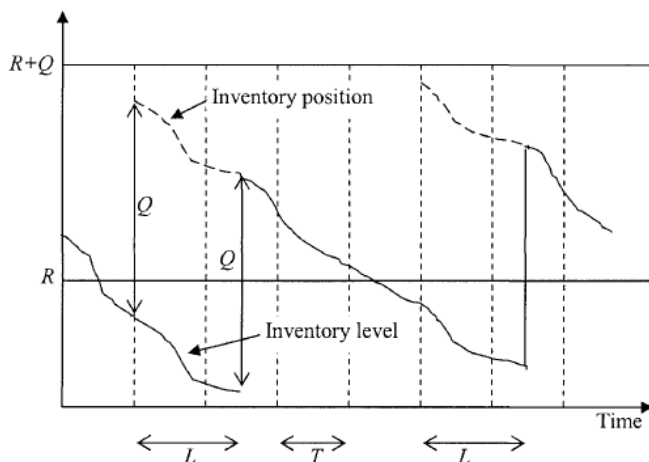


Figure 5. (R,Q) Policy (Axäter, 2006, p.50)

3.7 Service Levels and Safety Stocks

In a (R, Q) system, a common procedure to determine the required safety stock is to base it on achieving a predefined service level. Axäter (2006) present three definitions of service levels:

S_1 = probability of no stockout per order cycle,

S_2 = "fill rate" – fraction of demand that can be satisfied immediately from stock on hand.

S_3 = "ready rate" – fraction of time with positive stock on hand.

Worth noticing is that if the demand is continuous, S2 and S3 are equivalent (Axäter, 2006). S1 is usually used in combination with continuous review models and continuous demand. A disadvantage with using S1 for inventory control is that it does not take the batch size (Q) into account. In a (R, Q) policy the problem of determining S1 is about choosing R, such that there is a certain specified probability S1 for the demand during the lead time to be lower than R. With the assumption that the demand during the lead time is normally distributed with average mean μ' and standard deviation σ' , the problem can be formulated as:

$$S_1 = P(D(L) \leq R) = \phi\left(\frac{R - \mu'}{\sigma'}\right) = \phi\left(\frac{SS}{\sigma'}\right), \quad (7)$$

where the safety stock SS is defined as $R - \mu'$ and ϕ is the cumulative distribution for the normal distribution (Axäter, 2006).

For a (R, Q) policy and continuous normally distributed demand S2 and S3 is the probability of positive stock, which can be obtained from (8) below (Axäter, 2006).

$$S_2 = S_3 = 1 - F(0) = 1 - \frac{\sigma'}{Q} * \left[G\left(\frac{SS}{\sigma'}\right) - G\left(\frac{SS + Q}{\sigma'}\right) \right] \quad (8)$$

Where G is defined as:

$$G(x) = \int_x^{\infty} (v - x)\varphi(v)dv = \varphi(x) - x(1 - \phi(x)) \quad (9)$$

Note that $G'(v) = 1 - \phi(v)$.

In a situation where safety stock is used, the average stock on hand presented in section 3.4.1 (Economic Order Quantity) can be approximated as: (Axäter, 2006)

$$\text{average stock on hand} = SS + \frac{Q}{2}$$

This is evident, since the average stock without the safety stock is $Q/2$ and the average variation of the demand is 0 due to the normality of the demand.

3.8 Yield loss

Yield loss in production is volume lost due to unplanned events in the process. These events include everything from machine malfunction to lack of raw material.

Yield loss in production can be modeled, for example, using a stochastic proportional yield model where a certain quotient of the planned volume Y , $Z \in [0,1]$ is produced such as the resulting output is the product of the planned volume Y and the quotient Z . The stochastic quotient Z belongs to some arbitrary distribution. (Sonntag, 2017)

3.9 Statistical Theory

This section provides the reader with the basic statistics theory used in the analysis section.

3.9.1 Linear combinations of stochastic variables

The normal distribution has the property that the sum of independent normally distributed stochastic variables is normally distributed. This has the following effect if X and Y are two normally distributed stochastic variables (Blom, et al., 2005)

$$X \in N(\mu_x, \sigma_x)$$

$$Y \in N(\mu_Y, \sigma_Y)$$

$$X + Y \in N(\mu_X + \mu_Y, \sqrt{\sigma_X^2 + \sigma_Y^2})$$

3.9.2 Statistical fitting

Processes are rarely deterministic. A standard procedure for statistical distribution fitting can be described as follows (Laguna & Marklund, 2013):

- Phase 1. Identify appropriate distribution family by graphically presenting the data.
- Phase 2. Estimate distribution parameters based on the distribution family to develop a hypothesis for a specific distribution.
- Phase 3. Perform a statistical goodness-of-fit test to investigate if the hypothesis may be rejected. These phases continue until a hypothesis for a distribution cannot be rejected. If no well-known distribution family is appropriate, an empirical distribution may be used.

To manually perform this analysis may be very time-consuming for large data-sets, but Software tools are available to perform this analysis (Laguna & Marklund, 2013). Two commonly types of goodness-of-fit tests are the χ^2 -test and the Kolmogorov-Smirnov-test.

3.9.3 χ^2 -test

The χ^2 -test can be used to the the hypothesis that the data belong to a specific distribution. The hypothesis is described by (Blom, et al., 2005):

$$H_0: P(A_1) = p_1, P(A_2) = p_2, \dots, P(A_r) = p_r(\theta), \text{ for any } \theta \text{ (distribution parameter)}$$

Blom et Al (2005) explain that a common procedure is to use the maximum-likelihood method based on the observations to estimate the distribution parameters. T is then calculated as:

$$T = \sum_{j=1}^r \frac{(x_j - np_j^*)^2}{np_j^*} \quad (10)$$

x_j = actual frequency for the result

n = total data points

$p_j^* = p_j(\theta_{obs}^*)$

To be tested and compared to the tabulated value for χ^2 (r-k-1), where k is the number of estimated parameters. The hypothesis H_0 can be rejected on the significance level α if $T > \chi_{\alpha}^2(r - k - 1)$. It is important to point out if $T \leq \chi_{\alpha}^2(r - k - 1)$ it does not mean that the data follows the specific distribution, but rather that the hypothesis that the data follows the distribution, cannot be rejected (Blom, et al., 2005).

3.9.4 Kolmogorov-Smirnov test

The test compares the empirical distribution function with the cumulative probability function of the tested distribution. The empirical distribution function has the following form (Laguna & Marklund, 2013):

$$F_n(x) = \frac{\text{Number of } x_i < x}{n} \quad (11)$$

Where x_1, \dots, x_n are the values of the sampled data. The test measures the largest deviation between the theoretical and empirical cumulative probability distribution functions, for every given value of x . Laguna and Marklund (2013) explains the procedure for the test.

1. Order the sampled data from the smallest to largest value
2. Compute D^+ and D^- using the theoretical cumulative distribution function $\hat{F}(x)$:

$$D^+ = \max_{1 \leq i \leq n} \left[\frac{i}{n} - \hat{F}(x_i) \right] \quad (12)$$

$$D^- = \max_{1 \leq i \leq n} \left[\hat{F}(x_i) - \frac{i-1}{n} \right] \quad (13)$$

3. Calculate $D = \max(D^-, D^+)$.
4. Find the KS value for the specified level of significance and the sample size n .
5. If the critical KS value is greater than or equal to D , the hypothesis that the field data come from the theoretical distribution cannot be rejected.

4 Empirical Context

This chapter describes relevant information about the company. The supply chain is depicted, and relevant processes and activities are explained. The purpose of this chapter is to build a foundation for the analysis, identifying current parameters and situations while also introducing the reader to how the company currently operates.

4.1 Supply chain

The company uses a make-to-stock policy to provide goods to its customers. The company's supply chain in Sweden is illustrated with the high level flow chart, provided in Figure 6 below. The colour coding explained in Figure 6 illustrate which department is responsible for each operation.

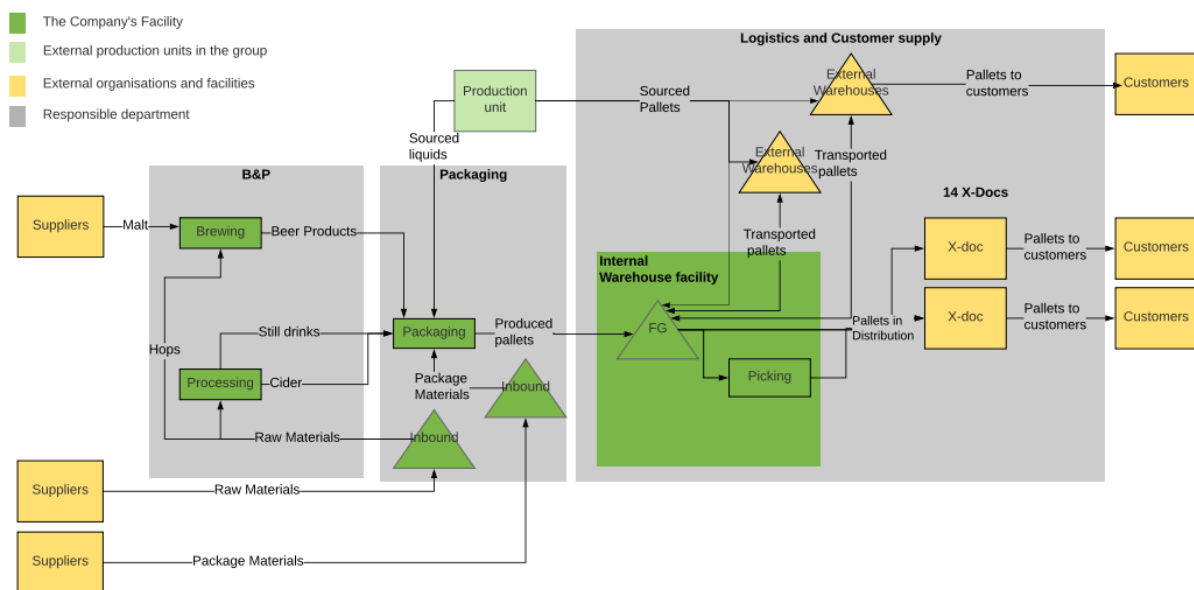


Figure 6: The company's supply chain in Sweden

Starting from the suppliers at the left side of Figure 6, the raw material is received at the processing facility. Packaging materials such as glass bottles and labels are received at the warehouse facility. These raw materials are purchased from a multitude of suppliers, from Sweden, Europe and other parts of the world. After the beverage is produced it is sent to be tapped and packaged in an operation called packaging, in which there are several different production lines.

From the packaging department pallets are sent to the finished goods warehouse where the majority of the stock is kept. Apart from this main warehouse at the production site, the company also rent warehousing space and services from a third-party logistics service provider, when the capacity of the main warehouse is insufficient. Most of sales need to be shipped from the company's warehouse, and stock moved to external warehouses most often need to be brought back to the main warehouse before being shipped. At the X-docs, see Figure 6, goods are consolidated for transports to its end customers.

If SKUs are needed at a certain time when it cannot be produced because of limitations and complexity in the production, SKUs and liquids can be sourced from other manufacturing units.

4.2 Processing

This section presents the relevant aspects of the operations under the department responsible for producing the beverage.

The beverage is produced using raw material delivered to the incoming warehouse and then stored in pressurised bulk tanks. Various production constraints for various products should be considered in this step. For some articles, extra constraints exist for the size of the batch due to raw material packaging that must be consumed immediately after it is opened. In this instance the batch size must correspond to a multiple of raw material packages. For other articles, constraints exist for the size of the batch due to the tank sizes. There is a minimal production volume affiliated with all products.

4.3 Packaging

The products are packaged at the packing lines in the manufacturing unit. The packaging facility contains seven packaging lines which use several types of bottles and cans in different volumes and with different production rates.

The packaging lines are open for production in accordance to the shift applied to that line, see Table 1. The time that employees are present at the lines is called the lines “opening hours”. This should not to be confused with the production hours of the line, which is the time of actual production. Other activities that are done during the opening hours are cleaning, training of personnel and maintenance. Table 1 shows the opening hours for each of the shifts used.

Table 1: Opening hours in production during a week.

Shifts	Hours
1-shift	40
2-shift	76
3-shift	114
4-shift	138
5-shift	168

The first activity at the line is to fill a package with its product. After that the packages are consolidated into larger selling units called pieces. The last activity at the line is to put the pieces on a pallet. The activity with the lowest throughput, the “bottleneck” of the machine, is the actual filling of the package.

All products manufactured by the company is associated to a specific “recipe group”. A recipe group is a range of products, defined by the company that shares the same characteristics. Each recipe group, and consequently all products included in it, can only be packaged on one line.

4.3.1 Production Fulfilment

The production fulfilment of the packaging lines states how much of the planned volume per week that was produced. The planned amount is the amount set for production the Sunday before the production week, which is measured against the actual output the Sunday at the end of the week. This amount can vary greatly, and the resulting volume for a week can both be higher and lower compared to the planned volume. Reasons for lower output than planned include machine breakdowns, issues that result in a lower production speed or a problem in material supply. Reasonings for a higher than planned output most notably includes a higher production speed than planned for and consequently an increase from the plan for lines starving for capacity. This puts extra strain on suppliers and purchasing department to make sure there are material in stock in case of extra production.

As can be seen in Table 2 below, the mean of the production fulfilment is generally below 100%. A production fulfilment below 100% signifies a yield loss, while a production fulfilment of above 100% signifies a yield gain. Later in the report both shall be named yield loss, where a negative yield loss signifies a yield gain.

Table 2: Average production fulfilment during the last 4 years for the four studied production lines.

Line	2014	2015	2016	2017
Line X	96,0%	95,3%	89,2%	85,5%
Line Y	95,4%	90,5%	93,9%	95,7%
Line Z	93,8%	86,7%	91,2%	79,3%
Line I	94,1%	92,5%	88,7%	93,0%

4.3.2 Changeover Process

The company use several production lines to produce their SKUs. Since the number of production lines are considerably less than the number of SKUs, and the machine need to be adjusted for different kind of SKUs, all lines are subject to changeovers.

The changeover requires different operations depending on which combination of SKUs is in succession of each other, signifying that the time for changeover is sequence dependent. For example, a change from a 12-pack to a 6-pack of the same beverage is fast while a change from a fruity beverage to a clear carbonated water will require additional operations.

The characteristics of the changeover, and the times and costs associated with it, vary from line and type of product. For weeks close to current time, where the production sequencing is known, a matrix is used to determine the planned changeover time in the production. For long-term planning, the sequencing is not known, and estimation must be used.

Two different definitions of the changeover time in the production exist in the company. The packaging operations define the changeover as tap-to-tap. This means the time from where the last package was filled of the old batch to the time where the first package is filled from the new batch. The planning department on the other hand define the changeover time as what is referred to as pallet-to-pallet. This is the time from where the last full pallet was

retrieved of the old batch by the forklifts to the time where the first full pallet of the new batch is retrieved.

The taping is the bottleneck on all lines in the packaging department.

Each changeover carries a cost of cleaning materials and a start-up waste in beverage. The time spent on changeover is also costing the company employee-time not spent producing. The lines are subject to fixed costs of depreciation, maintenance, utilities etc. The time spent doing changeover also result in more volume that need to be sourced, inducing more costs. Since determining these costs have not been a goal of the thesis, and the gathering of this data have been deemed to extensive for this project, these costs will be taken at face-value from the production controllers of the company.

Three different suggestions to approximate the changeover cost have been considered. First, all changeovers taking place on a line could be said to carry the same cost. Secondly, approximating on a recipe group level results in that only similar products carrying the same changeover cost. Lastly, an estimation on a SKU level could be done, resulting in all SKUs having their individual changeover cost. The chosen approach for this thesis is the recipe group level and the reasoning for this will be explained in chapter 5.

After the packaging operation is done and the pallets of produced SKUs are finished they are picked up by LGVs (Laser Guided Vehicles) and transported to the warehouse.

4.3.3 Line Efficiency

One of the major KPIs the packaging department is measured on is their output compared to the maximul theoretical output of the machines. One-hundred percent efficiency is defined as the line running full speed all the available time (opening hours), i.e., the entire time operators are scheduled to work. The efficiency is then the ratio of actual time run with the actual speed and the available time there are operators available running on maximum speed.

In a perfect world the difference from the actual efficiency and the maximum efficiency would be due only to change-over downtimes. However, the lines do not always run on maximum capacity when online, and they are subject to breakdowns and other stops reducing efficiency further.

Figure 7 below shows an example of how the opening hours is allocated on one of the lines. OEE (Overall Equipment Effectiveness) is the fraction of time the machine is running on full speed.

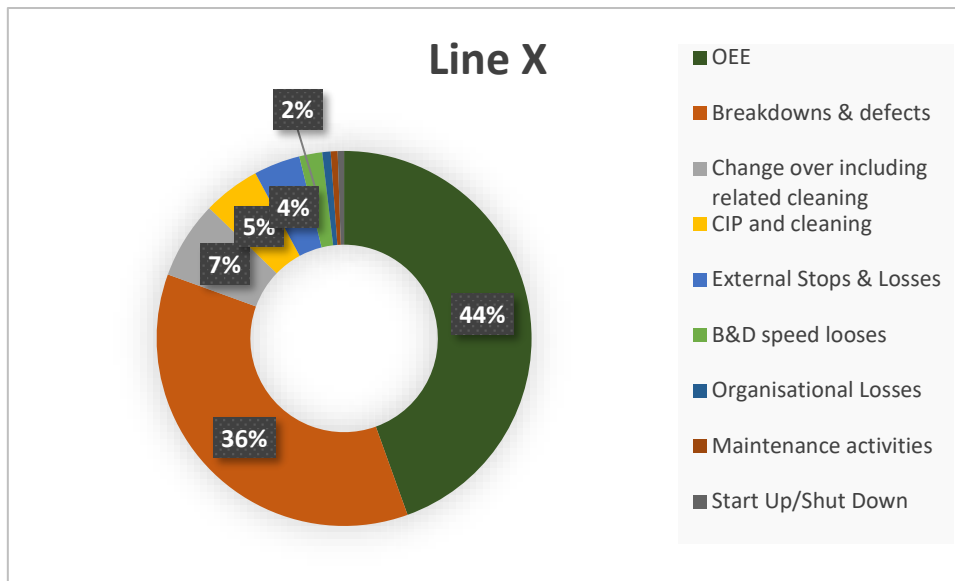


Figure 7: Activity distribution for the open time of line X.

The relationship between changeover time and efficiency is clear, the efficiency loss is simply the changeover time divided by the total time. The relationship between breakdown and efficiency is also clear, breakdown results in an efficiency of zero for the disrupted time.

The deviation from maximum line speed when it is running can be explained by several different factors. These include different mechanical problems, retrieval problems in the warehouse and ramp-up issues.

4.4 Warehouse

The company uses several warehouse facilities. Beside the main warehouse, the company have throughout 2017 rented spaces in four external warehouses. The inventories are transported between the locations by an external truck company. When the company ship inventory between the warehouses, they have the option to purchase a transport with goods one way (single transportation) or transportation of goods back and forth to a warehouse (double transportation). There is no special dedication of the articles to specific locations in the warehouses.

It is the planning department that decides what to transport between the warehouses and when. The decision is then communicated to the warehouse department which handles the administrative process of booking transportations and preparation of goods to be transported. The planning department receive a suggestion from SAP of what goods that should be transported and when, although what the planner chose to ship often deviate from SAP's suggestion.

How the finished goods are distributed among the warehouse is presented in figure 8 below.

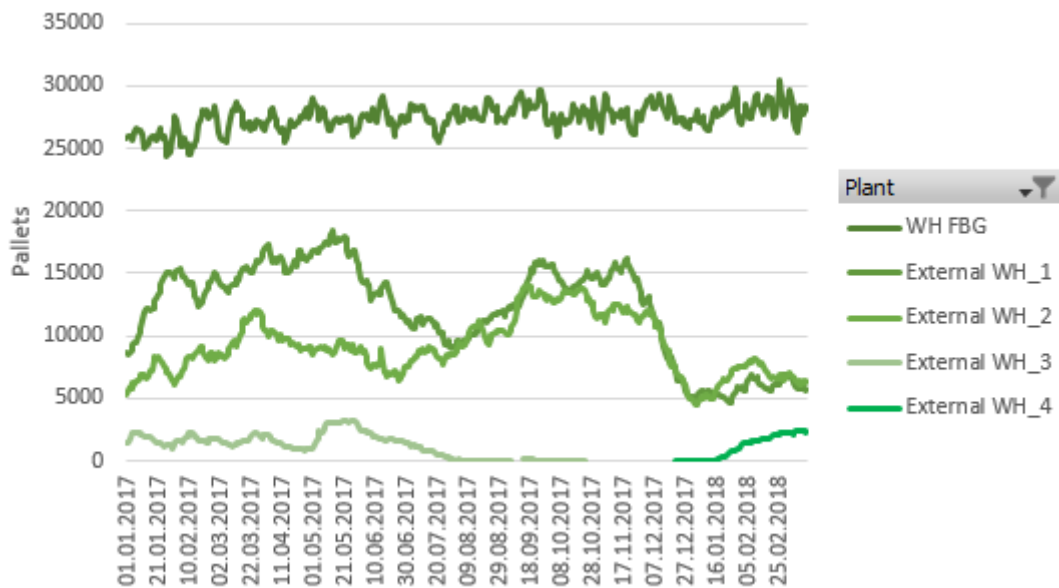


Figure 8 stock on hand at the warehouses dated back to January 1, 2017.

Figure 8 illustrate that the external warehouses are always used. The number of stored pallets at the external warehouses are varying throughout of the year while the main warehouse inventory are kept at around 27 000 pallets which corresponds to a utilization of 75%. This utilization is expressed as a target utilization in the main warehouse. The variations of inventory levels are an effect of seasonality and variations in demand which will be more thoroughly explained in the analysis.

4.5 Information systems

The company utilize several different IT systems to align and streamline daily operations and strategic decisions. This chapter will provide a brief overview of these systems.

4.5.1 SAP

SAP is the ERP (enterprise resource planning) system used by the company. It integrates and consolidates information form the whole enterprise, serving as the working platform for several functions of the company. This report will mainly focus on SAP functions tied to the planning of production and warehousing operations.

4.5.2 Production follow-up tool

As a graphical feedback tool from the production, the company uses a self-developed software. From this application the user can quickly and easily get a good grasp of how the production is performing. The information in the follow-up tool is available for all departments.

4.5.3 MES

The company's manufacturing execution system (MES), serves as the interface between the rest of the information architecture and the production floor. The MES measures, controls

and serves as the interactive software for the operators to enter or retrieve information to SAP.

The MES collect real-time data and transfer it both to the production follow-up tool and SAP, allowing the planning department to act in time to avoid or lessen the consequence of complications.

4.5.4 Warehouse Management System (WMS)

While SAP keep track of the high-level inventory management, the WMS have low level, more exact, information of the flow in the warehouse. As an example, SAP only have information of which SKUs that are kept in a warehouse and in which quantities, while the WMS can point to the exact location in the warehouse. The WMS is also used for planning and keeping track of ingoing and outgoing shipments

4.5.5 Business Intelligence software (BI)

The company uses a business intelligence service to retrieve data from SAP in manageable report formats which can also be converted to excel format. The service is flexible, and users have the ability to create new reports by using preset templates which can then be shared with other employees, creating a standardized report format which can be used for analysis.

As all the systems are connected to SAP, and the BI retrieves and presents the data from SAP, the BI can present data originating from the MES or WMS. This gives full insight in these systems from the BI.

4.6 Inventory Control

This section presents the relevant aspect of how the company is controlling their inventory and how their results are measured.

4.6.1 Batch Size

Currently the company does not use any theoretical model to determine the batch size in their production. SAP uses a batch quantity when scheduling the production that is based on either a fix quantity or the demand of a set number of weeks. These amounts are set when the product is accepted in the portfolio based on similar products and is iteratively updated if major failures are recognized.

4.6.2 Service Level

When a new customer order is received, the stock is immediately checked to verify that the full volume of the order can be satisfied from stock on the specified shipping date. The volume that is accepted is classified as ATP (Available to promise) and is confirmed to the customer. The fraction of the volume that cannot be satisfied from stock is classified as PO2-volume and is rejected. HL is an abbreviation for hectolitres.

$$PO2 - volume = Customer Order (HL) - Available to promise(HL)$$

When the promised order is to be picked from stock there is a chance that this picking will fail. Causes for this failure can include for example a stock-balance error or unforeseen errors in the production between the order confirmation and the shipping date. Volume that can be picked are classified as PA (Product availability) and volume that cannot be picked are classified as PO4-volume.

$$PO4 - volume = Available\ to\ promise(HL) - Available\ at\ picking(HL)$$

The company differentiate the required service level between their products, based on the products strategic importance for the company. The departments are measured on what they call "stock service level", which is the part of the total ordered volume that can be satisfied from stock. Linking to chapter 3.5 this is the same definition as for S2 in the literature. Formally, the stock service level is defined as:

$$SSL = 1 - \left(\frac{\sum PO2 + \sum PO4\ volumes}{\sum Order\ volume} \right) \quad (14)$$

4.6.3 Safety stock

The company base their safety stock calculation on a formula commonly used in industry. (King, 2011)

$$SS = Z * \sqrt{(LT * \sigma_D^2) + (\sigma_{LT} * D_{AVG})^2} \quad (15)$$

Where:

$Z = Z - score\ or\ safety\ factor\ (set\ by\ required\ servicelevel)$

$LT = Leadtime\ in\ weeks$

$\sigma_D = Standard\ deviation\ of\ demand\ per\ week$

$\sigma_{LT} = Standard\ deviation\ of\ leadtime\ per\ week$

$D_{AVG} = average\ demand\ per\ week$

This formula is derived from the cycle service level, or S1. (See chapter 3.5.2)

The company have made some alterations to the expression to customize it for their own organization.

$$SS = k * \sqrt{(LT * \sigma_{FE}^2) + (PE. CT) * Q^2} \quad (16)$$

$k = New\ safety\ factor$

$LT = Leadtime\ in\ weeks$

$\sigma_{FE} = Standard\ deviation\ of\ forecast\ error\ per\ week$

$PE. CT = Supply\ variability\ per\ week$

$Q = Average\ batch\ size$

Exactly how this alteration was made is unclear and will not be researched further in this thesis. The most important observation is that the average demand is no longer used but

instead the average historical batch size, a fact that need to be considered when examining the consequences of altering the batch sizes.

4.7 Activities in the Planning Department

This section aims to present the activities and processes which take place in the planning department. The section starts with introducing the operative aspects of how a batch size is determined and continues with more tactical aspects of the departments work.

4.7.1 Operative planning process

The planning department is planning what to produce at the different filling-lines and when to produce it. To do so, also the availability of raw material and the beverage needs to be considered. The production plan is shared with the filling line, the processing department and the warehouse to enable coordination of their operations. The procedure followed by the planning department is presented in Figure 9 below where the figures in the vertical line represent activities related to determination of the batch sizes. The figures to the left of the vertical line relate to activities in other parts of the supply chain. The work is facilitated by the SAP modules APO and ERP.

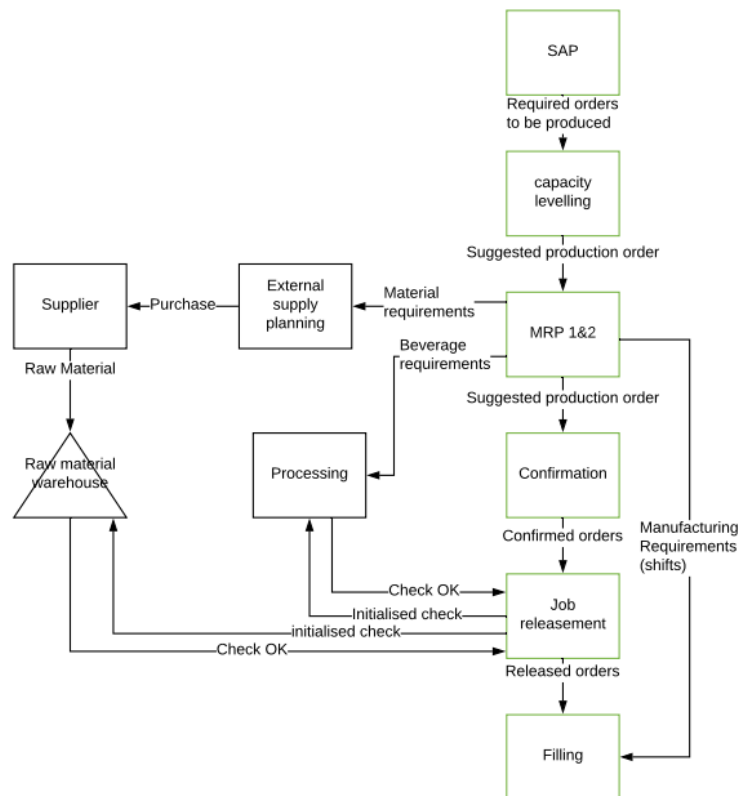


Figure 9 The operative planning process

SAP looks at the forecasted demand and inventory levels for the SKUs to suggest a production plan where production orders of all SKUs are put in. The order quantity is determined by choosing between a fix order size for the SKU and a dynamic order size equal

to a number of weeks estimated demand. The program does not take into account any form of capacity constraints.

The activity called Capacity levelling are performed in SAP every Sunday. In this activity SAP adjust the batch sizes by taking input from available capacity on the production e.g. shifts for the line and comes up with a suggested production order.

From the created production order SAP suggests purchase quantities for raw material for the external supply planning, and beverage requirements to the processing, in Figure 9 called MRP 1&2.

After these activities, the manual planning starts. Planners can change the batch sizes and the production order to increase the efficiency of the filling line and simplify the handling of the goods in the finish goods warehouse.

In the activity called confirmation a planner confirms the order which makes it possible to see it in the company's internal production system follow-up tool. In the activity called job releasement the status of an order changes from confirmed to released which means that the order is ready to be produced.

4.7.2 Stock building

The company have stated that during most the year one or more lines are in a stock building period i.e. in a period where they are pushing the inventory levels up in anticipation of a period where demand exceeds capacity. This need is displayed in Figure 10, which show the demand for each week divided by the maximum demand during the year and the maximum capacity of the line. The week with the highest demand of the year is, naturally, the week with the value 100% on the y-axis.

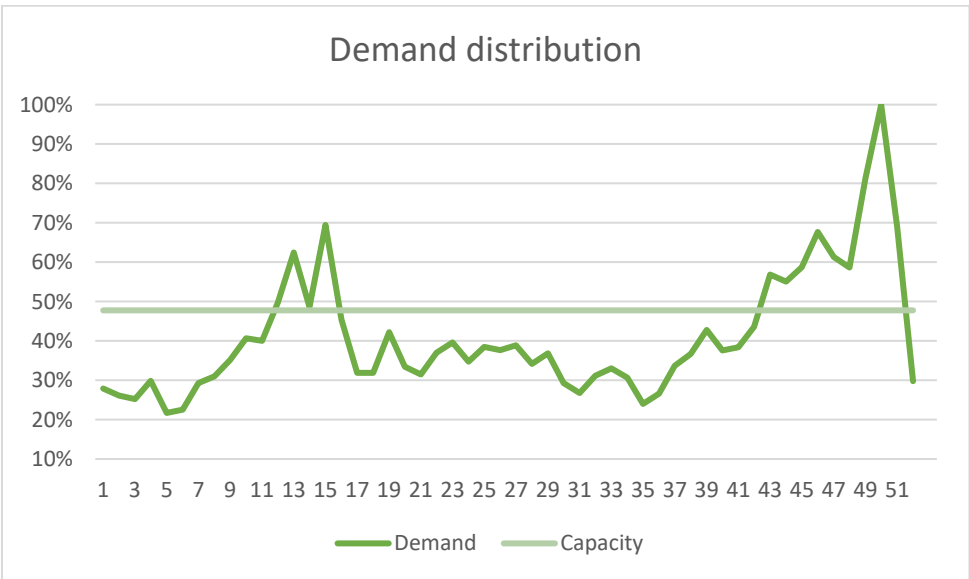


Figure 10: Demand of SKUs produced by line Y throughout the year, and the capacity of the line.

As is evident by the figure, the demand greatly surpasses the capacity of the line some periods of the year, and thus the stock need to be built up in anticipation of this during the weeks of lower demand.

The company is currently handling this situation by producing ahead of demand, and when this is not enough the products are sourced from elsewhere in the world. This results in higher cost of breakdown and changeover for these lines as any lost production volume will need to be procured from other alternatives. All non-productive time can be translated to lost produced volume and therefore more sourced volume. The sourced volume carries a high cost and thus the profit margin is significantly reduced.

4.7.3 Cycle planning of SKUs

Each SKU in the company's portfolio can only be produced on one line in the production facility. Since the difference of the product before and after the changeover is the major influence on how long time the changeover will consume, there is a strong incentive to run similar products in sequence. The company have translated this insight into cycled schedules for their production. For example, one week the line only produces fruity beverage and other week, only non-fruity beverages. This example entails that the cycle is two weeks for these products since every production would need to satisfy demand for at least two weeks until the next production. A common procedure is to include articles from the same recipe-group in the same cycled schedule.

4.7.4 Sales and Operations Planning at the Company

Sales and operations planning is a business process which is used by the company, and a structured procedure is followed. The procedure has four steps which are performed every month: Demand Review, Supply Review, Demand & Supply Reconciliation and Monthly S&OP meeting. The S&OP process which is performed in each country separately, is outlined in Figure 11. The arrows present the responsible function for the activity while the bullet points are the output from the activity.



Figure 11: The S&OP process at the company.

The process starts in the sales function where the marketing strategy, planned marketing initiatives and the forecast are analysed to derive the demand plan. The risks and opportunities of this plan are highlighted.

In the second step, the supply chain reviews their capabilities to facilitate this plan and update the plan according to their constraints. The review includes analysing the available capacity and if sourcing is necessary. Also, the risk and opportunities from the supply chain's perspective are highlighted. In times of uncertainty, the company need to make sure that it has a certain amount of buffer capacity i.e. a certain time where nothing is planned, to be able incorporate necessary additions to the plan.

In the step Demand and Supply Reconciliation, the demand and supply are aligned between managers from the sales department and the managers in the supply chain. The action plan is also updated together with the risks and opportunities.

In the fourth step each country's management team signs off on the plan. In each step the meeting time is tracked to evaluate the efficiency of the meeting.

In this way, the company is using their S&OP process with a bottom-up approach. The information is gathered in the departments and shared to be aligned in the company with guidance from senior management. The company use four KPIs related to the S&OP process namely Stock Service Level (SSL), Forecast Accuracy (FA), Forecast Bias (BIAS), Obsolesces as % of Cost of Sales (% CoS).

5 Analysis

This chapter presents how the theory is used to create the quantitative model to represent the company's situation. The intention is also to examine the consequences of different proposals to solve the problem, as well as other problems found during the analysis. Throughout the chapter we will refer to the model when results are presented. A closer outline of the model will be presented in the next chapter.

5.1 Mathematical Lot sizing

The purpose of the report was partially set to, create a quantitative model that takes relevant costs and variables into account when determining the production batch sizes. The model should be an asset to the planning team that can relatively easily be incorporated in the planning operations. The model should not be too vulnerable to variations in the performance of the supply chain and must be able to support many SKUs and production lines. It should also be easy to maintain and uphold while being relatively easy to understand. Three ways of modelling the lot sizing problem was presented in chapter 3, and in this section one of these will be chosen for this thesis.

5.1.1 EOQ

The EOQ formula suffers from drawbacks and assumptions, including:

1. Demand is constant, continuous and deterministic.
2. Ordering and holding costs are constant over time.
3. The whole batch quantity is produced instantaneously and delivered at the same time.
4. No shortages are allowed.

The question is not if the EOQ-formula is a perfect representation of reality but rather if it is "good enough" for the company's operations. A case shall be made for each point.

The first point, where the demand is assumed to be constant and continuous is likely the one that will be the hardest to justify. The demand of beverages varies widely for different seasons, for example, some beverages has a significantly higher demand during summers and some sodas only sell during winter. This weakness can, in general, be mitigated by increasing the frequency of the EOQ-calculation, especially for products that vary heavily.

As for the demand being deterministic, the consequences of this assumption will be discussed further when calculating the safety stock

The second assumptions, that ordering and holding cost are constant over time, hold true during the period between calculations, at least at a SKU level.

The third assumption instantaneous production and delivery is not consistent with reality. However, the production time is generally negligible compared to the holding time of the batch. A run that last for 5 hours and satisfies demand for one week can in the opinion of the writers be assumed to be instantaneous.

As the fourth point states, no shortages are incorporated since incoming customer orders are rejected if there is no stock on hand.

Finally, from chapter 3 it is also known that the EOQ-formula is not very sensitive to either having the wrong cost parameters, since for example a miscalculation in the order cost by 50% only affect the cost by 2%. The theory also suggests that straying from the calculated order quantity by a small amount does not have major impacts on the cost either, a fact that fits well with the company's operations where there are other factors to consider than the total cost.

Even though the EOQ-costs is only a modelled representation of the company's cost this fact is still seen as an implication that the model is robust.

5.1.2 Wagner-Whitin

The Wagner-Whitin largely follows the same assumptions as the EOQ, with the exception that the demand is no longer considered to be constant. The Wagner-Whitin have been found to be problematic to use in the company's MRP-system setup since there is no obvious way to choose the value of T, the number of periods calculated. There is also a problem that the demand is far from deterministic, faltering the whole point of the Wagner-Whitin optimization.

A considerable problem that have identified with the Wagner-Whitin algorithm is the difficulty of incorporating it in a model that handles the large number of SKUs that the company have in its portfolio.

5.1.3 Silver Meal

While the silver-meal heuristic is easier to compute, it suffers from the same limitations as the Wagner-Whitin, namely the difficulty to produce an excel-model computing the optimal batch size for a large number of SKUs easily at the same time.

5.1.4 Chosen Model

This master thesis will proceed with the EOQ-model, largely because of the reasons just stated. The EOQ-model presents a solution to the problem with the lot-sizing with the characteristics requested earlier, namely:

- Easily implemented in the workflow.
- Relatively easy to maintain.
- Easily scalable to many SKUs in an excel model.

The rest of the analysis will be conducted with the chosen mathematical model in mind. The batch size given from the EOQ-formula is denoted Q^* .

5.2 Changeover Cost

This section presents analysis related to the changeover cost and how it is derived for the company.

5.2.1 Changeover Times

In chapter four (empirical context) two separate times for changeover were defined and three different hierarchical levels to average the changeover times were suggested. It is now time to make a case for which of these will be used in the model.

As discussed in chapter 4, different departments at the company use different definitions of what the changeover time includes. Since all production lines share the fact that the bottling station is the line bottleneck it has been decided that the “tap-to-tap” time is the proper definition to use in this thesis. The reasoning for this is that it is when the tap is idle that the production is losing production time.

Moving on, we remind the reader that three different levels to measure the changeover time have been identified. Either an average for the line, for the recipe group or for the individual SKU can be used. The level used should accurately represent the impact a product has on the changeover cost over time. Starting with the approach to average on a SKU-level, this is problematic since some SKUs are systematically placed at the beginning of a chain of products from the same recipe. Consequently, this SKU will be punished by always having a longer changeover time than the rest of the SKUs from the same recipe, which will “freeload” on this.

Concerning the other two levels, line or recipe group, an analysis of how consistent the changeover time is on each level have been conducted. If all the recipes on a line would show similar changeover times it would be fair to say that the line itself have one change over time associated with it. If on the other hand the recipes vary this would not be a good approach since recipe groups with a longer and more complicated changeover would cost as much as easier change overs. Table 3 below show the different average changeover times of recipes at line I. Each cell represents one recipe group used on the line. The samples of changeover times are used to illustrate the variability.

Table 3: Average change over times of different recipe groups on one line during 2017 in minutes.

81,5	63,9	59,3	68,8
93,9	32,2	59,4	244,0
99,3	147,7	52,7	49,3
86,5	66,2	129,3	53,4
121,6			

From Table 3, it can be concluded that the changeover times on a line vary heavily from recipe to recipe.

In turn, table 4 illustrate that the different changeover times for each SKUs in one of the recipe groups, are relatively similar.

Table 4: Average changeover times of different SKUs in a recipe group during 2017 in minutes.

55,3	156,0	44,2	54,5
32,0	40,3	40,5	34,9
34,3	47,3	58,5	

Generally, the changeover times are more concentrated in Table 4, except for one entry that suffer from the problem described in the previous section. The conclusion of this analysis is that the most appropriate level to average the changeover times for are on a recipe group level.

The actual modelling for the average time is simple, consider the scenario that for a set period of time, t , x number of changeovers have been conducted. During the time t , y amount of time was spent performing the changeovers. Using simple arithmetic, one can arrive at the conclusion that the average changeover time equals the total time spent divided by the number of occasions, $\frac{y}{x}$.

5.2.2 Fixed changeover cost

Each changeover carries a fixed cost due a combination of material used and a fix ramp up time for the next production. The material includes cleaning supplies and wasted beverage due to start up and the time is tied to the ramp-up of the line when restarting production. The ramp-up time is not included in the actual changeover but can be seen as an efficiency loss for the next production. The ramp-up time is as stated before fix, but it carries hourly variable costs discussed below.

5.2.3 Variable Changeover Cost

The variable changeover cost is tied to the employee cost and the cost of lost production. Since the company uses a make to stock system, only a line in the need of sourcing to satisfy the demand carries a cost of lost production. This cost is the cost to source the quantity "lost" due to the stop in production. The employee cost is different depending on the shift but is essentially just cost per hour for the line.

5.2.4 Total changeover cost

The cost per changeover is the cost associated with changing from an arbitrary SKU to the SKU in question. This cost is simply the product of the changeover time and the changeover cost per hour as derived in the two previous chapters.

$$TCC_{SKU} = C_f + (C_v * t_c) \quad (17)$$

TCC = Total Changeover Cost for SKU

C_v = Variable cost per hour (Line specific)

t_c = Time per changeover (Recipegroup specific)

C_f = Fixed cost

The actual costs have been given from the controllers in the production.

5.2.5 Outcome

The results for the changeover costs are illustrated in Table 5. The costs can be applied as the changeover cost (A) in the EOQ formula, for the SKUs in the recipe-group.

Using the approach presented above, the changeover costs vary greatly between recipe groups belonging to the same production lines. In Table 5 the changeover costs at the four lines included in the study are presented.

Table 5: The Changeover cost for all recipes in SEK. Each cell in the columns represent one of the recipes of the line.

Line X	Line Y	Line Z	Line I
6133	15081	17393	13983
7300	18200	18687	14631
7399	18291	19578	14853
7733	18672	20305	15224
7950	19134	22153	15578
8191	19509	23326	16609
8454	20367	23801	19915
8512	20506	25286	
8578	20793	34707	
8807	22622	56238	
8996	23033		
9005	24090		
9883	24869		
10287	28054		
10392	29161		
10493	34228		
11719	45568		
12174			
12386			
13406			
14101			
14305			
14420			

The underlying reason for these variations are differences in the measured average changeover times historically for the different recipe groups. The reason that these times are so different is not something that will be investigated further in this report but will be left for future research.

5.3 Holding cost

This section will address how a suitable holding cost for the company’s supply chain were obtained. The approach follows the ABC-method for determining the holding cost. Necessary assumptions to determine the holding cost are explained throughout this section. The unit used in the EOQ-formula is hectolitre (HL).

Two different holding costs have been determined based on the activities in the warehouses. The first holding cost is for the external warehouses (h_{EXT}). The second holding cost is for

the main warehouse (h_{FBG}). h_{EXT} is used to determine the batch sizes in today's operations, and h_{FBG} are used to determine potential future batch sizes with an extension of the main warehouse. To obtain the cost of holding a pallet per day, last year's costs have been divided with the average number of stored pallets. The procedure of calculating h_{FBG} and h_{EXT} is more closely described in the next sections.

The later described procedures capture the costs of the activities in the warehouses. Added to the activity costs are also the cost of capital tied up in inventory. The cost of capital tied in inventory originates from the expected yearly return of investment which is set by the financial department of the international group. The cost of capital tied up inventory is calculated as:

$$TC_p = \frac{COGS * E_{ROI} * V_{SKU}}{\text{weeks per year}} \quad (18)$$

E_{ROI} – Expected yearly return of investment [%]

$COGS$ – Cost of Goods Sold [Cost per HL]

V_{SKU} – Pallet Volume [Hectolitres per pallet]

In this way a cost per pallet and week associated to capital tied up in inventory is obtained. This cost is unique for each SKU since each SKU has its own production cost.

5.3.1 Holding cost in today's operations

To represent the out of pocket holding cost per pallet and week in today's operations, only h_{EXT} is applied in the model, for all SKUs. The motivation is that there is no special dedication of positions in the warehouses for the SKUs. Which essentially means that even if a pallet is stored in the main warehouse, it pushes another pallet to the costlier external warehouses. Throughout a year, pallets are always stored at the external warehouses, which justifies the approach.

The company's payments related to the external warehouses are associated with transportations, rent and handling. The costs in the company's system are structured under these categories. Last year's costs, scaled down to the cost per day, are used to determine h_{EXT} :

$$h_{EXT} = \left(\frac{\sum_{i=1}^N \kappa_i}{P_{EXT}} + TC_p \right) * \frac{1}{V_{SKU}} \quad (19)$$

κ_i – Daily Cost for Category i

P_{EXT} = Average pallets in per day in External Warehouses

N – Number of categories

The procedure is enabled by assuming that the costs, and number of stored pallets at the external warehouses, will be approximately the same under next year as the last year.

5.3.2 Holding cost for an extended internal warehouse

It is assumed that by extending the main warehouse no external warehouses would be required. Therefore only h_{FBG} are used in the model to represent this situation. Another assumption is that the holding cost for a pallet will be the same in an extended internal warehouse, as the holding cost per pallet in the internal warehouse today.

The categories associated with handling a pallet in the main warehouse are rent, personnel, equipment and maintenance. The yearly costs are scaled down to daily costs to determine h_{FBG} with Equation 20.

$$h_{FBG} = \left(\frac{\sum_{i=1}^N \kappa_i * \rho_i}{P_{FBG}} + TC_p \right) * \frac{1}{V_{SKU}} \quad (20)$$

κ_i – Daily Cost for Category i

ρ_i – Marginal Fraction for Category i

P_{FBG} = Average pallets in per day in Falkenberg

N – Number of categories

The marginal fractions are assumed by the authors of this report while the costs are numbers from last year. This is done with the help of the supply chain director and his team, providing us with reasonable numbers.

The reason different categories are used in the procedures, is that the costs originate from different sources. h_{FBG} originates from internal costs in the company and h_{EXT} originates from actual payments to the third-party logistics company. The cost in both procedures are obtained from the warehouse controller. Although different categories are used, both procedures are capturing the cost of space and the handling.

5.4 Demand

The demand is modelled as a weekly average based on the forecast for the upcoming six months. In the model, the demand on SKU-level is used since it is chosen to be most representative because variations of demand among the recipe groups and the lines exist. The reason six months is used is because the model is primarily going to be updated after this time, in connection with the update of the safety stock. Figure 13 describes the aggregated demand on the four analyzed lines in the study throughout the year.

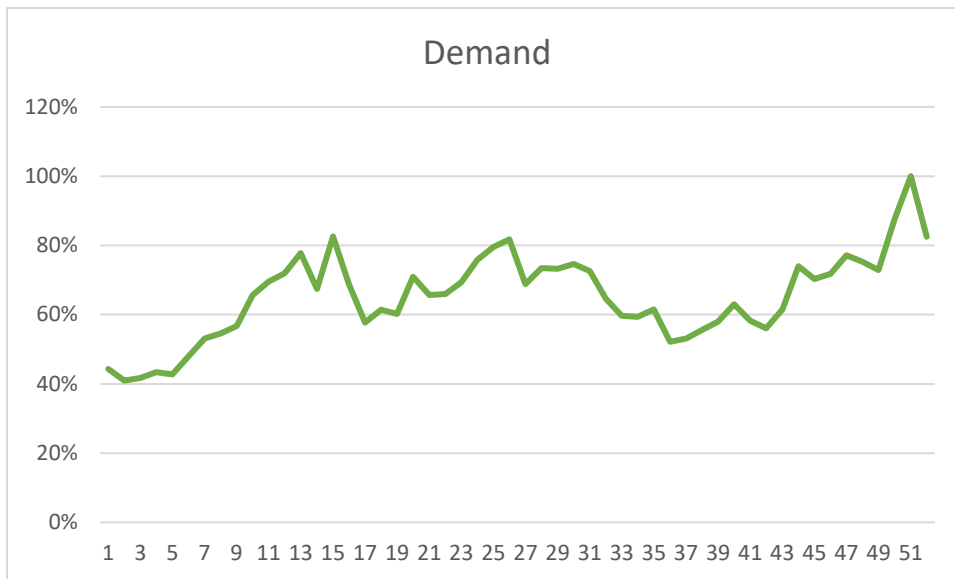


Figure 12. Demand for the SKUs on the four lines throughout the year.

Figure 13 indicates that seasonality exists among the articles, but not necessarily for all articles. Typical time periods with high demand is the summer, Christmas and Easter. The approach of using the average weekly demand over six months does not capture the seasonality and can be problematic to use for all articles since the demand is an input to the EOQ-formula. This is a shortcoming in the used approach further discussed in chapter 7.

5.5 Constraints in Processing

This section presents a procedure to include processing-constraints in the model. The constraints accounted for in this project is the quantified minimum batch sizes and the size of the raw material units. As stated in chapter four (empirical context). Certain SKUs are produced from raw material with short expiry date. Therefore, the whole raw material unit, or multiples of units, must be used to produce the batch. The minimum batch sizes and multiples therefor delimits the batch sizes which can be used. The used procedure is to adjust Q^* to the closest multiple or to the minimum batch size. Table 6 below show Q^* , the minimum batch sizes, the sizes of multiples and the constrained batch sizes for a selection of SKUs. The unit in the table is hector liter. The selection of SKUs is based on SKUs with representative constraints. The unit of the batch sizes in Table 6 is hectoliter (HL).

Table 6: Consequence of constraints on batch size

SKU	Q^*	min batch size	raw material multiple	Constrained Batch size	raw material units used
Constraints Example 1.	463.9	306.6	99.95	499.75	5
Constraints Example 2.	2077.8	306.6	99.95	2098.95	21
Constraints Example 3.	1742.0	204.4	66.64	1732.64	26
Constraints Example 4.	596.6	204.4	66.64	599.76	9
Constraints Example 5.	584.7	204.42	66.64	599.76	9

5.6 Statistical analysis related to Perished Goods

This section presents how the demand, forecast and the forecast error are analysed to evaluate how a maximum batch size could be determined based on statistical data for the parameters. The unit of measure in the analysis is Hectolitre (HL). The maximum batch size is determined based on the acceptable risk for perished goods. The volume corresponding to the acceptable risk is calculated with the cumulative distribution function based on the stochastic demand during the SKU's sellable time. The expected volume of perished goods associated with a batch is thereafter calculated. The approach presented in this section is a complement to the EOQ-calculations.

5.6.1 Maximum Batch Size

This section presents how the maximum batch size is determined. The chosen approach is based around an acceptable risk of perished goods. The analysis of the statistical parameters is carried out on a monthly basis such that every month become a sample. The sample size is chosen to a maximum of 38 months but varies between the SKUs depending on available data. The forecast error (FE) is defined as:

$$FE = \frac{\text{Forecasted Sales} - \text{Actual Sales}}{\text{Forecasted Sales}}$$

To determine if it is suitable to model FE with a normal distribution the data was examined. Figure 17 shows the histogram for an article which indicate that a normal distribution might be suitable for this particular article.

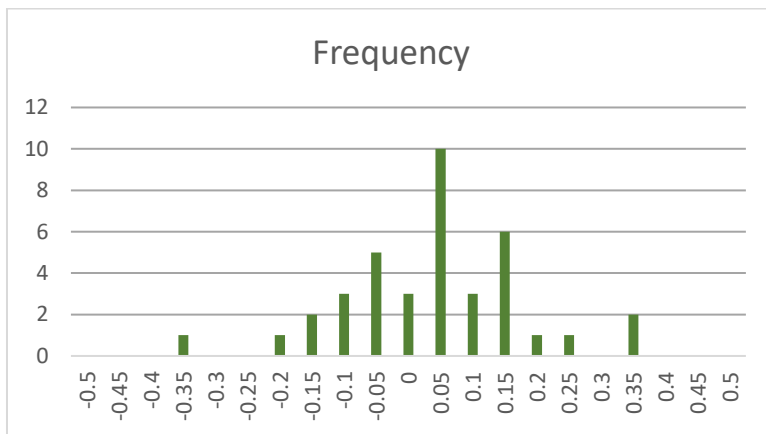


Figure 13 Histogram of FE for a SKU.

The Kolmogorov-Smirnov test was used to test if FE could be approximated to be normally distributed with the mean and standard deviation of FE from the samples. The Kolmogorov-Smirnov test for this article gave that the null hypothesis (H_0) i.e. the assumption that FE is normally distributed, could not be rejected on the significance level 0,05. The conclusion for this article was that it could be modelled as a normal distribution as:

$$FE \in N(\mu_{FE}, \sigma_{FE})$$

$$\mu_{FE} = 0,01$$

$$\sigma_{FE} = 0,14$$

The Kolmogorov-Smirnov test was performed on 230 SKUs, individually. The results were that for 204 of the 230 SKUs that were studied, H_0 could not be rejected on the significance level 0,05. The model also includes SKUs where no data were available to perform the Kolmogorov-Smirnov test. A discussion of how rejected null-hypothesis and SKUs without data were handled are presented in section 5.6.3.

Every SKU has an expiration date when it no longer can be sold to the customers. The dates vary from one to 22 months. The forecast error is used to describe the expected demand and how the demand vary during the time a batch could be sold. The demand during this time is modelled as a normally distributed stochastic variable (Y) with the following parameters:

$$\begin{aligned} \mu_{DoST} &= n * \text{monthly forecasted demand} \\ \sigma_{DoST} &= \sqrt{n} * \sigma_{FE} * \text{monthly forecasted demand} \\ Y &\in N(\mu_{DoST}, \sigma_{DoST}) \end{aligned}$$

The parameters are defined as:

- μ_{DoSL} = Expected demand for a SKU during the time a batch can be sold to customers
- σ_{DoSL} = Standard deviation of demand for a SKU during the time a batch can be sold.
- n = Number of months a batch can be sold to customers

The procedure is based on the theory of linear combinations (see section 3.9.1) and the assumption that the monthly demand is independent. More precisely, it is the stochastic variable for one monthly FE that should be independent from the stochastic variable of another monthly FE, for the approach to hold.

Goods perish when the batch size is larger than the demand during the time a batch can be sold. The procedure enables us to derive a maximum batch size based on the acceptable risk that perishable goods will occur, illustrated in Figure 14. This acceptable risk is therefore what decides how large the batch should be under the given data.

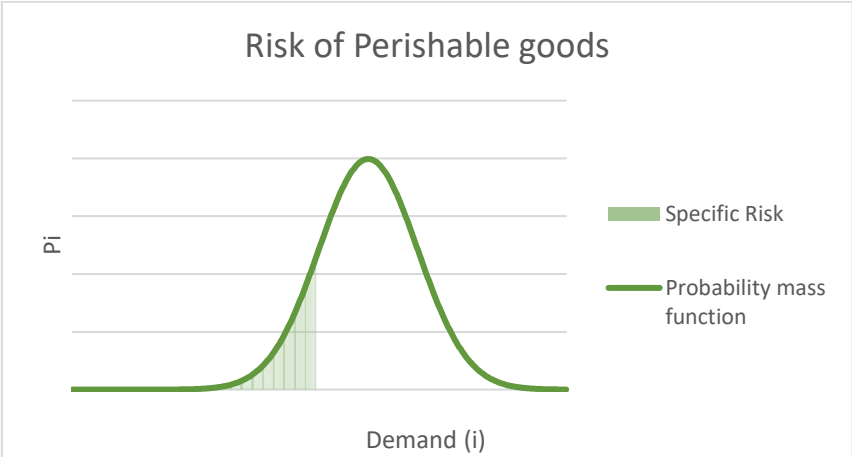


Figure 14 illustration of risk for perished goods.

If the batch size exceeds this maximum batch size, the risk of perishable goods is greater than the chosen risk level.

The standard deviation of the forecast error (σ_{FE}) indicate how difficult the SKUs are to forecast correctly. The greater σ_{FE} , the more the forecast errors vary. In the analysis, no outliers were excluded which might have affected the results. The SKU in the example above is a popular article with an overall accurate forecast but the model also includes more troublesome SKUs with greater σ_{FE} . Other possible reasons for a high standard deviation is a small sample size, where the outliers have greater effect than in a large one. Large σ_{FE} are troublesome because they might give a distribution $Y \in N(\mu_{DoSL}, \sigma_{DoSL})$ with probabilities among negative demand which do not represent to the reality. This is further discussed in section 5.6.3.

5.6.2 Expected volume of perished goods

This section builds upon the previous and explain how the expected volume of perished goods are calculated. The stochastic variable Y and the maximum batch size can be used to calculate the expected volume of perished goods for a batch, explained by (23).

$$\text{Expected volume perished goods} = \sum_{i=0}^Q P_i * (Q - i) \quad (21)$$

P_i – Probability that the demand during the time a batch can be sold is equal to i
 Q – Batch Size

Table 7 present the volume of expected perishable goods (HL) for a selection of articles that are chosen to be illustrative.

Table 7 results of MAXQ and expected perishable goods for a selection of SKUs.

SKU	MAXQ [HL]	Q* [HL]	Q*ok?	Normality OK?	Expected perished goods [HL]	STD FE
Perishability Example 1.	1018.164	1300.891	NO	YES	40.0	0.34
Perishability Example 2.	380.3702	572.2176	NO	YES	37.5	0.37
Perishability Example 3.	956.3725	1165.285	NO	YES	30.4	0.24
Perishability Example 4.	20931.36	4324.458	YES	YES	0.0	0.14
Perishability Example 5.	3001.397	1571.194	YES	YES	0.0	0.09

In the analysis, the volume of expected perishable goods is obtained based on Q^* from the EOQ-Calculations. For the SKUs in the table the expected volume of perished goods varies from 40 HL per batch and 0 HL per batch. The fourth column in the table indicate if Q^* is greater than the maximum batch size based on the chosen acceptable risk level. The maximum batch sizes are presented in column 2 and Q^* is presented 3. As expected, the largest volumes of expected perished goods occur when $Q^* > MAXQ$.

5.6.3 Discussion of approaches

The calculated batch sizes provide a support to the theoretically determined batch size calculated from the EOQ-model. In derivation of the maximum batch sizes, the risk for perished goods is set to 5%. This percentage is empirically chosen and is suggested to be set by the user based on what the company think is reasonable.

The maximum batch sizes and expected volume of perished goods are calculated with both h_{ext} and h_{FBG} applied in the EOQ-formula. Intuitively the expected volume of perishable goods increases with an increased batch size as a result of a lower holding cost for the extended warehouse option.

The problems of large σ_{FE} , rejected H_0 and articles without forecast data are handled by assuming a normal distribution of FE with $\sigma_{FE} = 0,5$, for the articles which suffer from any of these drawbacks. The assumption of 0,5 is empirically chosen and guided by the other standard deviations of the studied SKUs. To replace large σ_{FE} with a lower value could be seen as a standardized procedure to remove outliers. If $\sigma_{FE} > 0,5$, it is replaced with $\sigma_{FE} = 0,5$. The motive for the chosen procedure is the vast number of SKUs and that qualitative input to remove outliers would be required for each SKU with a large σ_{FE} , which not was feasible within the time frame of this thesis project. The consequence of the chosen approach is that it replaces high σ_{FE} with a lower value which essentially is the outcome when outliers are removed.

The assumption that the articles not included in the distribution fitting are normally distributed are supported by the fact that the majority of the tested articles H_0 could not be rejected. It is therefore assumed that H_0 cannot be rejected for the majority of the not tested articles, although it cannot be confirmed beforehand.

Rejected null-hypothesis are indicated with the value NO in the sixth column in Table 7. In this way the approach warns for when the values could not be trusted, due to the normal distribution being a faulty choice.

Regarding the risk for distributions with probabilities at negative demands because of large σ_{FE} , the maximum of cumulative percentages for the distributions of the SKUs are calculated to 0,56%. This percentage include articles with substituted σ_{FE} . This low percentage is considered to be of little impact for the results.

The presented approach uses an accepted risk for perished goods as a criterion to determine the maximum batch size and the expected volume of perished goods. Another approach would be to use the expected cost or volume of perished goods as a criterion to determine the maximum batch sizes. These criterions can be seen as more relevant to base the decisions on. Such a procedure was determined to be more complex and therefore not chosen.

5.7 Resulting batch sizes from the model

The previously described approaches to determine demand, holding cost and changeover cost renders the results presented in this section. The results are presented for the three

levels SKU, recipe-group and Line. The selection of SKUs for the results in this section is guided by previously used SKUs in the analysis, complemented with other SKUs to capture examples from various recipe-groups and all studied lines.

The calculated batch sizes for a selection of recipe groups are presented in Figure 15 together with the average batch sizes the last 12 months.

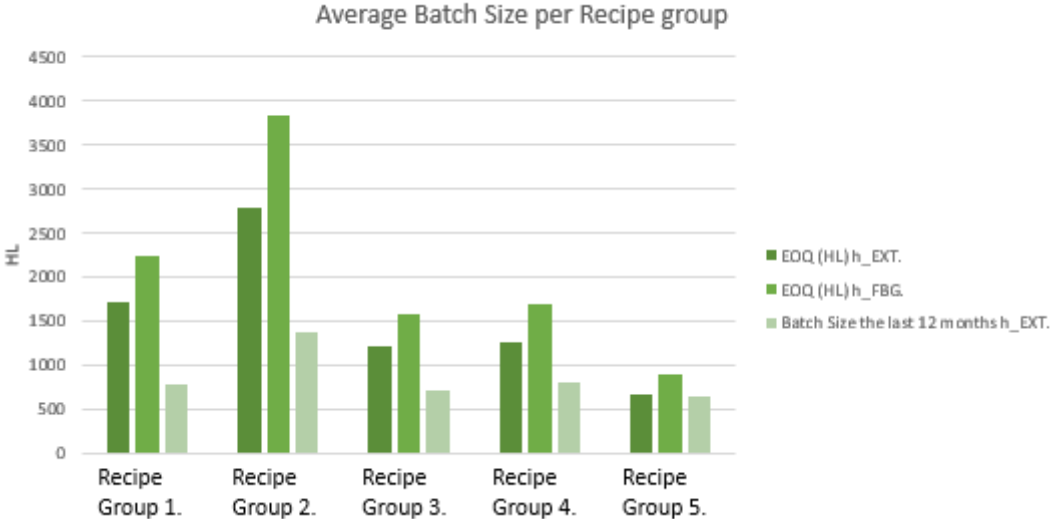


Figure 15. Average batch size per recipe-group.

In all of the presented recipe-groups, the average batch sizes increased compared to the average batch size of the recipe-groups during the last 12 months. Representations of recipe-groups from all studied lines are included In Figure 15. The analysis is performed for when both h_{EXT} and h_{FBG} are used in the EOQ formula. As expected the batch size is larger when h_{FBG} is used, as $h_{FBG} < h_{EXT}$.

If the same analysis is performed on a SKU-level the results show that both increased and decreased batch sizes exist. The analysis is presented in Table 8 below which include articles from the same recipe-groups as figure 15.

Table 8. Average batch sizes for a selection of SKUs

SKU	Line	EOQ (HL)	Average Batch Size the last 12 months
Result Example 1.	Line I	487.1	493.5
Result Example 2.	Line X	780.2	838.5
Result Example 3.	Line Y	1018.2	570.8
Result Example 4.	Line Z	380.4	429.3
Result Example 5.	Line Z	1571.2	791.1
Result Example 6.	Line Y	4324.5	2131.3
Result Example 7.	Line Y	956.4	475.5

The average batch size on the lines are presented in figure 16.

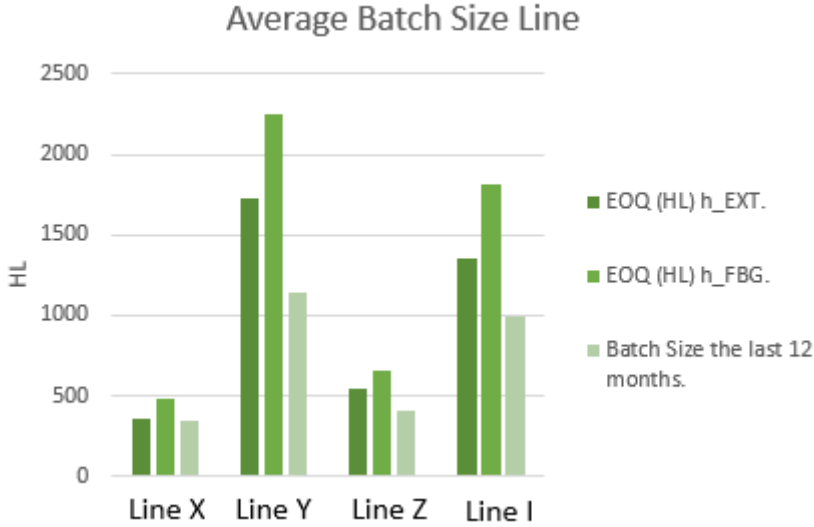


Figure 16 Average batch sizes on the four studied lines.

On a line-level the average batch size increase when the EOQ-formula is used, compared to the size of the average batch during the last 12 months.

Finally, an analysis has been made for one product to support or reject the suggested fact that deviating from the calculated batch size has a limited impact on the average costs. Figure 17 shows the cost for a value Q , using (1), with the optimal $Q \pm 20\%$ being shown between the dotted lines. It can easily be seen that within this interval the cost is a relatively constant function of the batch size. As long as the Q is chosen in this interval, the cost does not deviate much from its minimum.

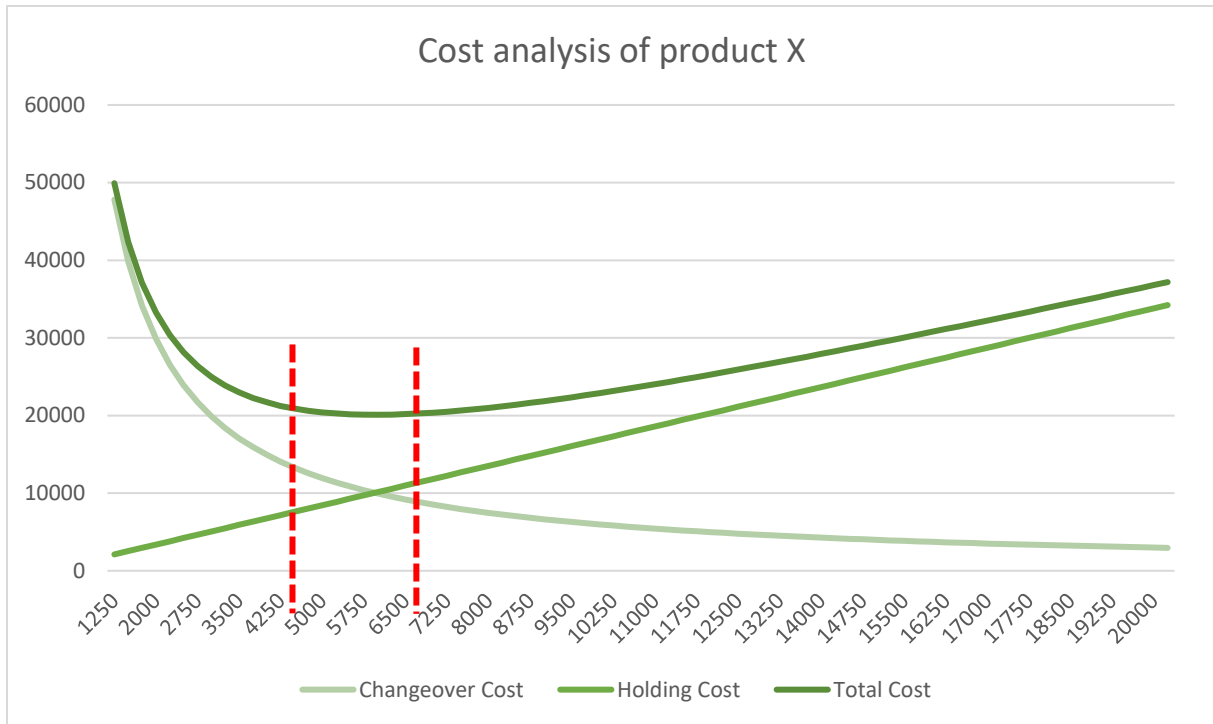


Figure 17 cost analysis when deviating from optimum batch size

This finding is supported by the theory in that the total cost is not affected much when the chosen Q deviate relatively little from the resulting Q from the EOQ model.

5.8 Safety Stock

This chapter will study the implications of the current safety stock formula and the consequences changing the batch sizes will have on the safety stock. A new theoretically sound method to calculate the safety stock is also proposed.

5.8.1 Implication of current setup

Recall from chapter 4 that the company currently uses a safety stock formula based on delivering a certain cycle service level S1 (proportion of stock cycles without a stockout). At the same time their operations are evaluated upon their stock service level, S2, defined in chapter 4. This implicates a discrepancy in how the safety stock is calculated and how it is later evaluated.

The implications of (16), shown again below, is that increasing the average batch size for an SKU, with all other variables remaining fixed, will also increase the safety stock of this SKU. This increase can be especially substantial if the supplier variability, (PE.CT), for the SKU is high.

$$SS = k * \sqrt{(LT * \sigma_{FE}^2) + (PE.CT) * Q^2} \quad (16)$$

In a further analysis of the last six months, both S1 and S2 are calculated using observed historical data. S1 is the fraction of weeks that had no stock out divided by the total number

of weeks and S2 is the fraction of delivered volume divided by all ordered volume. The resulting S1 is way off the target service level while the resulting S2 more closely follows the requested one. Table 9 below shows the result from the six months in S1 and S2 for the 10 SKUs with the highest sales volume.

Table 9: Last six months service level for the 10 SKUs with highest sales volume, as observed, and the target "stock service level".

SKU	S1	S2	Target
Example 1	88,2%	99,8%	98%
Example 2	84,4%	98,7%	99%
Example 3	78,1%	93,6%	99%
Example 4	100,0%	100,0%	99%
Example 5	72,7%	95,6%	98%
Example 6	96,8%	100,0%	98%
Example 7	84,4%	97,2%	99%
Example 8	93,3%	99,8%	98%
Example 9	100,0%	100,0%	99%
Example 10	78,1%	96,1%	99%

The company is using a safety stock formula that does not properly reflect their way of measuring their operations. The resulting S1 is not following the target while the resulting S2, that is not currently part of the safety stock calculation, seem to follow the target more closely. The simplest explanation for this is that the input data for the safety stock formula are not correct, resulting in a lower resulting S1 for the used safety stock. The company obtain better results in their fill rate even though it is not a part of their safety stock calculation, something that might have several explanations.

1. The safety stock calculated using S1 might coincidentally be a good fit.
2. The operational planning team is manually changing the plan when unforeseen events occur to ensure supply availability.
3. The safety stock does not make a significant impact on the service level due to constant high stock levels.

Not much can be said about the first point more than that it is highly unlikely that the company's homemade formula can make a good calculation for all SKUs. The second point would indicate a lot of time spent on "fire-fighting by the operational team, working in a reactionary way solving problems as they arise instead of staying proactive. Since a stock out would cause a bigger immediate reaction from the organization than stock building it would be natural to push a higher production than strictly needed. The third point indicates that the stock is constantly higher than needed to keep the requested service level, most likely due to stock building situations.

An important fact to remember is that the safety stock is designed to meet a requested service level. The desired outcome is that the resulting service level equals the request and it should be neither higher nor lower. Calculating the safety stock in an incorrect manner might

not only result in too low service level but also a too high, resulting in excessive costs. The historical data of the last six months reveal that 113 of 176 (64,2%) articles have had a higher fill rate than 99.3%, which is the highest target.

The data shows that SKUs with a high sales volume show results close to the requested S2 while showing a considerably lower S1 than requested, while many low-volume SKUs sustain a higher fill rate than necessary. This strongly implicate that the resulting S1 does not reflect the calculations that have been made for safety stock and in turn that the current safety stock calculation is essentially inconsequential to the resulting service level, most likely due to operational manual adjustments.

With this in mind, the second and third point seem both seem to be reasonable. Keeping a high stock due to stock building in production helps keep the service level up even with a poor safety stock calculation. When outside of a stock building phase the second point seem like a good explanation for the high-volume articles, the ones that make the biggest impact on warehousing operations, stay close to the target service level while smaller articles keep a too high service level in general.

5.8.2 A new suggestion

To summarise the last chapter, the company is evaluated on their fill rate, S2, while dimensioning their safety stock in accordance to a formula originating from a S1 approach.

The implications of using the formula for fill rate presented in chapter 2 is evaluated in this section.

Reminding the reader of the formula to determine safety stock that corresponds with a service level S2 under Normally distributed customer demand.

$$S_2 = 1 - \frac{\sigma'}{Q} * \left[G\left(\frac{SS}{\sigma'}\right) - G\left(\frac{SS + Q}{\sigma'}\right) \right] \quad (8)$$

Noting that the loss function (G(x)) is strictly decreasing with an increasing input it can be concluded that an increased Q contribute to lower the safety stock in this formula.

A weakness with this formula is that it does not consider the supply reliability, and since the company's production lines suffer from a high degree of variation in yield of the batches this can result in a non-reliable safety stock.

So, is there any way to amend the standard deviation term of the formula to include the yield variation of the production lines? Johan Marklund, professor at Lund University and the thesis supervisor suggested to include the yield loss as an increase in customer demand during the period. This would mean that a loss in yield is modelled as an increase in demand and thus contributing to a higher variation.

From chapter three it is known that two independent stochastic variables that are normally distributed can be summed by combining them as

$$X + Y \in N\left(\mu_X + \mu_Y, \sqrt{\sigma_X^2 + \sigma_Y^2}\right)$$

In chapter three it is also suggested that yield can be modeled using a stochastic variable, the quotient of the planned volume that is completed as output. In the literature it is suggested that $Yield \in [0,1]$ but since the yield can be over 100% in this case, this is extended to $Yield \in [0, \infty]$. The same reasoning applies to the yield loss, which simply equals $1 - yield$. The conclusion is that the yield loss is also a stochastic variable, $Yieldloss \in [-\infty, 1]$.

This stochastic variable belongs to an arbitrary distribution, but if this distribution can be approximated as normal a solution to the problem have been found.

The deviation of the forecast has already been shown, in section 5.4, to be normally distributed. It is fair to assume that the customer demand and the yield loss of the production lines are independent. The yield loss has no connection to the forecast accuracy, and vice versa.

The only thing remaining is then to show that it is reasonable to assume that the yield loss is normally distributed. To find the yield loss, the measurement production fulfillment is used, which equals the measure yield in the literature. The yield-loss is simple to derive from the production fulfillment data in the same way it is from yield.

$$Yield\ Loss = 1 - Production\ fullfilment$$

Data from the last year was pulled from the system and a histogram were made of the production fulfillment for 52 weeks. This is presented in Figure 18.

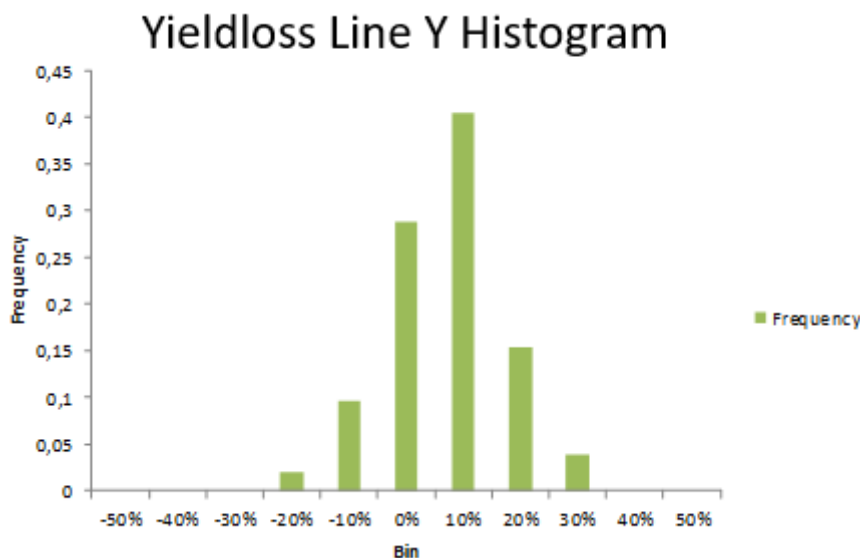


Figure 18: Histogram of yield loss in percent for Line Y, a negative yield loss means the produced quantity was larger than the planned.

The data suggest that while far from perfect, the normal distribution is at least fair to use with regards to the production fulfillment. Since this is the only distribution that would work well with the chosen approach, the hypothesis that $Production\ Fullfilment \in N(\mu, \sigma^2)$ is

accepted without further investigation. Table 10 below shows the calculated mean and standard deviation of the yield loss for the four studied lines.

Table 10: Mean and standard deviation of yield losses for the lines in this study, note that it is displayed in units of percent.

Lines	μ	σ
Line X	10,39%	13,9%
Line Y	2,28%	9,7%
Line Z	15,01%	16,8%
Line I	6,21%	10,2%

To make sense of this combination, the yield loss from production can be interpreted as an increase in demand, as the volume lost in production might just as well have been a customer coming in to make a last-minute order of more volume. The combined stochastic variables of customer demand and production yield loss therefore create the new variable that we simply call demand.

The resulting standard deviation used in the formula is, consequently:

$$\sigma' = \sqrt{\sigma_D'^2 + \sigma_Y'^2}$$

σ_D' = standard deviation in customer demand in HL(Hectoliters) during leadtime

σ_Y' = standard deviation for yieldloss in percent times the batchsize in HL during leadtime

The result of the new equation is that the batch size “pulls” in two different directions. To increase the safety stock due to the yield loss aspect and to decrease safety stock due to a higher fraction on time with higher stock. This is a more correct representation than the current method used and will not result in a flat increase of all articles on safety stock if batch sizes are increased but rather only if the yield variation demands it.

The resulting formula for safety stock is, consequently, (8), where the standard deviation used is the one obtained as:

$$\sigma' = \sqrt{\sigma_D'^2 + \sigma_Y'^2}$$

$$S_2 = 1 - \frac{\sigma'}{Q} * \left[G\left(\frac{SS}{\sigma'}\right) - G\left(\frac{SS + Q}{\sigma'}\right) \right] \quad (8)$$

While hard to solve algebraically, one can easily solve for the safety stock numerically using a computer.

5.9 Effects on finished goods inventory

The new way of calculating safety stock, combined with the new batch sizes calculated with the EOQ model results in a dramatical decrease by about 35% in the total safety stock for the studied SKUs.

This result is a consequence of not only penalizing the safety stock when the batch size increases for an SKU, but also include a parameter that considers the increased fraction of time spent with no real risk for stock out. A high variability in yield of the line producing the SKU leads to an increase in safety stock when the batch size increases. On the other hand, the increased batch size reduces the need for safety stock due more time spent with no real risk of stockout. Figure 19 below shows the change in safety stock.



Figure 19: Safety stock for new suggestion and Current setup

Figure 19 visualize the reduction of safety stock for the new suggestion compared to the current setup. A reduction could be found both when h_{EXT} and h_{FBG} are used.

The average new stock on hand is calculated as:

$$Average\ stock\ on\ hand = SS + \frac{Q}{2}$$

Figure 20 present the aggregated average stock on hand, of the SKUs produced at the lines.

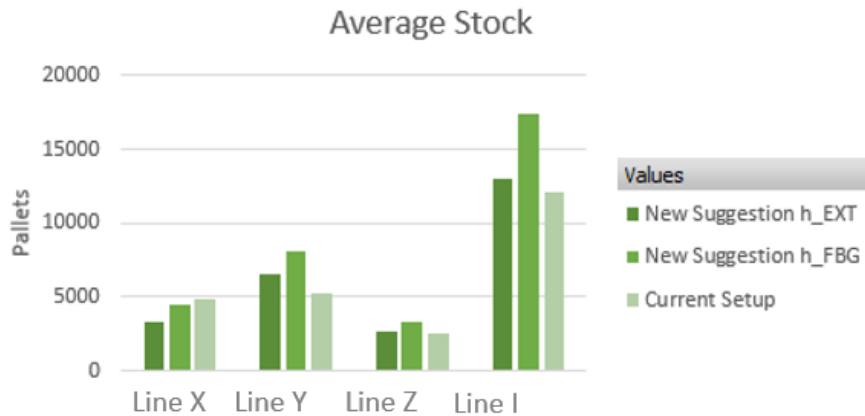


Figure 20 Contributions of average stock on hand from the studied lines.

The new suggestion to calculate the safety stock reduce the safety stock compared to the current setup. The batch sizes from the EOQ-model increase the average batch size and therefore contributes to a larger stock on hand. Figure 20 indicate that in today's operations with pallets stored at external warehouses, these changes which influence the average stock on hand in different ways, together has little effect compared to the current setup.

5.10 Effects on production

With the calculated batch size from the EOQ formula, further analysis can be made. Derivation of parameters such as average coverage time for a batch, which is the time a batch will stay in stock until depleted could be calculated as:

$$\text{Average coverage time} = \frac{Q}{d} \quad (22)$$

The coverage time is what will be used to guide the cycle planning of the articles i.e. between what time interval specific articles should be produced.

The average production hours per week required to satisfy demand is calculated by multiplying the weekly demand with the time used to produce one piece of the SKU which is based on the expected production rate.

$$\text{production hours per week} = D * \frac{1}{\text{Expected production rate}} \quad (23)$$

*Expected production rate = Maximum production rate * expected OEE.*

The expected production rate is based on how efficient the line is operating i.e. it is the nominal production rate scaled down with the OEE. This metric is not changed by the EOQ but static with the demand and production rate.

The average changeover time which is calculated per week, is calculated by inverting the average coverage time which gives the average number of changeovers per week.

$$\text{Average changeover time per week} = \text{Average coverage time}^{-1} * \text{changeover time} \quad (24)$$

This metric is highly dependent on the EOQ. By combining the average time to produce for each week with the average time for changeover, for each article on a line one can see how much time needs to be allocated to the line each week, and if the current capacity is enough to handle it. Table 11 present the calculated parameters for the selection of SKUs, previously used.

Table 11. Calculated parameters for the selection of articles

SKU	Line	EOQ (HL)	Coverage Time (Weeks)	Producing hours per week	Average number of changeovers per week	Changeover time per week
Result Example 1.	Line I	487,1	13,4	0,2	0,1	0,1
Result Example 2.	Line X	780,2	2,2	6,0	0,5	1,0
Result Example 3.	Line Y	1018,2	8,3	1,1	0,1	0,5
Result Example 4.	Line Z	380,4	9,3	1,3	0,1	0,3
Result Example 5.	Line Z	1571,2	3,4	9,9	0,3	0,8
Result Example 6.	Line Y	4324,5	1,3	25,9	0,8	0,9
Result Example 7.	Line Y	956,4	6,4	1,6	0,2	0,3

The producing time and changeover time can be combined to obtain the average required production time per week for each SKU. The production time is the average required time per line and week, to meet the average demand. From a planning perspective the required production times of the SKUs are of great interest. Table 12 present the results of the needed capacity for the analyzed lines.

Table 12. Production time per week

Line	Shift	Open Hours	Production time h_{EXT}	Production time h_{FBG}
Line X	3-shift	114,0	108,6	102,6
Line Y	5-shift	168,0	158,2	153,5
Line Z	4-shift	138,0	111,0	107,7
Line I	5-shift	168,0	173,6	168,9

The table indicate that Line I does not have enough capacity. Lack of capacity needs to be addressed with sourcing. A possible way for improvement would be to increase the number of shifts. This is not an option on Line I since it already has 5 shifts. One should bear in mind that this analysis includes all articles scaled down to a week. Due to seasonality, for some SKUs the need for production seldom occurs throughout the year. One should also bear in mind that an increase of shifts has effects on other parts of the supply chain such as processing and the warehouse.

Table 12 show that the production time is higher with (h_{EXT}) than (h_{FBG}). The production time includes both the changeover time and the production time to cover the demand during the

coverage time. The times are normalised to a week. Figure 21 show how these times relate to each other when the different holding costs are applied.

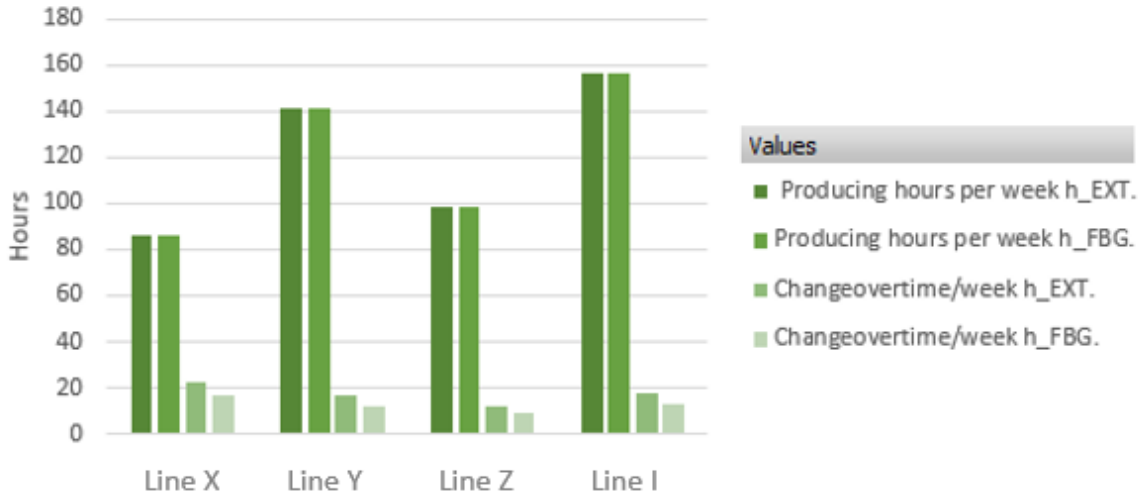


Figure 21: Changes in production time and changeover times at the lines.

The figure illustrates that the production time per week to cover the demand during the coverage time are the same. What is reducing the production time is the changeover time. This analysis illustrates that larger batch sizes increase the theoretical OEE which enables more efficient usage of the resources and less open time for the same volume.

From the insights of the required time in Table 12, possible discrepancies can be acted upon. If the needed capacity exceeds the open time several strategic options are available such as invest in production capacity by increasing the number of shifts or invest in equipment. Such analysis is out of scope for the model.

Two tactical decisions can be identified related to the issue with limited capacity. The company is currently handling it in two ways, increase the stock or outsource some of the volume.

5.11 Cycle planning

This section presents how the cycle planning is taken into consideration. The procedure uses the coverage time presented in the previous section. A summary of each recipe group is made to guide the user to a fitting cycle for the recipe group. In the example in Table 13, eight SKUs belonging to the same recipe is shown with the coverage time of the batch size resulted from the previous steps. This coverage time is then altered for all the SKUs to make them share a common denominator and thus able to share cycle. Note that this table will suggest batch sizes not calculated through the minimum cost approach, which should be understood by users in their operational work.

Table 13: The Cycle-planning helper.

SKU	Coveragetime (W)	New suggested cover time
Example 1	4	4
Example 2	4	4
Example 3	4	4
Example 4	6	4
Example 5	42	40
Example 6	10	8
Example 7	9	8
Example 8	8	8

5.12 Summary

With the objective to create a quantitative model to determine production batch sizes and evaluate the consequences on the warehouse and production operations, several key areas have been analysed.

A mathematical model was first chosen to find the batch sizes that entail the lowest cost to the supply chain, the EOQ-model. This model was chosen based on a pro-con approach, comparing it to other models, with the company's supply chain characteristics kept in mind.

Input values were then produced to be used as input data in the model, and three equations were presented to calculate these were produced. This resulted in (18), (19) and (20).

$$TCC_{SKU} = C_f + (C_h * t_c) \quad (18)$$

$$h_{EXT} = \left(\frac{\sum_{i=1}^N \kappa_i}{P_{EXT}} + TC_p \right) * \frac{1}{V_{SKU}} \quad (19)$$

$$h_{FBG} = \left(\frac{\sum_{i=1}^N \kappa_i * \rho_i}{P_{FBG}} + TC_p \right) * \frac{1}{V_{SKU}} \quad (20)$$

The resulting batch sizes of the model were presented and compared to the current average batch sizes. The determined batch sizes, as calculated in the model, are generally larger than the historical average. Aggregated on a line level, the new average is higher for all lines. It is also shown that if the main warehouse would be expanded, the resulting batch sizes would be greater still.

With the new economic order quantities in hand, an approach to solving the perishability problem was analysed. By using a statistical analysis of historical forecast accuracy, and the future demand, a maximum batch size was introduced. This maximum batch size is determined to allow no more than a 5% risk that goods will perish, and it may reduce the EOQ-quantity.

Early in the project the company's current safety stock formula was identified to be contingent on the chosen batch sizes, and an effort to gauge the consequences to the safety stocks when altering the batch sizes were made. This analysis identified problems with how the company currently calculates their safety stocks. An evaluation of the current approach was made and an alternative suggestion to solve the problems was then introduced. The new solution greatly decreases the total safety stock level, reducing many SKUs safety stock while increasing it for a smaller number of SKUs.

We concluded the chapter by illustrating the impact using our model can have on the finished goods and production departments, showing a slight increase in total stock and a decrease in changeover time for the production when using the new batch sizes and safety stock calculations.

6 Model Outline

In this chapter, we present the Excel-model that is handed over to the company. The objective of the chapter is to give the reader an understanding of the work done with the model and how it uses the analytical conclusions to create value to the company's operations.

The model first uses the input values for each SKU to calculate an economic order quantity. This quantity is then compared to the maximum batch size and the feasible batch sizes for the SKU and is modified accordingly. The resulting batch size is then used both to provide management with an idea of how much capacity is needed for the line, and to help the operational planners in their work.

6.1 Application of the Model

A suggestion is to apply the model and determine new batch quantities in connection to the updates of the safety stock levels, which currently take place once every six months. This is a suitable time to change the batch sizes since the batch sizes is an input to the safety stock formula the company is using. In this way, the model will serve as a tool on a tactical level. We suggest that these tactical batch sizes are extended to the operative planning process by letting them constitute the fixed choice in SAP and serve as a guidance for the planners.

6.2 Model procedure

The core is the EOQ model, while the rest is suggested to consist of "tiers" that will be used to modify the EOQ solution according to operational planning constraints and characteristics. Figure 22 shows the idea in a graphical way to visualize what the tiers will consist of and how they work. First the EOQ model will produce a preliminary batch size according to the strengths and weaknesses of the model (See 5.1). After this, the succeeding tiers will alter, or suggest an alteration, for the batch size to fit with operational parameters. The effects on the finished goods inventory and production are thereafter analysed. Lastly, the cycle planning for the SKUs in the recipe groups are determined.

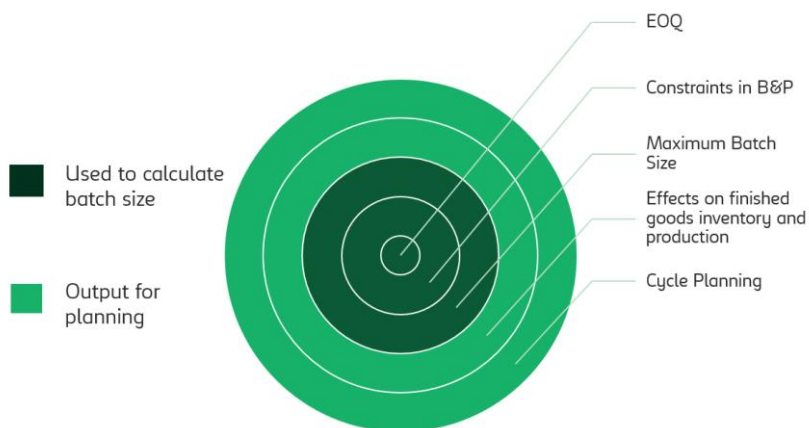


Figure 22: Tiers of suggested model

The flowchart in Figure 23 below describes the procedure for determining the batch sizes. The first step of the model is the EOQ calculation, executed with the values obtained in chapter 5. The resulting batch sizes are then compared to the maximum batch quantity for the considered SKU, derived in chapter 5, and scaled down if needed. Continuing, the batch size is altered in accordance with the operation constraints of the process, presented in chapter 4.

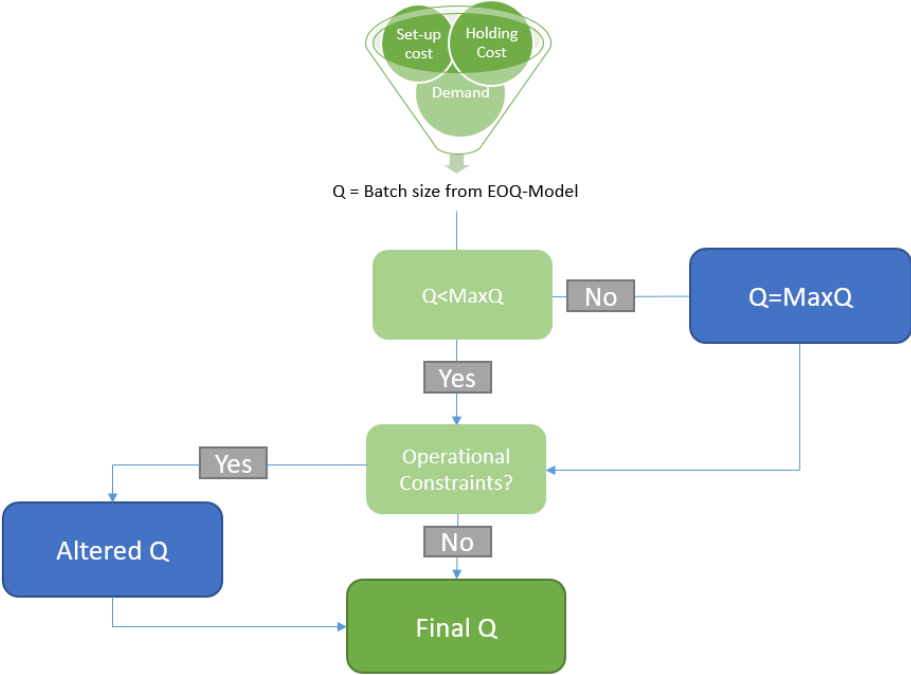


Figure 23: Flowchart of working model procedure.

The model will determine the final quantity based on constraints for the minimum batch size and the calculated maximum batch size, choosing the closest feasible Q to Q* within the accepted interval. This is illustrated in Figure 24 where the bars illustrate the feasible batch sizes. The minimum and maximum batch sizes determine the interval of feasible batch sizes.

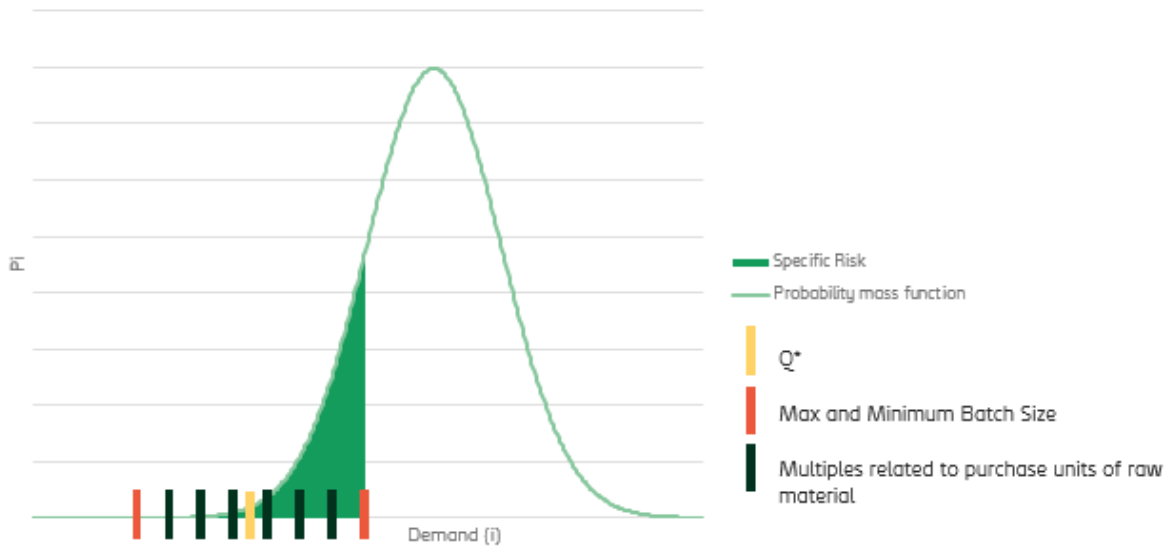


Figure 24. Illustration of selection of possible batch sizes.

6.3 Model procedure to evaluate effects.

The determined batch sizes and the calculated parameters are used to evaluate the effects on the production operations and the finished goods inventory. The batch sizes and the calculated parameters are in the model structured in a table, see Table 14. Pivot tables are applied on the data in the table to aggregate the production time, safety stock and average stock for the SKUs, on each line.

Table 14. Data aggregated to evaluate effects on production and finished goods inventory for a selection of SKUs across the 4 lines included in the report.

SKU	Line	EOQ (HL)	Coverage Time (Weeks)	Producing hours per week	Average number of changeovers per week	Changeover time per week	SS (HL)	Average Stock (PAL)	Average Batch Size the last 12 months	Current SS	Current Average Stock (PAL)
Result Example 1.	Line I	487,1	13,4	0,2	0,1	0,1	138,3	59,5	493,5	328,1	89,6
Result Example 2.	Line X	780,2	2,2	6,0	0,5	1,0	212,0	169,0	838,5	699,5	313,9
Result Example 3.	Line Y	1018,2	6,5	1,1	0,2	0,6	144,2	113,4	570,8	230,0	89,5
Result Example 4.	Line Z	380,4	6,2	1,3	0,2	0,5	222,8	63,7	429,3	393,8	93,9
Result Example 5.	Line Z	1571,2	3,4	9,9	0,3	0,8	472,7	194,2	791,1	699,6	159,7
Result Example 6.	Line Y	4324,5	1,3	25,9	0,8	0,9	1007,8	550,4	2131,3	1244,3	401,0
Result Example 7.	Line Y	956,4	5,2	1,6	0,2	0,4	103,2	100,9	475,5	137,7	65,2

Reminding the reader that the fourth column, coverage time, is used to determine cycle time as previously explained.

6.4 Input Data

The format of the input data for the model, and what data is needed, is of vital importance for the usage of the tool. The need for simplicity is strong and it is preferable that all data used in the model to be readily available in report formats.

The tool requires several kinds of input data. This data is divided in five different categories, shown in Figure 25.

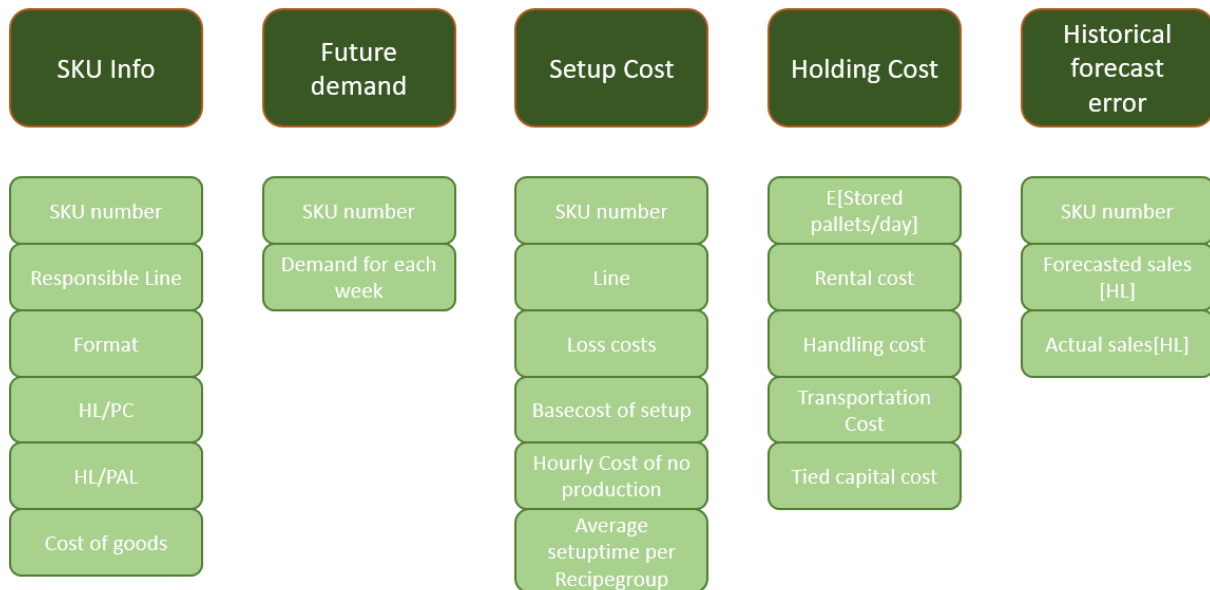


Figure 25: The different input categories of the model

The company's Business Intelligence tool have been found to be the best tool to handle this, as reports can be crafted to essentially match any need. Most of the data needed can be taken directly from the system but some of it must be modified slightly to fit the required format of the model. An example of this is the average changeover time per recipe group where the report returns historical productions orders and the user needs to create an average per recipe group.

Each input category is a separate sheet in the model except for the historical forecast error. The data over the historical forecast error are used in another sheet where the maximum batch sizes are calculated.

7 Discussion

The purpose of this project was to derive a quantitative model which determines the batch sizes in a better way and evaluate the impact of potential changes in the supply chain. The project was initiated by the planning department to bring consensus between various entities in the supply chain by using facts and figures. One obvious problem which complicates the development of the model is the complex supply chain with a vast number of articles and limited capacity, which most of the available theoretical models do not include. This complication is especially experienced at the planning department which must plan for different ambitions from various departments in the company. The literature has pointed out this problem and highlighted it as a strategic problem and thus the created model is suggested to be a tactical tool to guide the activities in the operational planning. Consequently, the model is not created to solve the complex problems of the supply chain but rather to focus on providing a cost-based solution for the supply chain which can be used as a baseline for operative work.

On a tactical level, the company uses S&OP as a business processes to handle the complex supply situation. The effort put in to handle the supply situation on a tactical level indicates that strategic decisions as investments in assets, facilities or product portfolios might need to be reviewed to operate in a better way. Such analysis is outside of the scope of this project but pointed out as potential for improvement of the performance of the supply chain.

7.1 Sensitivity analysis

The current analysis is made using data from last year's operations. As the production and warehouse operations are subject to constant change (and hopefully improvement). The statistical parameters of the stochastic variables derived in the analysis are also subject to change. This primarily affect the costs used for the EOQ-model as well as the forecast-accuracy of the demand, and these should be revised as time goes on. For the maximum batch sizes, relatively small changes in the standard deviation of the forecast accuracy can have a large impact on the maximum batch sizes and expected volume of perished goods.

Changes in the standard deviation of yield from the lines and the demand accuracy also have significant impact on the safety stock calculations and a reduction of these can lead to reductions in the total stock. One should be aware of the assumptions regarding for independent stochastic variables, used in the linear combinations. If strong correlations are present, the safety stock calculations and the modifications of the EOQ solution are affected.

Assumptions have been made for h_{FBG} , which affect the results from the EOQ-Model. However, as discussed in section 5.7, the EOQ-model is relatively robust to errors in the input parameter.

Finally, the EOQ-formula works best when the demand is relatively stable. SKUs that show a big variation in demand should have the timeframe of the collected critical values lowered, thus increasing the frequency of the analysis, for it to be accurate.

7.2 Scientific contribution

The purpose of the report was mainly to solve a problem provided by the company and most of the effort have been given to this task. However, the thesis can be used as a reference of how to handle various decisions in an industry with similar characteristics to the one examined. These include a complex portfolio and relatively clear warehousing costs.

This project contributes with a new approach where the results from the EOQ-formula is adjusted based on perishability and constraints in the manufacturing. In addition, the way of modeling the holding cost vary from the most common way used in industry by using an activity-based costing approach instead of the same holding cost rate for every SKU.

The way of modeling the safety stock including the yield loss in the fill rate formula is found not to be not commonly used in theory. This report used these relatively new approaches in a case study with relevant results.

7.3 Areas for future improvement

As with most research, there are always room for further investigation. Related to the holding cost for the extended main warehouse, assumptions for the marginal fraction have been made. These assumptions are suggested to be reviewed by people with expert knowledge of the warehouse operations.

Another area to further investigate is the changeover costs and the suggestion of including fixed overhead costs such as depreciation to the changeover cost for lines with capacity limitations. This was rejected, since no theory was found to support this.

The batch sizes determined by the model are suggestions on a tactical level for the upcoming six months. It is likely that the suggestions from the model will be changed in the operative planning process due to complexity reasons. To handle the alterations of the batch sizes in the operative planning process, an extension of the model, or perhaps separate complementing model are identified as opportunities to guide the operative planning process. Trade-off analysis could be performed to point out the best alterations for the situation.

For some SKUs, best practice would be to decrease the timeframe of the calculation because of a varying demand due to seasonal effects. A suggested development of the model is therefore to build in more detailed way to model the demand during specific time-periods based on characteristics for the article's demand. This would result in a higher frequency of changing the batch size that would better reflect the changes in demand during the year. The negative part of this is, naturally, the increased complexity and the increased workload of using the model more frequently.

8 Summary and Conclusions

The current method of determining the batch sizes at the company relies heavily on the individual planner's experience and empirical knowledge. The planning management wanted to investigate how the quantities of the production orders can be better chosen based on costs in the supply chain. They therefore requested a quantitative model which could guide the planning department in their future work. Therefore, the project's purpose was set to create a quantitative model that takes relevant costs and variables into account when determining the production batch sizes. The objective was also to evaluate the impact the model would have on finished goods inventory and the production capacity.

The company's current supply chain structure has been examined and the costs in this supply chain that relate to the batch sizes have been modeled in a straightforward manner. The approach to modeling the holding cost stock have been conducted with an activity-based costing approach. A solution for cost modeling of the sourcing aspect in the changeover cost have also been presented.

The model alters the batch size from the EOQ-formula when the risk of perished goods and the constraints of the processing department are considered. The model can be used for investigating the production and warehousing operations. For example, an analysis of how the new warehouse project would affect the stock and production capacity is presented.

To conclude, relevant theoretical models to determine batch sizes exist. The best choice of model for the company has been concluded to be the EOQ-Model, because of its simplicity and robustness. When this theory is incorporated in our model together with analysis of perished goods and constraints in processing, the model indicates that larger batch sizes than today should be used. An extension of the warehouse is assumed to decrease the holding cost and therefore increase the batch sizes further.

Regarding the consequences on the supply chain, the analysis of required production resources indicate that the limited capacity would require sourcing of products, even with the changed batch sizes.

A special finding concerns the company's current safety stock formula. The company is currently dimensioning their safety stock levels based on a formula that calculates the probability of no stock out per order cycle, but they are evaluated on the fill rate. With continuous usage of the current formula, the safety stock, and thus the average inventory would increase with increased batch sizes. A proposed suggestion of how to calculate the safety stock which incorporate the yield loss, is developed in collaboration with Johan Marklund, the supervisor of this project at Lund University. The new suggestion together with the increased batch sizes, result in a reduced safety stock. These changes result in a minimal change to the average stock on hand. The most effective way to further decrease the safety stock for the company is to lower the variability of the production yield.

9 Recommendations

The recommendation to the company is to start using the provided model to determine the batch sizes.

To make sure the model works accurately, the input data must be maintained and updated. The planning department is suggested to review the parameters every time the model is used, for example by inviting representatives from the different departments to evaluate the costs used. The company is suggested to put more effort into determine a holding cost for the extended warehouse.

This report brings attention to the company's safety stock formula, derived from a stock out probability per order cycle perspective and not ready rate which the supply chain is measured on. A new suggestion of how to calculate the safety stock based on the fill rate which incorporated the yield loss, is suggested.

Opportunities to further develop the model have also been identified. Firstly, the user friendliness which is especially apparent in the process of updating parameters such as cost or article data. Two other opportunities relate to possible extensions of the model. The first one is to incorporate seasonality, and the second is to better visualise consequences of changing the batch size from the initial suggestion.

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