Balancing the Costs for Finished Goods Inventory and Production Capacity in a Make-to-Order Company

A Case Study at Tetra Pak

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PREFACE

This master thesis project is the final step on my journey to becoming Master of Science in Industrial Engineering and Management. During this last semester of my education, I have had the chance to put the theories from university into practice, which has been a very rewarding experience.

I would like to thank everyone who has contributed with their knowledge and time in order to help me finalize this thesis. In particular I would like to thank Gabriel Dallari at Tetra Pak, who initiated the project and supported me throughout the process. I would also like to direct a special thank you to my supervisor at LTH, Peter Berling, for his much appreciated input and support.

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ABSTRACT

In most manufacturing companies, it is necessary to carry inventory to a greater or lesser extent in order to disconnect the activities in the supply chain that are not conducted at the same pace. This way, a smoother flow through the chain, from raw material extraction to arrival at the final customer of a finished product, is facilitated. However, different parts of a company often have conflicting goals when it comes to inventory decisions. From a financial point of view, for example, it is beneficial to have as little capital as possible tied up in inventory, while high stock levels can enable an even level of production and better customer service.

However these different goals are prioritized, the benefits in one department will incur costs in another one. The purpose of this project is to investigate how these costs are connected to each other, and increase the understanding of how they affect the total cost of ownership in a make-to-order company. Moreover, a model that describes the relationship between the different costs and that calculates a near cost optimal production plan over a given planning horizon will be developed.

An interview based, deductive case study with focus on finished goods inventory at Tetra Pak in Lund has been conducted to state an example of a typical make-to-order firm. Company specific cost factors have been identified and used for setting up an aggregate planning model and making calculations for a cost optimal production plan in an example case. Furthermore, the cost factors have been compared individually in order to establish an understanding of how they are interrelated in isolated decision situations.

It can be concluded that while the costs for inventory and production are relatively easy to determine, due to their concrete nature, other costs related to inventory and production management are more difficult to estimate. One such cost is the one of insufficient customer service, as this parameter cannot be measured only in financial terms, but also have soft aspects that have to be taken into consideration. It is therefore recommended that companies that wish to use methods similar to the one exemplified in this study, bear in mind that their strategic priorities have to be taken into account when making decisions based on the suggested cost optimal production plan.

SAMMANFATTNING

I de flesta tillverkande företag är det nödvändigt att, i större eller mindre utsträckning, hålla lager för att jämna ut taktskillnader mellan olika aktiviteter i försörjningskedjan. På detta sätt möjliggörs ett jämnare flöde från råmaterialutvinning till slutkund av en färdig produkt. Olika verksamheter inom samma företag har emellertid ofta motstridiga mål när det kommer till beslut om lagerhållning. Ur ett finansiellt perspektiv är det att föredra att ha så lite kapital som möjligt bundet i lagertillgångar, medan höga lagernivåer kan göra det möjligt att hålla jämn produktionstakt och erbjuda bättre kundservice.

Hur än dessa olika mål prioriteras, kommer de vinster som görs i en del av verksamheten att medföra kostnader i andra delar. Syftet med detta projekt är att undersöka hur dessa kostnader är sammanlänkade, samt att skapa ökad förståelse för hur de påverkar den totala ägandekostnaden i ett företag som tillverkar mot kundorder. Utöver detta kommer en modell som beskriver relationen mellan olika kostnadsfaktorer och räknar ut en nära kostnadsoptimal produktionsplan över en given planeringshorisont att tas fram.

En intervjubaserad, deduktiv fallstudie med fokus på färdigvarulager hos Tetra Pak i Lund har genomförts som ett typexempel på ett företag som tillämpar tillverkning mot order. Företagsspecifika kostnadsfaktorer har identifierats och använts för att ställa upp en modell för huvudplanering och uträkning av en kostnadsoptimal produktionsplan i ett exempelfall. Till detta kan läggas att alla kostnadsparametrar har jämförts individuellt, för att skapa förståelse för hur de är relaterade till varandra i en enskild beslutssituation.

Det kan konstateras att medan kostnader för lagerhållning och produktion är relativt enkla att bestämma, då dessa är av konkret natur, är det svårare att uppskatta andra kostnader relaterade till beslut om lager och produktion. En sådan kostnad är den för otillräcklig förmåga att bemöta kundernas önskemål, eftersom detta är en parameter som inte kan mätas enbart ur ett finansiellt perspektiv, utan även har mjukare aspekter att ta hänsyn till. Det är därför att rekommendera att företag som önskar använda modeller liknande den som använts i denna studie tar i beaktning att deras strategiska prioriteringar bör tas med i beräkningarna när beslut fattas baserat på modellens resultat.

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In this chapter, the reader is introduced to the project and the context in which it has been carried out. After a brief presentation of the background, the problem statement and the purpose of this study are discussed in further detail. Project delimitations are defined, before closing the section by outlining the report structure.

1.1 Background

In a supply chain, materials flow constantly on their way from raw material extraction to arrival at the final customer of a finished product. Ideally, these material flows would proceed smoothly, without interruption. Such ideal conditions would, however, require that all activities along the supply chain were conducted at the same pace and in perfect coordination with each other, which in practice is nearly impossible to achieve. By disconnecting the different parts of the chain, reproduction of disruptions from one part to another can be avoided. The main purpose of inventories is to create such disconnections and hence compensate for the inevitable lack of continuity and coordination between activities. Specifically, finished goods inventory separates the rate of production from sales and distribution processes (Mattsson and Jonsson, 2003).

In general, different departments within the same company often have conflicting goals related to inventory decisions. From a financial point of view, the goal is to keep the costs for stock as low as possible, which means that the firm cannot have a large amount of capital tied up in inventories. Production managers, on the other hand, strive for high and even utilization of capacity, which often requires goods to be produced and put in stock before the actual demand occurs in the market. Last, but not least, the company has to consider the minimum service level they want to provide to their customers, and what stock levels are necessary to achieve this objective.

However these different goals are prioritized, the benefits in one department will incur costs in another one. A common understanding within the firm of the relationship between the conflicting goals and the total cost of ownership would facilitate decision making on how to prioritize in different situations. Therefore, the connection between the costs for holding inventory and the costs for avoiding doing so is an interesting and relevant topic to investigate further.

1.2 Problem description

Tetra Pak manufactures machines for filling and packaging of liquid foods. The company applies make-to-order production, and as any other manufacturing company Tetra Pak carries inventory of finished goods. To run a cost effective business it is important to know how each activity along the supply chain contributes to the total cost of ownership, and the keeping of finished goods in stock is one such activity of which the cost has to be considered.

Today, Tetra Pak is making large efforts to keep track of their stock levels. The number of machines in stock is measured at the end of each month and year, and there are also statistics of the average number of machines in stock at month end. However, these measurements do not provide the full picture of the stock situation, which makes it difficult to determine each machine's contribution to the total cost of ownership. To improve the overview, an additional measurement of the average number of stock days has been added in 2015.

Although Tetra Pak is measuring the cost for the storage space at the warehouses, there are other costs related to inventory decisions, e.g. costs for having overcapacity or empty slots in production, or not being able to deliver orders on time, which are currently not kept track of. Not knowing the size of these costs makes it difficult to evaluate the inventory costs and decide if it is more beneficial to keep a machine in stock or reallocate production capacity. This project investigates the different cost components related to finished goods inventory decisions which contribute to the total cost of ownership of Tetra Pak equipment. The ambition is that the results will lead to increased understanding of the inventory cost situation within Tetra Pak, and provide an overview of the connections between inventory costs and production planning in general.

1.3 Purpose

The main issue in this project is, as mentioned above, that the factors that impact the total cost related to finished goods inventory of Tetra Pak equipment need to be identified and determined. For the company to acquire a better overview of the cost picture, the purpose of this study is to find answers to the following questions:

➢ What parameters affect the total cost for keeping a machine in stock?
➢ What are the alternatives to putting equipment in stock, and what are the cost consequences of these actions?

Moreover, an expected outcome of the work is a suggestion for a way of determining the most cost efficient balance between inventory and capacity costs. Against the backdrop of an analysis of these aspects, final conclusions and recommendations will be made.

1.4 Delimitations

The problem described in the previous section is quite extensive, and in order to be able to provide adequate results within the time frame of the project, the scope has to be narrowed down. The different types of delimitations chosen, as well as their relevance for the project, are discussed below.

1.4.1 Delimitations regarding the production facilities

Tetra Pak has production facilities in Sweden, Italy and China. Since the data availability from the Chinese plant might be limited, and in order to have an appropriate size of the project scope, the focus will be put on evaluating the costs for the Swedish and Italian facilities.

1.4.2 Delimitations regarding the product portfolio

Tetra Pak's product portfolio generally consists of two types of equipment – filling equipment and distribution equipment. The filling equipment is, in general, produced internally at Tetra Pak, while the production of distribution equipment is outsourced to several external suppliers. Since the scope of the project has to be adjusted to fit the time frame defined for a master thesis, it has been decided that only filling machines will be included in the analysis, excluding distribution equipment and other equipment related to filling machines (e.g. kits for package volume conversion). Furthermore, the scope will be narrowed down to investigating only the costs for filling machines belonging to the so called A3-portfolio, which make up 90% of Tetra Pak's sales. The concept of the A3-portfolio will be explained further in Chapter 4.

1.4.3 Delimitations regarding the system boundaries

When analyzing the costs in a supply chain, there is a need to define which parts of the chain should be included in the analysis, and which are possible to exclude. A wider scope will naturally enable more precise calculations, but will also significantly increase the complexity of the analysis. In this project, as the goal is to provide a basic understanding of the cost concept, only the parts of the supply chain that are directly connected to the finished goods inventory, i.e. the production and the finished goods warehouse, will be included. The parts of the supply chain that consider raw materials, parts and modules will thereby be excluded from

the scope, which means that these parameters will not constitute constraints in the final analysis.

1.5 Disposition

1.5.1 Introduction

In this chapter, the reader is introduced to the project and the context in which it has been carried out. After a brief presentation of the background, the problem statement and the purpose of this study are discussed in further detail. Project delimitations are defined, before closing the section by outlining the report structure.

1.5.2 Methodology

This chapter introduces a number of concepts related to project methodology. Thereafter, the methods chosen for this particular study are outlined, followed by a description of the working process considering literature review and data collection. The final section of the chapter deals with validation and criticism of the sources used.

1.5.3 Theoretical framework

The theoretical framework contains a review of existing literature and research within the fields of inventory control and capacity management. After explaining the purpose of keeping inventory and the costs related to doing so, the chapter continues with an introduction to the costs for capacity management. The last section of the chapter focuses on describing an aggregate planning model for production planning decision making.

1.5.4 Empirical data

Chapter 4 starts with a short introduction to Tetra Pak's business and overall strategy, followed by a general description of the supply chain studied. Thereafter, the individual parts of the supply chain are discussed in further detail, from forecasting, via capacity planning to production and inventory. The final sections of the chapter focus on customer service and financial aspects.

1.5.5 Cost parameters

The fifth chapter is dedicated to discussion of the cost parameters relevant in this particular case. Each parameter is presented separately with regards to how it has been determined and its relevance for the aggregate planning model that will be introduced in Chapter 6.

1.5.6 Model for cost minimization

This chapter provides an outline of the aggregate planning model used to find an efficient balance between inventory and capacity costs in this specific case. After an introduction of the model setup, assumptions and the determination of input parameters are discussed. Then an example case illustrates the functionalities of the model, before closing the chapter with individual comparisons of the different cost parameters.

1.5.7 Discussion

In Chapter 7 the assumptions, cost parameters, constraints and simplifications of the aggregate planning model developed are discussed in order to point out their impact on the model results. The final section of the chapter brings up the drawbacks of the model and their impact on its usability.

1.5.8 Conclusions and recommendations

The final chapter of this report discusses the conclusions of the results obtained in the project as well as recommendations for how these results can be used in practice. Moreover, suggestions for future research and the author's personal reflections on the contribution to increased knowledge of inventory and capacity planning in general are presented.

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2 METHODOLOGY

This chapter introduces a number of concepts related to project methodology. Thereafter, the methods chosen for this particular study are outlined, followed by a description of the working process considering literature review and data collection. The final section of the chapter deals with validation and criticism of the sources used.

2.1 An introduction to methodology

This project is planned and executed according to engineering practice through the use of scientific methodology, as per the guidelines of LTH (2014). According to Höst et al. (2006), a project which has been carried out according to these principles typically provides results that have strong support in already existing knowledge. Moreover, methods and sources are declared with total transparency, in order to enable independent scrutiny of the work done.

The appropriate methodology to apply will, however, change depending on the characteristics of the project in question. Since the methodology will set out the framework for the realization of the project, it should be chosen so that it supports the purpose and leads the way towards the goals to be obtained.

As mentioned in Chapter 1, the main purpose of this study is to determine the cost for Tetra Pak's finished goods inventory of filling machines, and compare these to the costs for avoiding putting machines in stock. There is already an extensive amount of research done within the fields of inventory control and production capacity planning, and the objective in this case is to use these theories and look deeper into a specific case from a holistic point of view. This project approach corresponds to what Denscombe (2009) denotes as a case study with a problem solving focus.

2.2 Quantitative and qualitative studies

A study is, in general, either quantitative or qualitative. Quantitative studies are characterized by the fact that they include measurable data, which is analyzed and evaluated with numerical and/or statistical methods. Qualitative studies, on the other hand, look into data that cannot be expressed by numbers, but is of a more intangible nature. Instead of focusing on numerical values, the qualitative analysis observes the existence of certain words and descriptions of reality and the object of study as such. In short, it can be said that quantitative studies result in tangible results of numerical type, while qualitative ones describe the situation from a human

point of view. Due to the abstract nature of qualitative data and methods, these are less suitable for generalization than quantitative ditto (Denscombe, 2009).

2.3 Induction, deduction and abduction

When taking on a project, there are two primary ways of approaching it. Deduction is a way of reasoning that starts from a theoretical point of view and formulates hypotheses which are then tested empirically, while inductive reasoning starts by observing reality and thereafter comes to theoretical conclusions based on the empirical observations. Abduction is achieved when these two different methods are combined, taking both theory and empirics into account at once.

2.4 The credibility of a study

Before relying on the results of a study, one has to evaluate its credibility, which depends on three parameters – reliability, validity and representativity. The characteristics of these concepts, as defined by Höst et al. (2006), are introduced below.

2.4.1 Reliability

The term reliability refers to the authenticity and credibility of the data collection and analysis performed. To achieve good reliability, it is important that data is collected in a structured way, and that the methods used are declared in a way that allows the reader to form an opinion of the quality and credibility of the work. Moreover, the selection and criticism of sources are of great significance in order to make sure that the results obtained are not mere coincidences.

2.4.2 Validity

When evaluating the validity of a study, the focus is put on determining whether the methods chosen actually measure parameters which are relevant to the project. Therefore, it is important to motivate the measurements done and what will be the use of their results. Such motivations give the reader the opportunity to understand the connections between the measurements and the study objective.

2.4.3 Representativity

The representativity of a study indicates to what extent the results can be generalized and applied in other cases than the one investigated. Case studies are normally not generalizable, but exceptions can be made for contexts similar to the one in which the investigation is

performed. Therefore, a thorough description of the context increases the representativity of a study.

2.5 Choice of methods

In line with the principles of scientific methodology, this section is dedicated to describing and motivating the methods used in this project. As the existing theories of inventory control and production planning are widely used in practice, the purpose of this study is not to develop and test new ones. Instead, a deductive approach has been assumed, where the theoretical framework is used as a basis for the data collection and analysis. This way, the results and recommendations will conform to well-recognized methods, and hence be easier to employ.

Moving from theoretical to empirical data collection not only facilitates the processes of formulating the problem statement and finding the key questions to be answered during the data collection. It also enables the reinforcement of results and arguments, which is a vital part of scientific methodology. Hence, the deductive approach provides a way to come to well-grounded conclusions that find support in already tested and approved theories, which is why it has been considered the most appropriate approach for this project.

Going back to the problem description and purpose from the previous chapter, it is clear that the results to be obtained are essentially of a quantitative kind. This means that the data needed in order to formulate relevant conclusions and recommendations first and foremost is of numerical nature. However, to understand the background of the problem and the context in which Tetra Pak is operating, some qualitative information needs to be acquired as well. This qualitative data is also needed in order to be able to formulate constraints and conditions for the analysis of the quantitative data.

It is common to work with interviews for collection of qualitative data. In this case, the numerical data needed for the analysis has also been obtained through oral and written communication, rather than through analysis of extensive ranges of data from business systems or databases. The benefits of collecting data through interviews include the possibilities to obtain in-depth information, which can be validated in the course of the interview. The deep knowledge acquired in this way can help the interviewer realize facts that otherwise might have been overlooked. These benefits, in combination with the fact that data collected through interviews often has a direct connection to reality, are the main reasons for the choice of interviews as the primary method for data collection in this study.

In particular, a semi-structured interview approach has been adopted to obtain the data necessary for the analysis of this specific case. Choosing to work with semi-structured interviews allows the interviewer to move within a pre-defined set of topics, and follow up on interesting answers. Furthermore, the interviewee is given the opportunity to elaborate on relevant points, which increases the chances of obtaining a clear picture of the context, which is important for the final results of the analysis (Denscombe, 2009). Therefore, the semi-structured interview approach was considered the most appropriate one for the project at hand.

2.5.1 Working process

A thorough review of literature within relevant fields of research is a key factor in establishing a foundation on which to base the data collection and analysis. To ensure that the theoretical framework provides all the information required to support the outcomes of this project, the literature study was divided into two separate, yet related, parts. The first part aims to compile the basic knowledge needed to formulate relevant problem statements and collect essential empirical data. After a first round of data collection, the gaps that had not yet been covered by the initial literature study were revealed. These revelations were then used as the basis of a more in depth review of specific topics and methods, which generated new ideas of which data needed to be collected. The result of this approach was an iterative process where empirical and theoretical data was combined in order to render the clearest picture possible of the context.

Having outlined the theoretical and empirical backgrounds of the case, a more thorough collection of empirical data was carried out, mainly through interviews as mentioned in the previous section. The information obtained was compared to existing research, in order to ensure the equitableness of the data, and then analyzed by using the aggregate planning method described in section 3.4. The separate cost parameters identified were also compared individually to provide a clearer picture of the cost structure and the relationships between different cost factors. Finally, the input data and the assumptions made were analyzed and discussed, in order to identify possible sources of error.

2.6 Validation and criticism of sources

To give the reader an opportunity to determine the degree of reliability of this study, it is necessary that the sources used are validated and criticized. As far as the written sources are concerned, these have all been found either in well-renowned scientific journals or in books

from publishing companies that are known for good quality educational literature. Moreover, several publications by the authors referenced have been used or recommended as course literature in relevant courses within supply chain management and logistics at LTH, which implies that the quality and relevance of these authors' works has been scrutinized and approved by people with extensive knowledge on the topics discussed.

When it comes to the thoroughness of the literature review, it has been rather difficult to find specific in-depth studies on inventory and capacity control in make-to-order production where the batch size is always one single item. Therefore, focus was instead put on collecting general theory on these topics, and to find a method that could be applied in a case where the batch sizes cannot be changed and production for safety stock is not possible. Many of the sources used have been frequently referenced by other authors; in particular, Silver et al. (1998) has been the basis of many articles reviewed in the search for relevant literature. The frequent referencing of the literature used is an indication that these sources are highly trusted within the fields of inventory and capacity control, and therefore can be considered reliable and relevant to this project.

Collecting the empirical data has been a process of finding relevant people to interview and to put the correct questions to the ones that were able to answer them. As the author's contact network within Tetra Pak is limited, it has been necessary to rely on the company supervisor's guidance on whom to contact for information within different fields. This can somewhat be seen as a limitation, since the possibilities to validate the answers with different contacts are reduced. However, the majority of the most relevant questions have been asked to people in different positions, so that the answers could be compared and differences questioned and clarified.

Collecting quantitative data mainly through interviews has made it difficult to perform extensive analysis and validation of this information, due to the scarce amount of data available for comparisons. When possible to obtain data from multiple sources, however, the numbers from the different informants have been compared, to see where there are mismatches and what might be the reasons for these. The main reason for data not matching between different sources was concluded to be the human factor, i.e. the fact that data is not always entered in a business system in a consistent manner. The errors or mismatches that were found have been amended, so to exclude as much incorrect data as possible from the analysis.

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3   THEORETICAL FRAMEWORK

The theoretical framework contains a review of existing literature and research within the fields of inventory control and capacity management. After explaining the purpose of keeping inventory and the costs related to doing so, the chapter continues with an introduction to the costs for capacity management. The last section of the chapter focuses on describing an aggregate planning model for production planning decision making.

3.1   The purpose of inventory

As mentioned in Chapter 1, inventories are held in order to disconnect the flows in a supply chain, thereby enabling different activities being carried out at different paces. Other than this main purpose, there are several other motivations for keeping materials or products in stock. Nahmias (2005) has compiled a list of situations when carrying inventory could be beneficial. This list includes, inter alia:

➢ *Smoothing* – when there are changes in the demand pattern over time, production can be initiated in advance to avoid the need for capacity adjustments related to demand peaks. Products that are produced before they are actually requested will be put in stock until the actual demand occurs.

➢ *Uncertainties* – uncertainties regarding customer demand, lead times, and supply of material and other resources are often seen as major concerns within manufacturing companies. Through carrying inventory, a firm creates a buffer against such uncertainties.

➢ *Economies of scale* – when the costs for setting up the production equipment before starting to produce a new batch are high, it is important that each batch contains enough units to justify these setup costs. Such economies of scale might result in finished goods inventories being built up.

➢ *Logistics* – this term refers to constraints that may arise in the processes of production or distribution and which will require that items are put in stock. An example of such a constraint would be the sailing schedules of transportation vessels.

No matter the reasons for keeping stock, the costs and consequences for doing so have to be evaluated against alternative possibilities. The following sections of this chapter will look deeper into relevant costs for stock keeping and other options, and how these costs can be determined in theory and practice.

3.2 Costs for carrying inventory

There are three primary types of costs related to inventory – holding costs, shortage (or stock-out) costs and ordering/setup costs. Each of these cost types will be further discussed below.

3.2.1 Holding costs

The inventory holding cost, often denoted h in literature, is defined as the cost for keeping one unit in stock for one unit of time (Berling, 2005). This cost is composed of the following four components:

➢ *Capital costs* related to the tied up capital that could have been used for alternative investments.

➢ *Storage space costs* including all costs associated with providing physical storage space for the inventory.

➢ *Inventory service costs* such as taxes and insurance.

➢ *Inventory risk costs* related to damage, obsolescence or other factors that cause the product value to decrease during the time in stock.

A common assumption made is that the capital cost is the dominant factor in the total inventory holding cost. In the literature, h is therefore often approximated to be the value of the variable cost for replenishment (C_k) of a product k multiplied by a constant representing the carrying charge, κ, of that product (Berling, 2005). This relationship can be expressed as

$$h = \kappa C_k \tag{1}$$

The constant κ is in practice often estimated by accounting managers, or set to a number recommended in literature. A common choice is 25%. Since this way of determining the carrying charge of inventory is commonly accepted and practiced, it has not been challenged by many researchers. However, Berling (2005) suggests that this traditional calculation model may not be as accurate in cases where the holding cost is not dominated by the cost for capital. Based on the concept of activity based costing (ABC), he has defined the holding cost for a product k as

$$h_k = \sum_{i=1}^{M} \lambda_{i,k} \, \kappa_i \tag{2}$$

where $\lambda_{i,k}$ is the amount of activity i used to store one unit of product k, M is the number of activities and κ_i is the cost per unit for activity i. In cases where the capital cost is not the

dominant factor in the total holding cost, this method can be used to calculate h in a more accurate way.

Moreover, La Londe and Lambert (1977) point out that it is appropriate for companies to make calculations of all cost components with the numbers and prerequisites that apply to their specific situation. Therefore, each of the four holding cost components will be reviewed below to provide an understanding of how they can be determined in practice.

3.2.1.1 Capital cost

In general, the capital cost of inventory, C_{cap}, approximately follows the linear relationship

$$C_{cap} = \kappa_c C \tag{3}$$

where C is the amount invested in one unit of inventory, and κ_c is the expected rate of return for an alternative investment opportunity. It is often difficult to decide how these factors should be determined, and the literature provides quite different methods as presented below.

Determination of the variable unit cost, C

La Londe and Lambert (1977) argue that C consists of two components to be considered when determining the size of an investment. First, there is the investment in the actual inventory, which could have been used for alternative investments. The costs that are relevant are the directly variable costs for inventory replenishment. This reasoning is also supported by other authors, e.g. Berling (2005) and Silver et al. (1998). Second, there is the investment in assets, such as handling equipment. These investments should, however, only be included in C if they vary directly with the amount of inventory held.

Nahmias (2005), on the other hand, suggests that the investment cost C is set to the book value of one unit of inventory. An advantage of this method is that these numbers are easily accessible, which facilitates the determination of the capital cost of inventory. However, Silver et al. (1998) point out that the unit value must include the total amount of money spent to make an item available, and that this value in most cases does not correspond to the book value that has been assigned by the accounting department.

Determination of the expected rate of return, κ_c

According to Berling (2005), there are two main methods of determining κ_c that are widely accepted – the weighted average cost for capital (WACC) and the opportunity cost. The opportunity cost corresponds to the highest expected return on an alternative investment, or

can be estimated to the company's target rate of return or current rate of return. WACC is calculated according to the formula

$$WACC = \frac{\sum_{i=1}^{N} r_i MV_i}{\sum_{i=1}^{N} MV_i} \qquad (4)$$

where N is the number of sources of capital, r_i is the required rate of return for security i, and MV_i is the market value of all outstanding securities i. In the industry, however, the factor κ_c is usually set to the cost for borrowing money. All the data needed for making calculations of κ_c according to these methods should be readily available in the financial statement of the firm.

Berling (2005) argues that both the opportunity cost and WACC methods often overestimate the capital costs, mainly due to the fact that inventory investments typically constitute a lower risk than the alternative investment options.

3.2.1.2 Storage space cost

As the storage space cost is related to the cost for physically storing the inventory, this cost will vary depending on two main factors – the type of warehouse used and the requirements of the goods stored. There are four main types of warehouses that could be considered (La Londe and Lambert, 1977):

➤ *Plant warehouses* – these warehouses are company-owned, which means that the costs for the space are normally fixed. Unless the storage space can be used for other productive purposes, if not used for storage, these costs should not be included in the variable holding cost.

➤ *Public warehouses* – companies can rent space in public warehouses, and are then usually charged based on the weight or volume of the inventory held. Since the charges are directly related to the amount of goods stored, they should be included in the holding cost.

➤ *Rented/Leased warehouses* – rental of warehouse space is in general contracted for a predefined period of time. Consequently, the rental charges will not vary with every change in the amount of inventory stored, but only when a new contract is negotiated. As the major part of the cost is fixed in nature, it should be left out when calculating the holding cost.

➤ *Privately owned warehouses* – for this type of warehouse, one should not include costs that could be eliminated by closing the warehouse or changing to public warehouses in the inventory holding cost.

3.2.1.3 Inventory service cost

As mentioned above, the inventory service cost includes taxes and insurance costs. The cost for taxes can be determined by multiplying the book value of the inventory with the tax rate, and hence this cost varies more or less directly with the size of the inventory. To calculate the tax rate, La Londe and Lambert (1977) recommend taking the actual taxes paid during the previous year over the average inventory value of that year. This number should then be multiplied by 100% to receive the rate.

When it comes to insurance, the fact that it is often purchased for a specified period of time implicates that the insurance costs are not directly proportional to the value of inventory. However, it is common to update the insurance fees periodically, based on expected changes in the inventory value. As a result of this custom, a linear relationship between the two can be assumed (La Londe and Lambert, 1977). It is worth noting that cost factors that influence the insurance fee, but do not vary with the amount of inventory, should not be included in the inventory service cost (Berling, 2005).

3.2.1.4 Inventory risk cost

The inventory risk cost is not to be confused with the financial risk related to carrying inventory, which is included in the capital cost. Instead, the inventory risk cost includes costs for damage related to the amount of inventory held, obsolescence, pilferage and relocation of goods from one warehouse location to another.

The inventory risk cost can be estimated by multiplying the inventory value with a constant rate of deterioration. A good approximation of this constant is obtained by calculating the previous year's risk costs as a percentage of that year's total value of finished goods (La Londe and Lambert, 1977).

3.2.2 Shortage costs

Shortage costs can be defined as the costs that occur due to the fact that customer demand cannot be fulfilled because of a stock-out or insufficient production capacity. In the short-range perspective, the shortage costs mainly include lost sales and discounts or penalty fees that have to be paid to the customers that are kept waiting. The long-range shortage costs consist of components such as future lost sales or lost goodwill, which are typically much more difficult to determine than the short-range costs.

3.2.3 Ordering and setup costs

When an order is placed to production or an outside supplier, there is normally a fixed cost connected to the order placement. This fixed cost is independent of the order size, and should be weighed against the expected cost for keeping a batch of the product in stock. This way, it is possible to determine an appropriate order size from a cost perspective (Berling, 2005).

The literature brings up two different denotations of the fixed cost incurred at order placement. The following definitions are suggested (Berling, 2005; Silver et al., 1998):

> ➢ *Ordering cost* – the ordering cost is related to an order placed to an outside supplier, and includes the costs for order handling and monitoring, and inspection of the goods (if any).
> ➢ *Setup cost* – the setup cost occurs when the firm starts the internal production process of an order. This cost consists, apart from the same cost components as the ordering cost, of the wages of the personnel setting up the equipment for production, the cost for decreased production speed during the initial phase after a setup, and the opportunity cost for production capacity that could have been used in an alternative way.

Berling (2005) argues that, ideally, only the marginal costs for a placed order should be included in the ordering/setup cost, which means that this cost would vary depending on the amount of free capacity. Constantly making new calculations of the ordering/setup cost would, however, neither be practical nor realistic. A way of obtaining an estimation of the cost for placing an order would be to calculate the average ordering cost over a pre-defined time period, as suggested by Bose (2006).

3.3 Costs related to capacity management

Even though the customer demand for a product in most cases varies in a seasonal way, companies often prefer to have an even use of capacity over time. This way the capacity costs are decreased, but on the other hand more products have to be put in stock when demand is low. The kind of inventory used to smooth a firm's capacity over the seasons is called leveling stock (Jonsson and Mattsson, 2009). In order to be able to decide whether to produce for stock or not, the costs related to carrying such inventory has to be weighed against the savings in capacity costs.

According to Jonsson and Mattsson (2009) there are two main strategies for adjusting capacity utilization. The *level strategy* means that capacity is not at all adapted to any changes in customer demand. Instead, either delivery time or stock is utilized to ensure smooth capacity utilization. The *chase strategy* is the opposite of level strategy, i.e. the capacity is always adjusted so that it follows the changes in customer demand.

Since these strategies take the complete opposite approaches, they are suitable for use in different cases. The level strategy is a good choice when inventory and backorder costs are relatively low, while the chase strategy is preferable when the required skill level among workers is low or the competition for employment opportunities is high, so that the work force can easily be increased or decreased as needed (Silver et al., 1998). In practice, however, a combination of the two is usually applied.

The costs to be considered when looking into capacity decisions are, other than the cost for carrying inventory, the following (Nahmias, 2005; Silver et al., 1998):

> ➢ *Regular time costs*
> ➢ *Overtime and subcontracting costs*
> ➢ *Costs for changing the rate of production*
> ➢ *Costs for idle capacity*
> ➢ *Short-term costs for insufficient capacity*

The remainder of this section will discuss the behavior each of these cost parameters.

3.3.1 Regular time costs

The regular time costs are the costs for producing one unit of a product during regular working hours. The total amount of regular time costs is the sum of direct and indirect costs for material, labor and manufacturing expenses. Looking into the behavior of the costs for labor, they typically increase as a result of higher rate of production since it can be assumed that a higher production rate requires at least the same amount of resources as a lower rate.

A large part of the regular time costs consist of the wages paid to the workforce. When the production rate is adjusted by increasing and decreasing the amount of personnel, the cost for wages can be seen as proportional to the size of the workforce, as shown in Figure 1. However, as a result of union contracts and other social factors, the workforce often has to be kept constant over time. Therefore, the cost for wages usually remains fixed, as represented by the dashed line in Figure 1 (Jonsson and Mattsson, 2009).
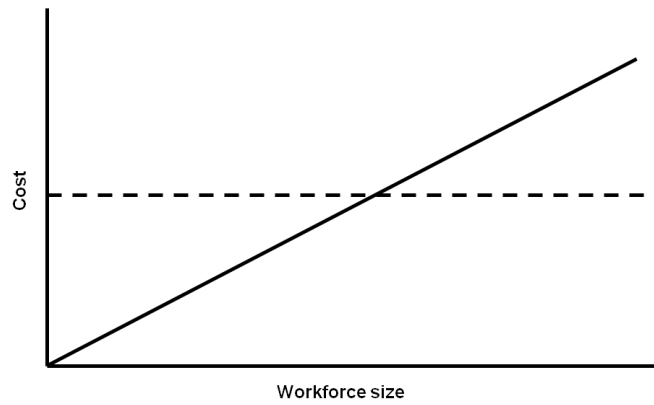
Figure 1 Cost for wages in production as a function of the size of the workforce

3.3.2 Overtime and subcontracting costs

According to the literature there are two types of costs that are associated with producing outside the regular working hours. Overtime costs are the costs for having the regular-time employees working after the normal working hours, and subcontracting costs occur when production is performed by an outside supplier.

Nahmias (2005) assumes that these costs can generally be seen as linear. Silver et al. (1998) on the contrary, argue that for a given workforce size, the cost function behaves as illustrated in Figure 2. They explain that initially only bottleneck operations will require overtime work, but the more the production rate needs to be increased, the more of the operations have to be run at overtime. Therefore, the curve becomes steeper at higher rates of production.
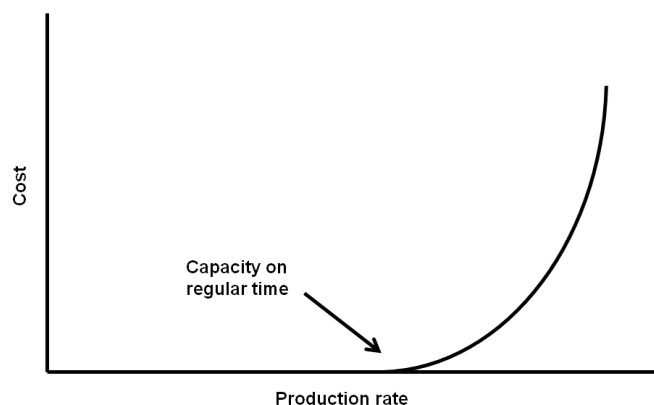
Figure 2 Cost for overtime as a function of the production rate at a given workforce level

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3.3.3 Costs for changing the rate of production

The major part of the costs for changing the rate of production consists of costs for changing the size of the workforce. These costs include, for example, hiring and training costs when new personnel is hired, and severance pay when workers are fired. Moreover, decreasing the workforce can result in decreased worker morale, of which the cost effects are hard to determine (Nahmias, 2005; Silver et al. 1998).

A typical cost curve for changed rate of production is illustrated in Figure 3. Nahmias (2005) considers a model where the costs for hiring and firing are linear functions of the number of employees. Since the cost for decreasing the workforce with one employee is usually not the same as for hiring an additional one, the cost curve is asymmetric around the vertical axis.
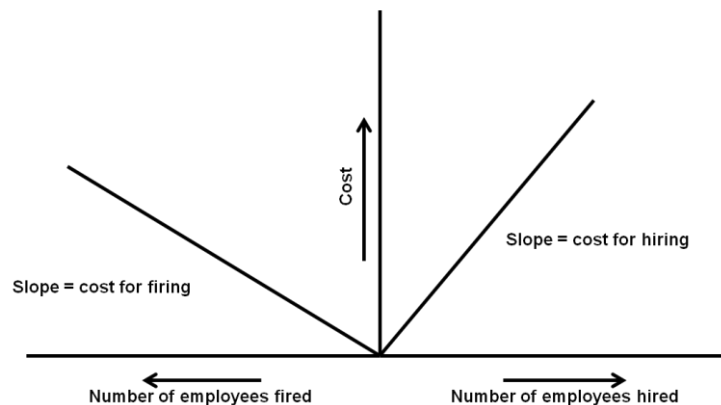
Figure 3 Costs for increasing and decreasing the workforce in production

3.3.4 Costs for idle capacity

According to Nahmias (2005), the cost for idle capacity can often be set to 0 in the aggregate planning problem (see section 3.4), since these costs in most cases have already been taken into consideration when calculating the cost for labor or lower rate of production. However, having idle capacity in one phase of the production process could result in higher costs in other phases, if the production flow in subsequent processes is disrupted due to the idling capacity in a precedent process.

3.3.5 Short-term costs for insufficient capacity

The short-term costs for insufficient capacity correspond to the costs for shortage or stock-outs from a short time perspective. These costs were discussed in section 3.2.2 of this report.

3.4 Aggregate planning

A common way of determining the most cost efficient solution for capacity allocation and inventory is to use some sort of aggregate planning model, or the classical EOQ-model (Economic Order Quantity), as described by e.g. Nahmias (2005), Chopra and Meindl (2007) and Silver et al. (1998). Moreover, Wagner and Whitin (1958) formulated a dynamic programming model for determination of optimal production schedules. Both the EOQ-model and the method suggested by Wagner and Whitin (1958) are based on the possibility to optimize the total cost by choosing the order quantity that gives the best balance between costs for carrying inventory and fixed order costs. Since the order quantity in the production of Tetra Pak filling machines is fixed due to the fact that the machines are highly customized, this section will focus on describing the aggregate planning approach.

3.4.1 The purpose of aggregate planning

Aggregate planning can be used within a firm to determine the best levels of parameters such as capacity, production, subcontracting and inventory from a cost perspective. The main target is to meet the customers' requests and at the same time maximize the profit. As the name implies, the method provides a solution of aggregate decisions rather than very detailed ones. This level of detail makes the method appropriate for decision making with a planning horizon of approximately 3 to 18 months. Since this time frame in general does not allow making decisions on production levels per SKU (Stock Keeping Unit) or arranging for increased capacity, aggregate planning is first and foremost a method of determining how to best utilize the resources currently available within the company (Chopra and Meindl, 2007).

The main parameters to be determined in the general aggregate planning problem are the following:

> *Production rate* – the number of units produced per unit time
> *Workforce level* – the number of workers or units of capacity required in production
> *Overtime* – the amount of overtime to be used
> *Machine capacity level* – the number of units of machine capacity required
> *Subcontracting* – the number of subcontracted capacity units needed

➢ *Backorders* – the number of units of demand that are not fulfilled in the period requested, but that are carried over to coming periods

➢ *Inventory level* – the number of units in stock in each period over the planning horizon

Chopra and Meindl (2007) point out that in order for the aggregate planning to be as effective as possible, it is important that the planning is not only focused internally within a company, but that a holistic supply chain perspective is adopted as well. Since both upstream and downstream partners in the chain will be the sources of many constraints in an aggregate planning model, understanding the connections between the different parts of the supply chain is of great value when determining an ideal solution.

3.4.2 Formulating the aggregate planning problem

Chopra and Meindl (2007) have stated the aggregate planning problem as follows:

"*Given the demand forecast for each period in the planning horizon, determine the production level, inventory level, and capacity level (internal and outsourced) for each period that maximizes the firm's profit over the planning horizon.*"

Therefore, in order to determine a solution to the problem, the planning horizon has to be determined, as well as the information suggested below (Chopra and Meindl, 2007; Nahmias, 2005):

➢ *Demand forecast* for each period *t* during a planning horizon of *T* periods
➢ *Regular time costs*
➢ *Overtime costs*
➢ *Costs for subcontracting*
➢ *Costs for changing capacity* by hiring or laying off workers
➢ *Costs for idle capacity*
➢ *Number of labor/machine hours* required per unit
➢ *Costs for holding inventory* per unit and time unit
➢ *Stock-out/backorder costs* per unit and time unit
➢ *Number of units produced* per worker and time unit

It is worth noting that this information should be adapted to each company specific situation in order to make the model as accurate and relevant as possible. This means that parameters may be added or excluded from the model depending on the situation. Having defined the

input data, a mathematical model of the problem should be formulated. How this is done is described in the next section.

3.4.3 Solving the aggregate planning problem

The usage of linear programming to find a solution to the aggregate planning problem is an efficient approach suggested by several authors, e.g. Nahmias (2005), Silver et al. (1998) and Chopra and Meindl (2007). However, the application of this approach requires that all cost functions defined in the model are at least piecewise linear. Moreover, all the problem variables have to be non-negative in order for the model to work as intended. This section will be dedicated to demonstrating the setup of a standard linear programming model, as suggested by Chopra and Meindl (2007) and Nahmias (2005).

First, the decision variables must be identified. The most common ones are the following for each period t in the planning horizon:

$$W_t = \text{ workforce size in period } t$$

$$O_t = \text{ number of hours of overtime worked in period } t$$

$$U_t = \text{ number of hours of idle capacity in period } t \text{ (“undertime”)}$$

$$P_t = \text{ total number of units produced in period } t$$

$$S_t = \text{ number of units subcontracted in period } t$$

$$H_t = \text{ number of workers hired in period } t$$

$$F_t = \text{ number of workers fired in period } t$$

$$I_t = \text{ inventory level at the end of period } t$$

$$B_t = \text{ number of units stocked out/backordered at the end of period } t$$

The costs related to each of these decision parameters are known, as well as the initial level of inventory. Moreover, the maximum production allowed per period is a known factor, and the demand per time period is represented by a forecasted number of orders expected. Last, the length of the planning horizon has to be determined. These parameters are denoted as below:

c_R = cost per time period for regular time production

c_O = cost per hour of overtime production

c_U = cost per hour of idle capacity

c_S = cost per subcontracted unit

c_H = cost for hiring one worker

c_F = cost for firing one worker

c_I = cost per period for carrying one unit of inventory

c_B = cost per period and stock $-$ out/backordered unit

I_0 = initial inventory on hand at the start of the planning horizon

W_0 = initial workforce size

D_t = forecasted demand in period $t, 1 \leq t \leq T$

n_R = number of units that can be produced per worker during regular time

n_O = number of units that can be produced per hour of overtime

O_{max} = maximum overtime hours allowed per period

T = number of periods within the planning horizon

The target is to minimize the total cost by changing the decision parameters. With the denotations above, the objective function can be stated as follows:

$$\min \sum_{t=1}^{T} c_R W_t + c_O O_t + c_U U_t + c_S S_t + c_H H_t + \qquad (7)$$

$$+ c_F F_t + c_I I_t + c_B B_t$$

subject to the following constraints:

$$W_t = W_{t-1} + H_t - F_t \text{ for } 1 \leq t \leq T \text{ (workforce balance)} \qquad (8)$$

The workforce balance constraint indicates that the workforce size in period t has to be equal to the number of workers in period t-1 adding the number of workers hired in period t and subtracting the number of workers fired.

$$P_t \leq n_R W_t + n_O O_t \text{ for } 1 \leq t \leq T \text{ (capacity constraints)} \quad (9)$$

When it comes to capacity constraints, the total production has to be less than or equal to the maximum number of units that can be produced in total during regular time and overtime.

$$I_{t-1} + P_t + C_t = D_t + B_{t-1} + I_t - B_t, \quad (10)$$

$$\text{for } 1 \leq t \leq T \text{ (inventory balance)}$$

When calculating the inventory balance, the total demand of period t is taken as the sum of the forecasted demand for period t, plus the number of backorders B_{t-1} from the previous period. This net demand is filled either directly from the inventory of period t-1 (I_{t-1}) or from the production of period t (P_t). At the end of the period, the demand is either entirely fulfilled, resulting in an inventory I_t larger than or equal to 0, or there is some demand left unfulfilled, resulting in a positive number of backorders, B_t.

$$O_t \leq O_{max} \text{ for } 1 \leq t \leq T \text{ (overtime constraints)} \quad (11)$$

The number of overtime hours in period t cannot be greater than the maximum overtime limit.

$$W_t, O_t, U_t, S_t, H_t, F_t, I_t, B_t \geq 0 \text{ for } 1 \leq t \leq T \text{ (non} - \text{negativity)} \quad (12)$$

All decision variables have to be non-negative.

It should be noted that additional constraints could be added to the model so that it reflects a company specific situation. Exactly what those constraints might be will not be discussed here, since they will vary depending of the requirements and conditions for the company and situation studied. The changes relevant for this particular case will be discussed in Chapter 6.

4   EMPIRICAL DATA

Chapter 4 starts with a short introduction to Tetra Pak's business and overall strategy, followed by a general description of the supply chain studied. Thereafter, the individual parts of the supply chain are discussed in further detail, from forecasting, via capacity planning to production and inventory. The final sections of the chapter focus on customer service and financial aspects.

4.1   Company description

Tetra Pak aspires to supply its customers with all the equipment necessary for processing, packaging and distribution of food and beverages. A large part of this business is the manufacturing and sales of machines which can be combined into complete packaging lines that serve the particular needs of each customer. Based on the field of application, all Tetra Pak equipment is divided into two main groups – filling and distribution equipment. The filling machines fill the product into packages and seal them, while the distribution equipment serves functions such as cap and straw application, film wrapping and packaging of primary packages into secondary packages. Most filling equipment is produced internally at Tetra Pak, and the production of distribution equipment is mainly outsourced to external suppliers.

The filling machines are categorized based on the type of packages that they fill. There are five portfolios in total; Carton Economy, Carton Value, Carton Bottle, Carton Gable Top and Carton Food. This project focuses on investigating the costs for stock of finished A3-filling machines, which belong to the Carton Value portfolio, and make up approximately 90% of Tetra Pak's total yearly sales. These machines can fill packages of the types Tetra Brik, Tetra Gemina or Tetra Prisma, illustrated in Figure 4, in several different package volumes, depending on the machine configuration chosen by the customer. Besides the choice of package type and volume, there are several other parameters which each customer has to specify in their order, to get a machine that is adapted to the specific requirements for packaging of their products.

Figure 4 Tetra Brik Aseptic, Tetra Gemina Aseptic and Tetra Prisma Aseptic

There are three different machine types belonging to the A3-platform, and these are briefly described below for the reader to get an understanding of the difference between them. Figure 5 shows an example of a Tetra Pak packaging line, and Table 1 shows a range of general characteristics of the three machine types studied. It should be noted that weights, dimensions and machine values vary with the configuration and customization of the machines, and these values are therefore represented by average numbers in the table.

➢ *A3/Speed* – Tetra Pak A3/Speed, which is the fastest of the A3-machines, comes in two versions that operate at different speeds. For packaging of family size packages the capacity is 15000 packages/hour, while a speed of 24000 packages/hour can be obtained for portion packages.

➢ *A3/Flex* – this is the most flexible machine in the A3-portfolio, with an output capacity of up to 8000 packages/hour.

➢ *A3/CompactFlex* – this machine is relatively small and flexible, and has a capacity of producing 9000 portion packages/hour.

Figure 5 Example of a Tetra Pak packaging line

Table 1 Characteristics of the machine types studied

Machine characteristics	A3/Speed	A3/Flex	A3/CompactFlex
Max. number of packages/hour	9000-24000	4500-8000	7500-9000
Package types	Tetra Brik Aseptic Tetra Prisma Aseptic	Tetra Brik Aseptic Tetra Gemina Aseptic Tetra Prisma Aseptic	Tetra Brik Aseptic Tetra Prisma Aseptic
Package volumes (ml)	100-1000	500-2000	80-375
Weight (kg, average, gross)	16200	14300	10900
Area (m^2, average)	32	27	26
Demand in 2014			
- *Req. ETD[1] in 2014*	114	98	147
Average stock days in 2014			
- *All machines dispatched*	16	13	14
Machine value (k$, average)	4320	4320	2880

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[1] Estimated Time of Dispatch

When it comes to company strategy, Tetra Pak has four main strategic objectives which should all be taken into consideration throughout the project:

➢ *Growth in all markets*
➢ *Accelerate value driven innovation*
➢ *Drive environmental excellence*
➢ *Strengthen operational performance*

In particular, the objective of strengthening the operational performance is relevant to this project. In essence, this objective consists of three parts – cost and complexity reduction, quality leadership and improvement of productivity and customer service. It is known from several sources that the financial goals for each of these parts are often not completely aligned. Reducing the costs and complexity might put both quality and customer service at stake, and too much focus on high performance only could cause the costs to increase rapidly. Therefore, Tetra Pak finds it relevant to map the costs related to inventory decisions and relate them to costs in other parts of the supply chain.

4.2 Supply chain structure

Tetra Pak Packaging Solutions, which are responsible for manufacturing the packaging line equipment, sells its products to the final customers via Tetra Pak market companies. There are 32 market companies spread all over the world, and which are selling and distributing equipment to customers within their respective geographical areas.

The part of the physical supply chain studied in this project consists of Tetra Pak's own production facilities in Lund (Sweden) and Modena (Italy), which deliver finished filling machines to two external warehouses – one in Helsingborg and one in Modena. Thereafter, the goods are shipped to the final destination requested by the relevant market company. Figure 6 illustrates the physical supply chain structure. The dashed frame symbolizes the limits of this project.
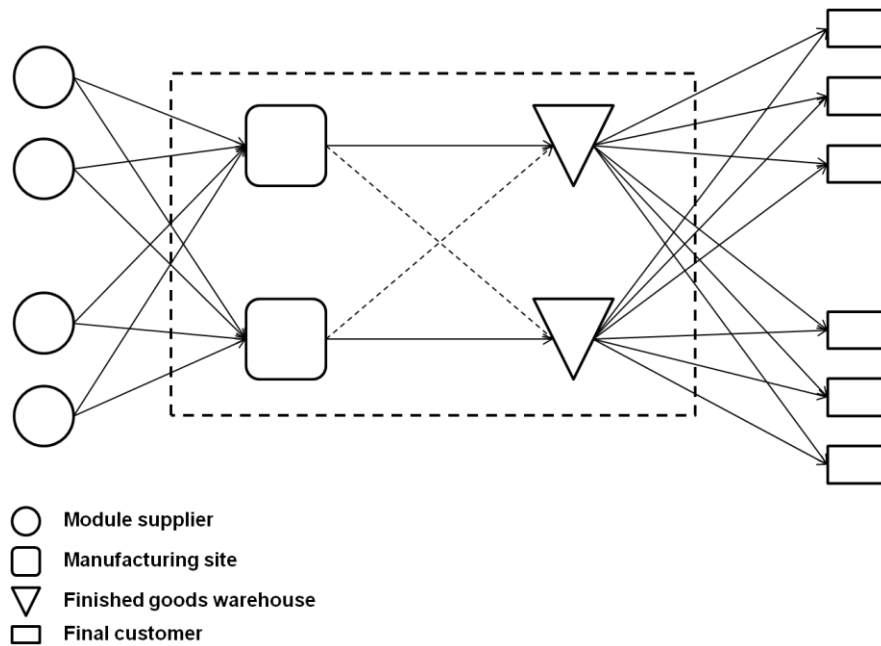
Figure 6 Overview of the physical supply chain studied

4.3 Demand and forecasting

The forecast of demand of Tetra Pak machines is set yearly for the short term of one year, and for the long term of the two years thereafter. These forecasts are then the starting point for decision making regarding budget, production and capacity levels. The method used is a rolling forecast that is continuously revised based on the actual order intake and new information from the different markets. At the end of each year, representatives from all market clusters enter their demand forecasts for the three following years, which are then reviewed on a monthly basis by reconfirming the forecasted demand for the remaining part of the year. In theory, the result of this practice would be that demand was known with relatively good accuracy one year in advance. However, since customers can decide to change, postpone or anticipate the forecasted orders with short notice, reality becomes more complex.

To make sure that the forecast reflects the actual demand to the greatest extent possible, and to keep track of the forecast accuracy, there is one long-term and one short-term measure for the markets. The short-term measure reaches five months ahead in time, and considers the number of machines per machine type. Every month, the actual number of orders with requested delivery date in that month and that have actually been placed and dispatched is compared to the forecast from five months ago. Over the long term, only the total number of machines, independent of machine type, is measured. For the markets to be compliant to the

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measures there must be a match between the forecast and the actual number of machines ordered.

An issue with the short-term measure is that a requested estimated time of arrival (ETA) five months ahead means different requested estimated times of dispatch (ETD) depending on where the final customer is located. For European markets, an ETA five months ahead corresponds to an ETD that is also approximately five months ahead in time, since the transportation routes are in general less than two weeks for such shipments. For overseas shipments, on the other hand, the ETD could be only three months ahead, meaning that when the forecast is set, such orders should already have been placed by the market companies, considering a committed delivery time of approximately 12 weeks. Since the capacity is set 3-4 months in advance, it is difficult to use the short-term measure for capacity planning purposes. (Zoboli, 2015)

4.4 Capacity and planning

When setting the capacity levels for filling machine production, the number of machines that need to be produced during a certain amount of time (i.e. that has a requested ETD within a pre-defined time period) is determined based on the demand forecast. The capacity is then set based on the TAKT time, which is defined as the time between production start of subsequent machines. Hence, high demand means a short TAKT time and increased capacity, and vice versa. While the maximum total number of A3-machines that can be produced in one week is 12 for the two production plants together, the target TAKT is 1 in the Modena plant (5 machines per week), and 1.25 in Lund (4 machines per week).

When the TAKT is set, Tetra Pak instructs their suppliers of modules to adapt their production and stock levels so that they are able to deliver the modules at the scheduled production start of each machine. Fulfillment of these TAKT agreements with the material suppliers is of great importance, since the changes in production rates resulting from changes in the TAKT time are amplified upstream in the supply chain. This bullwhip effect is illustrated in Figure 7.

Platform level   Machine level   Module level

Amplitude of production
rate fluctuations

Position in the
supply chain
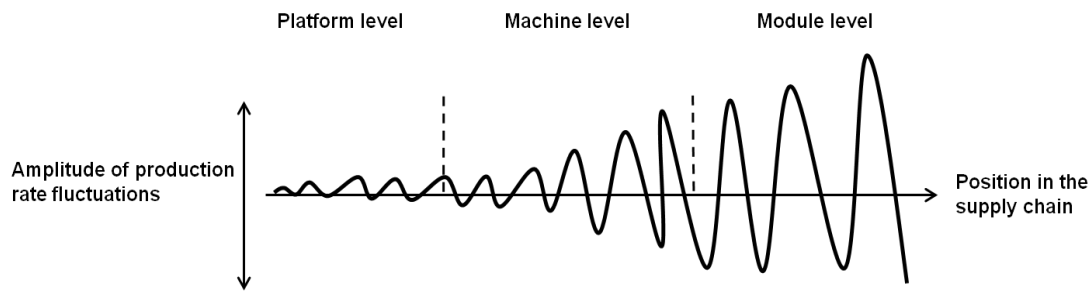
Figure 7 Amplification of production rate fluctuations along the supply chain

At every TAKT change, there is a period for adaptation of 72 calendar days, which is the time it takes for a new TAKT to become effective and to generate a new slot in production. In practice, this means that it takes 72 days until the time interval between finished machines corresponds to the new TAKT time. Due to this relatively long time for adaptation, the capacity and TAKT are kept at a stable level when possible, making only small changes, instead of following every change in demand. In general, the TAKT time is not changed more often than once per month, and big TAKT changes are done stepwise in order to avoid large fluctuations in production rates along the supply chain. To optimize capacity utilization and not lose capacity, future orders are anticipated to fill empty production slots when demand is low, i.e. capacity leveling.

When planning how to utilize the available capacity, Tetra Pak makes strategic prioritizations based on a pre-defined "priority ladder". In this hierarchy, two of the most important priorities are to fulfill the customers' requests and to keep the TAKT agreements with the suppliers. Keeping low stock levels in finished goods inventory has not been one of the main objectives, and therefore focus has been put on optimal capacity utilization rather than reduced time in stock. (Fuca, 2015)

If all available slots are not used for production, i.e. all the capacity available is not utilized, costs can occur in different parts of the supply chain. First, there can be costs for not fulfilling the TAKT agreements with the suppliers, and second costs can occur internally in the production if resources are left idling or capacity has to be increased in future periods to cover the demand. These costs are difficult to estimate, since a missed slot does not automatically mean that workers remain idle or that no value adding activities can be carried out in the meantime. However, Tetra Pak has made calculations of the average cost per missed slot, which is set to $59040. (Dallari, 2015)

4.5 Production

Due to the high degree of customization of Tetra Pak machines according to every customer's request, it would be very difficult, or even impossible, to start to produce a machine according to the forecast unless an order has been placed from the customer with all the machine specifications requested. Therefore, Tetra Pak does not start production until an order is received from the market companies. Each machine that is in production, and later in stock, hence has a designated final customer for which it has been produced. There are exceptions to this general rule, however, including for example cancellations and postponements of orders that have come too far in the production process for the production to be stopped.

All A3-machines can be produced either in Lund or in Modena, depending on capacity availability. In general, approximately 60% of the production takes place in Italy, and the remaining 40% in Sweden. However, the orders received are allocated between the two plants so that the degree of occupation is kept at an acceptable level in both locations. This means that when demand is low, the production split is closer to 50/50 between the two facilities.

The production setups at the two factories are somewhat different. The Italian plant only produces machines belonging to the A3-platform, which means that they can dedicate all their available capacity to this kind of production. In the factory there is an internal workforce of 27 test engineers, which can produce a total of approximately 4 A3-filling machines per week without hiring external resources. In Lund, on the other hand, there is production of both A3-machines and machines from the Carton Bottle and Carton Gable Top portfolios, which means that the capacity that can be used for A3-production is highly dependent on the order intake of orders of other equipment. There are two teams of internal staff in Lund, one of which is dedicated to production of A3-machines. This team comprises 17 test engineers plus four employees who cannot take part in the machine testing phase, and hence work only with assembling, dismantling and packing of machines. Some of the resources in the two teams in Lund are multi-skilled, and can switch teams to cover for demand peaks, which makes it difficult to determine an exact number of A3-machines that can be produced per week using only internal staff. However, there is always enough capacity to produce at least 3 A3-machines per week without using external resources. Of the total working hours available in both production plants, a share of 80% is dedicated to actual production activities, and the remaining time is used for other tasks such as administration and meetings.

All modules from different suppliers are delivered on the day of production start to the relevant Tetra Pak plant, where they are immediately used. Hence, the stock of modules is built up at the suppliers based on the agreed TAKT time, instead of keeping materials in stock internally at Tetra Pak. Currently the module suppliers have a delivery accuracy of 99%, which means that there are practically no delays caused by missing modules. (Abbate, 2015; Dallari, 2015; Wahlgren, 2015)

4.5.1 Lead times

The lead time for a filling machine order can be split into four parts:

➢ *Queue time* – the time during which an order is maintained in the backlog waiting for available capacity in production.

➢ *External lead time* – the time it takes for the suppliers to deliver the modules required to assemble the machine.

➢ *Internal lead time* – the time from assembly start until the machine is finished and ready to be delivered to the customer.

➢ *Stock time* – the time between the actual finish date of the machine and the dispatch from the warehouse.

The queue time depends on, among other factors, the capacity level chosen at a certain time. If there is overcapacity in the factory, orders can be taken into production quicker, which will reduce the queue time. However, there are risks involved in always keeping a high capacity level. To avoid missing production slots when the capacity is set to a higher level than required, future orders might have to be anticipated to fill up the empty slots, which will result in increased stock time.

For the external and internal lead times there are fixed standard levels. The external suppliers, who deliver the modules required to build a complete filling machine, have committed to a lead time of 17 days. The assembling, testing and dismantling of the machines in the internal production has a standard lead time of 19 days, of which 13 days are dedicated to testing. The total lead time that Tetra Pak promises to the customers for A3-machines is 73 days from order placement to dispatch. (Abbate, 2015)

4.5.2 Production costs

Apart from the overhead costs and the cost for space in the production halls, the cost for production includes the cost for labor. The amount of workers that are working on a machine

at the same time varies through the different production phases. While assembling and dismantling requires 2 to 3 employees, only one member of staff is needed per machine during the testing phase.

Tetra Pak uses a combination of internal employees and external workers. The internal manpower is kept to a level slightly lower than the expected need, in order to minimize the risk of having excess capacity. The plants in Lund and Modena have different approaches when it comes to using external manpower. In Lund, the activities of assembling, dismantling and packing of machines are always performed by external resources, bought at a total price of $5628 per machine. In Modena, however, production of up to 4 machines per week can be entirely performed by the internal employees. If the production rate exceeds 4 machines per week, 4 external workers need to be hired per extra machine, at a cost of $195/hour. These resources are hired for a full week at a time, which means that Tetra Pak will be charged for 40 hours per external resource.

The external resources can be seen as a rubber band, which gives Tetra Pak the opportunity to easily increase capacity when the demand is high. On the opposite, when the demand is lower than expected and future orders cannot fill the empty slots, members of the internal staff are first designated to do other work in production, and if there are still too many members of staff available, labor will be utilized for other activities within Tetra Pak. This way, the amount of idle labor is kept as low as possible, which is favorable from a cost perspective.

The cost for regular time production is the same for the plants in Lund and Modena. The cost is set to an hourly rate of $1585/hour of production, which includes the cost for labor as well as overhead costs. This rate is determined based on the budgeted number of working hours and the budgeted costs that will occur during this time. If overtime is used, the cost per hour will increase with 20%, which equals a cost of $1900 per hour. However, overtime is generally used only to cover for unforeseen events and extra activities, such as training, and not for covering demand peaks. (Abbate, 2015; Wahlgren, 2015)

4.6 Inventory and warehouses

The current situation of finished goods inventory at Tetra Pak is reviewed week by week, and also at the end of each month and year. The main targets that are monitored are the amounts of filling and distribution equipment in stock, and the number of stock days for each piece of equipment in stock at month and year end. At the end of 2014, the average number of filling machines in stock at the end of each month was 18 machines (including the machine types

that are not in the scope of this project), and the target set for 2015 is 15 machines on average at month end.

Moreover, an average number of stock days per machine type has recently been introduced as a measure to be followed up each month, since this will provide a more complete picture of the situation. At month end the total number of days in stock for all the finished machines that have not yet been dispatched is divided by the number of machines in stock, generating a month end average number of stock days for the machines. The month end averages are then consolidated into a year-end average, which in 2014 was 50 days for filling machines. For 2015 the target is to have an average number of stock days of 43 days for all filling machines. (Cea, 2015)

To be able to estimate and calculate the actual costs for inventory keeping per year, it is also interesting to find out not only the average number of stock days for the machines that have been in stock at the end of a month, but also the average time in stock for all machines dispatched during a year. Therefore data of number of stock days per machine that was dispatched during 2014 has been extracted from Tetra Pak's business system. Table 2 summarizes the findings of these extractions.

Table 2 Number of stock days per machine type 2014

Number of stock days	A3/Speed	A3/Flex	A3/CompactFlex
Average	16	13	14
Median	7	8	9
Minimum	0	0	0
Maximum	175	109	89

As mentioned above, there are two external warehouses with which Tetra Pak has contracts for rental of space for storage of finished goods. In most cases (with very few exceptions), goods produced in Sweden are kept in stock in Helsingborg, and goods from Italy are stored in the warehouse in Modena. Since the terms and conditions for each warehouse are different, they will be discussed separately below.

4.6.1 Helsingborg warehouse

With the external warehouse in Helsingborg, Tetra Pak has an agreement of services, fees and conditions, which is valid for a fixed period of time (currently two years). According to this

agreement, the warehousing fees include the cost for all duties and taxes connected to the provision of the services (unless otherwise agreed), and will stay fixed throughout the term of the contract. The cost for rental of storage space is $21/m^2$ and month, and Tetra Pak pays for 500 m^2 of storage space, regardless of the actual usage.

Apart from the cost for space there are also handling fees, which include loading and unloading of goods, goods marking and administration. Tetra Pak is charged based on the following:

➢ Number of man hours spent on handling the goods ($360/hour)
➢ Number of overtime hours used ($190-480/hour depending on day and time)
➢ The usage of forklifts, capacity of 8/16 tons ($125/290/hour)
➢ Goods marking material (full cost)

The machines produced in Lund are packed internally at Tetra Pak, which means that there is no need for the machines to be taken to the warehouse in Helsingborg to perform this activity. Hence, it is possible to take the goods directly from production to stuffing. In general, however, most of the machines pass through the warehouse and are kept in stock for a short period of time before dispatch. (Amaya, 2015; Fort, 2015; Paradis, 2015)

4.6.2 Modena warehouse

At the warehouse in Modena Tetra Pak rents a total space of 6400 m^2, of which 400 m^2 are uncovered. The area available for storage of equipment is approximately 2200 m^2, and the remaining space is dedicated to packing, and storage of palletized goods. The contract with the warehouse runs over a fixed period of time (currently six years).

The rental cost for the total space available is $526/m^2$ and year, and includes manpower, surveillance, maintenance and handling of damaged goods. The charge is fixed in the contract with the warehouse, and Tetra Pak is currently paying for 6000 m^2, with the possibility to increase with another 400 m^2 with the uncovered space when there are peaks. In addition to the charge per square meter, there are fees for handling of arriving and departing goods, which are specified as follows:

➢ Cost for each unit of loading (UoL) entering in stock ($36)
➢ Cost for each UoL taken out of stock ($36)
➢ Packaging of filling machines ($4320 each)

> ➢ Shuttle for transport of goods from Tetra Pak production facility to the warehouse, and vice versa ($612 per each shuttle, on average 3-4 shuttles/day)

At the Italian production plant, no cleaning or packing of the filling machines is performed. These activities are instead outsourced to the warehouse, which means that all the machines have to pass through the warehouse before they are considered ready for dispatch. (Pignatti, 2015)

4.6.3   Insurance of machines in stock

The insurance agreements for finished goods inventory of Tetra Pak machines are set up based on the budgeted number of machines that are expected to be put in stock at a specific location during a period of one calendar year. When the premium is determined, the total value of inventory and Tetra Pak owned assets is considered, which means that there is no separate insurance agreement for the inventory. Except for the value of inventory and assets, the premium rates are also based on assessments of risk exposure at the warehouses (Financial Controller Site, 2015). The premium rates that are currently used are 0.2% for the warehouse in Helsingborg and 0.1% for the warehouse in Modena. It should be noted that, similar to all other financial information in this report, the premium rates have been altered due to confidentiality reasons.

4.6.4   Taxes on inventory

Tax payments are handled on corporate group level, which means that at year end, all assets belonging to all Tetra Pak companies are reviewed and included in the annual accounts (Nilsson, 2015). Then, taxes are paid on the total profit of the year but there are no direct taxes paid on inventory.

4.7   Fulfillment of customer request

The measure that Tetra Pak uses to determine how well the customers' requests are served is based on the delivery performance per complete packaging line. This means that all the orders belonging to a particular line have to be delivered according to the customer's request in order for the request to be considered as fulfilled. Hence, the result of this measure is dependent not only on the internal production, but also on the delivery performance of the external suppliers of distribution equipment.

Further, the measure is divided into two parts. First there is a net measure, which keeps track of whether the actual delivery date is within the time that the customer has requested or not.

The second part of the measure considers the fact that orders are sometimes received too close to the requested delivery date (RDD), which makes it difficult or impossible for production to finish a machine accordingly. As mentioned before in this report, Tetra Pak has a committed delivery time of 73 days with the customers, which means that if an order is placed at least this amount of time before the requested ETD, the machine should also be delivered as requested. According to the definition of the measure, an order is fulfilled if:

➢ The order is confirmed with ETA at port of destination earlier than or equal to the RDD from customer, or
➢ The order has planned finish date within the committed delivery time of 73 days.

The target is to have 80% fulfillment of all filling lines, and 90% for all filling machines. (Ballesteros, 2015)

It is difficult to determine the monetary value of fulfilling the customers' requests. If an order is lost due to the fact that the customer is not willing to wait for as long as the production needs to complete the request, there is an opportunity cost for the lost sales. Moreover, if Tetra Pak fails to serve its customers over the long term, the company reputation will be damaged and large customers could be lost forever. A rough estimation implies that losing a large customer could mean that 30% of the sales for a market are lost (Dallari, 2015). However, it should be mentioned that for a customer to be lost forever, it would most likely require severe lack of customer service and delivery reliability. No calculations on the probability of losing customers and the financial impact of such events have been found during the data collection for this project.

In Tetra Pak's general conditions for sale of capital equipment (i.e. all filling and distribution equipment) there are regulations for the market companies' right to compensation upon delivery delays caused by the manufacturer. The general rule is that for every full week that the equipment is delayed after the confirmed ETA, the market company is entitled to compensation corresponding to 0.45% of the total order value, with a maximum limit of 4.5%. However, to receive the compensation, the market company needs to file an official claim which demonstrates that damages have been paid to the final customer. Furthermore, it is required that Tetra Pak has received instructions for shipping arrangement in accordance with the general conditions.

The value of customer service should not be measured only in financial terms, but must also be connected to the Tetra Pak company strategy. In the balanced scorecard of the company, customer service is the second most important factor, right after financial results. Therefore, as mentioned in previous sections, the fulfilment of customer request is of great importance throughout the whole supply chain.

4.8 Finance

There are a few financial parameters that have not yet been discussed in this report. The first one that should be mentioned is the value of the machines at the point of entry in stock. Since the machines are all configured according to the customer orders, the values vary depending on both machine type and the complexity of the machines. The values that will be used in this project will, however, be the average purchase price for each machine type, which comprises the average cost for modules and materials as well as the standard overhead costs occurred in production. The overhead is estimated to be approximately k$173 per machine, including the cost for labor. For A3/Speed and Flex, the machine value is set to k$4320, while A3/CompactFlex is valued to k$2880. (Dallari, 2015)

Furthermore, to determine the cost for inventory, one needs to know the rate of return on the tied up capital. Today, there is no official rate of return that is used within the whole Tetra Pak organization. In general, however, calculations are based on an average rate of return of approximately 10-15%. Unfortunately, it has not been possible to retrieve any information about the background and the determination of these numbers. Looking at data of all Tetra Pak investment rates globally, the average rate can be determined to 12.5%.

[Skriv text]

5 COST PARAMETERS

The fifth chapter is dedicated to discussion of the cost parameters relevant in this particular case. Each parameter is presented separately with regards to how it has been determined and its relevance for the aggregate planning model that will be introduced in Chapter 6.

5.1 Inventory holding cost

The parts of the inventory holding cost that are relevant in this project are presented in Table 3. In sections 5.1.1 through 5.1.4 the calculations and assumptions on which each of them is based will be discussed. It is worth noting that the capital cost is the dominating cost factor for all machine types.

Table 3 Summary of the cost components of the inventory holding cost

Costs	A3/Speed		A3/Flex		A3/CompactFlex	
	Lund	*Modena*	*Lund*	*Modena*	*Lund*	*Modena*
Capital cost ($/week)	10385	10385	10385	10385	6925	6925
Storage space cost ($/week)	154	323	130	273	125	263
Service cost ($/week)	166	83	166	83	110	55
Total holding cost ($/week)	10705	10791	10681	10741	7160	7243
Average total holding cost ($/week)	**10748**		**10711**		**7202**	

5.1.1 Capital cost

According to the literature, the capital cost of inventory generally follows the linear relationship

$$C_{cap} = \kappa_c C \qquad (13)$$

where *C* is the amount invested in one unit of inventory, and κ_c is the expected rate of return for an alternative investment opportunity. In this case, the value of *C* will be set to the standard purchase price of each machine, which includes the cost for purchasing modules and material for production as well as production overhead costs and labor.

When calculating the capital tied up in inventory in order to make decisions whether to produce for stock or not, only the costs for capital that is tied up earlier than necessary should be taken into consideration, since these are the costs that will be dependent of such decisions. The fact that the internal workforce in Tetra Pak is fixed, and the staff can perform other tasks when demand is low, means that when a worker is used in production, there is less capacity

available for other value adding activities. Hence, the cost for labor should be taken into account when determining the tied up capital. For the external resources, all the costs for these should be included, since the number of externals hired will vary directly with the rate of production.

The remaining overhead costs should ideally be subtracted from the machine value when calculating the tied up capital. However, it has not been possible during this project to obtain a cost split of the total machine purchase price, which makes it very difficult to determine how much of the value that should be excluded from the calculations. Therefore, the decision has been made to use the total purchase price as the value of *C*.

The rate of return used will be the average investment rate of approximately 12.5% globally for Tetra Pak. The main argument for this decision is that it will render a result that can be related and compared to other Tetra Pak investments without having to consider the fact that different rates have been used.

The capital cost for each machine type, when using the numbers suggested above, is presented in Table 4.

Table 4 Capital cost per machine type

Cost components	A3/Speed	A3/Flex	A3/CompactFlex
Machine value (k$)	4320	4320	2880
Annual rate of return	12.5%	12.5%	12.5%
Capital cost ($/week)	10385	10385	6925

5.1.2 Storage space cost

The theory suggests that the fixed costs for space in rented or leased warehouses should not be included in the inventory holding cost. In this particular case, however, when the fees per square meter are based on estimations of the amount of inventory to be held, future contracts become somewhat dependent on the decisions of whether or not to produce for stock. Therefore the cost for space utilization in the warehouses will be accounted for in the storage space cost for each machine type. There are different ways of making such calculations. The first one is to see the storage space cost as a fixed rate per square meter, independent of the

stock level. With this approach, there would be no drawbacks in terms of costs in continuing to produce for stock when the inventory level is already high.

Another approach would be to make an attempt to find a cost curve for the marginal cost for putting one additional unit in stock, depending on the available space. This approach would be most useful in cases where the demand fluctuates frequently and the level of production is also highly variable. Since Tetra Pak does not have the opportunity to quickly change the production rates based on fluctuations in demand, due to the large amplification of such changes along the supply chain, the benefits of a dynamic charge are seen as too small for such calculations to be made within the scope of this project. Therefore, the square meter fees will be seen as fixed.

Apart from the square meter fees, there are also other costs included in the contracts with the warehouses. For these to be included in the storage space cost in this project, they have to be dependent either on the time that an item stays in stock or the inventory level itself. Starting with the warehouse in Modena, the only charges defined in the contract are the ones for putting a unit in stock, taking it out again, and packing of the machines. Since all machines will enter the warehouse for packing and then be taken out of stock, and the fees are fixed for all three activities, these costs will not be dependent neither on time in stock nor inventory level. Therefore they will not be taken into consideration here.

For the warehouse in Helsingborg, the charges are a bit more complex, based on the amount of handling and the handling equipment used. Assuming that the machines are not moved around in the warehouse once they have been put in stock, the amount of handling dependent on the time a machine stays in stock should be very low. However, the inventory level could affect the amount of handling required, since the probability of having to transport the machines longer distances to reach an appropriate storage location will increase when the level of inventory is high. To find the cost curve for this increase would require detailed insight in and analysis of the ways of working at the warehouse, which is not considered to be within the scope of this project. The dependency of other equipment than the machines studied here would also have to be considered, adding yet another level of complexity to the analysis. Therefore, the variations in the amount of handling required for each individual machine will be neglected. The weights and sizes of the machines are considered to be equal enough for the amount of handling required to be seen as the same for each machine type as well. When it comes to the equipment used, all machines can be handled with the same kind

of forklift. Therefore, the cost for handling will neither depend on the type of forklift used. Against this backdrop, the handling fees will not be included in the storage space cost in Helsingborg.

To calculate the storage space fee per machine and week, the square meter charges from the warehouse contracts were re-calculated from yearly and monthly charges into weekly ones as per the following formulas:

$$\text{Helsingborg: } 21/\text{m}^2/\text{month} \times \frac{12 \text{ months/year}}{365 \text{ days/year}} \times 7 \text{ days/week} = \quad (14)$$

$$= \$4.8/\text{m}^2/\text{week}$$

$$\text{Modena: } \frac{526/\text{m}^2/\text{year}}{365 \text{ days/year}} \times 7\text{days/week} = \$10.1/\text{m}^2/\text{week} \quad (15)$$

These values were then multiplied by the area occupied by each machine. The storage space charges for the three machine types per warehouse are shown in Table 5.

Table 5 Storage space cost per machine type and warehouse

Space cost/warehouse	A3/Speed (32 m²)	A3/Flex (27 m²)	A3/CompactFlex (26 m²)
Helsingborg ($/week)	154	130	125
Modena ($/week)	323	273	263

5.1.3 Inventory service cost

Since the insurance premium is based on the estimated number of machines that will be put in stock over the year, an increase in the number of machines produced in advance will most likely result in a higher premium at the next evaluation. Therefore, the cost for insurance will be included in the inventory holding cost. Based on the annual premium rates of 0.2% for Helsingborg and 0.1% for Modena, the insurance costs per machine type and warehouse will be the ones shown in Table 6.

Table 6 Insurance cost per machine type and warehouse

Insurance cost/warehouse	A3/Speed	A3/Flex	A3/CompactFlex
Helsingborg ($/week)	166	166	110
Modena ($/week)	83	83	55

Since there are no taxes paid directly on inventory, no tax costs will be taken into consideration in the inventory service cost.

5.1.4 Inventory risk cost

Since damage or deterioration of the goods in stock is very uncommon for Tetra Pak machines, and there is no data available on previous risk costs, this parameter will be excluded from the analysis.

5.2 Shortage cost

The shortage cost for machines that are not delivered according to the customer's request will be set to the penalty cost of 0.45% of the order value, which the market companies can claim upon order delay. The order values will be estimated to 125% of the machine values, based on the machine sales prices. Based on these calculations, the total cost for every time unit that a machine is backordered is shown in Table 7. It should be noted that the order values will vary depending on machine configurations and the amount of machine accessories ordered. These variations will, however, not be taken into consideration in the shortage cost.

Table 7 Shortage cost per machine type

Shortage cost	A3/Speed	A3/Flex	A3/CompactFlex
Penalty cost ($/week of delay)	24300	24300	16200

5.3 Order cost

The order or setup cost is only relevant in cases when the batch sizes can be adjusted in order to find the optimal balance between inventory and production costs. Since the production of filling machines always has to be pursued one machine at a time, the order cost will be neglected in this case.

5.4 Costs for regular time production

As mentioned in the previous chapter, Tetra Pak uses an hourly rate for the regular time internal production. In an ideal case, the overhead costs that are not dependent on the decision to produce for stock or not should not be included in the regular time production costs. However, since it has not been possible to obtain the cost split for the production costs, it is neither possible to determine the actual production cost per machine. Instead, the total production cost will remain constant, as long as the number of machines produced does not exceed the number that can be produced by the internal workforce.

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The limit above which external resources are needed varies between the two production plants. For the plant in Modena, it is easier to determine the number of machines that can be produced with only the internal workforce, since all their capacity is used for A3-machine production. In Lund, however, the fact that the capacity available for production of A3-machines is dependent on the order intake of machines from other platforms as well makes it more difficult to set such a restriction on capacity. Furthermore, as all assembling and dismantling in Lund is done by external resources, the cost curve will not look the same as the one for the Italian production.

The look of the cost curve for the cost for production with external resources as a function of the number of machines produced per time period is shown in Figure 8. The costs for external resources per machine used for the illustration have been set to the values presented below.

Cost for external resources in Modena, at production rates above 4 machines per week:

$$\$195 \times 40 \text{ hours/external} \times 4 \text{ externals/machine} = \qquad (16)$$

$$= \$31200/\text{machine}$$

Cost for external resources in Lund, regardless the number of machines produced per week:

$$\$11255/\text{machine}$$

On average, the cost for external resources per machine will be \$5628 for production rates up to 4 machines per week, and thereafter it will be \$21228 per machine.
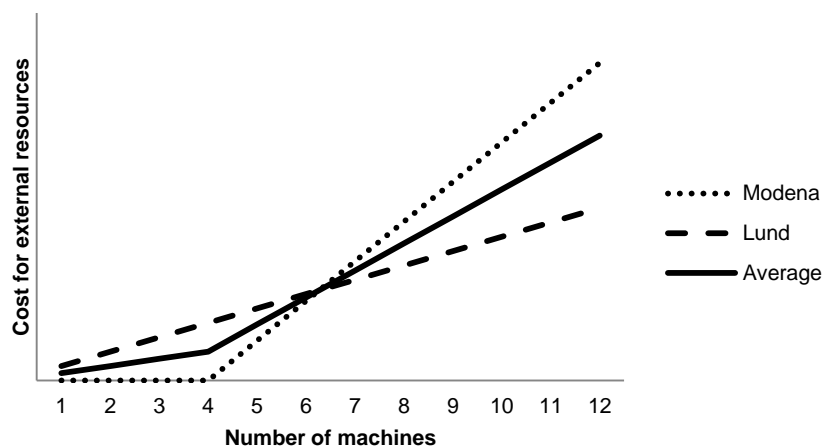
Figure 8 Cost for external resources as a function of the number of machines produced per period

Comparing these cost curves to the looks of the ones in the literature, it is noted that they behave in a similar way as the cost for labor illustrated in Figure 1. In Modena, the curve is a mix of the dotted and the continuous lines in Figure 1, with a fixed cost internal workforce and a linear increase of the total cost when the amount of workforce needed exceeds the normal level. Lund on the other hand has a linear cost increase independent of the number of machines produced. The resulting average cost will increase at one rate for production levels of 1-4 machines per week, and at a higher rate when the production output is above 4 machines per week in total.

5.5   Overtime costs

The costs for overtime will be set to the costs for regular time production plus 20%, since this is the general rate used for Tetra Pak production. This means that the cost per overtime hour of production will be $1900. However, since overtime is not used to cover demand peaks, these costs will not be included in the aggregate planning model to be presented in Chapter 6.

5.6   Costs for missed slots

As mentioned in section 4.4, Tetra Pak has estimated the cost per missed slot to a value of $59040. This cost includes missed time in production, cost for unutilized space and expected costs occurring in other parts of the supply chain.

5.7   Costs for changing the rate of production

In this case, the cost for changing the rate of production refers to the costs for changing the capacity by hiring and firing workers. In a relatively short-range perspective, for which the use of aggregate planning is appropriate, the time frame is in general too short for managing capacity in this way. Moreover, the nature of the contracts with the workers makes it almost impossible to fire workers for the only reason that it would be beneficial from a short-range cost perspective. Therefore hiring new staff at demand peaks, and laying workers off when demand is low, is not a sustainable strategy. Due to these arguments, the costs for hiring and firing will not be taken into consideration here.

[Skriv text]

6   MODEL FOR COST MINIMIZATION

This chapter provides an outline of the aggregate planning model used to find an efficient balance between inventory and capacity costs in this specific case. After an introduction of the model setup, assumptions and the determination of input parameters are discussed. Then an example case illustrates the functionalities of the model, before closing the chapter with individual comparisons of the different cost parameters.

6.1   Model setup

The model that will be used to find the ideal balance between the costs discussed in Chapter 5 is an aggregate planning model with values and parameters adapted to the specific situation at Tetra Pak. To limit the number of parameters, the two production plants are seen as a single one. In this model, only the costs that are considered relevant for the decision whether to produce equipment for stock or not will be taken into account. These costs are the following:

c_{iI} inventory holding cost per week and machine type i

c_{iB} cost per order not delivered as requested per week and machine type i

c_R cost per machine produced by regular workforce

c_E cost per machine where external workforce is required

c_M cost per missed slot

The decision variables are

R_{it} number of machine i produced by regular workforce in period t

E_{it} number of machine i where external workforce is required in period t

S_t number of slots available in period t

I_{it} number of machine i in stock at the end of period t

B_{it} number of machine i backordered at the end of period t

In period 0, the following input parameters are assumed to be known:

D_{it} demand of procuct i in period t

S_t for $1 \leq t \leq 10$, number of slots available in periods $1 - 10$

$P_{it} = R_{it} + E_{it}$ for $1 \leq t \leq 6$, production of product i in periods $1 - 6$

I_{i0} stock of machine i in period 0

B_{i0} number of backorders of machine i in period 0

I_{max} maximum inventory allowed per period

S_{max} maximum number of slots possible per period

B_{max} maximum number of backorders allowed over the planning horizon

To get the total cost for a period t, the following cost function is used

$$C_t = c_M(S_t - \sum_{i=1}^{3} R_{it} + E_{it}) + \qquad\qquad (17)$$

$$+ \sum_{i=1}^{3} c_{iI} I_{it} + c_{iB} B_{it} + c_R R_{it} + c_E E_{it}$$

and the target function will be

$$\min \sum_{t=1}^{T} C_t \qquad\qquad (18)$$

subject to (for $i = 1, 2, 3$ and $t = 0, 1, \ldots, T$)

$$I_{it} = \max(0, \ I_{i(t-1)} - B_{i(t-1)} + R_{it} + \qquad\qquad (19)$$

$$+ E_{it} - D_{it}) \text{ (inventory balance)}$$

$$B_{it} = \max(0, -(I_{i(t-1)} - B_{i(t-1)} + R_{it} \qquad\qquad (20)$$

$$+ E_{it} - D_{it})) \text{ (backorder balance)}$$

$$\sum_{i=1}^{3} I_{it} \leq I_{max} \text{ (max. possible stock per period)} \qquad\qquad (21)$$

$$\sum_{t=1}^{T} \sum_{i=1}^{3} B_{it} \leq B_{max} \text{ (max. backorders in planning horizon)} \qquad (22)$$

$$S_t \leq S_{max} \text{ (max. number of slots possible per period)} \qquad\qquad (23)$$

$$\sum_{i=1}^{3} R_{it} \leq R_{max} \text{ (max. number of machines by internal staff)} \quad (24)$$

$$\sum_{i=1}^{3} R_{it} + E_{it} \leq S_t \text{ (total production vs. available slots)} \quad (25)$$

$$R_{it}, E_{it}, S_t \geq 0 \quad \text{(non} - \text{negativity)} \quad (26)$$

$$R_{it}, E_{it}, I_{it}, B_{it}, S_t \in \mathbb{N} \text{ (positive integer parameters)} \quad (27)$$

Table 8 shows the meaning of the indices *i* and *t*, and the following sections will explain the background of this model setup.

Table 8 Explanation of the indices *i* and *t*

i	*t*
1 – A3/Speed	*0* – the period previous to the first in planning horizon
2 – A3/Flex	*T* – last period in planning horizon
3 – A3/CompactFlex	

6.2 Assumptions

To be able to use the aggregate planning method for determination of the best balance between inventory and capacity costs, there is a range of assumptions that have to be made. These are listed below along with brief explanations of why they are needed. A discussion on how these assumptions will affect the results of the model is found in section 7.1.

➢ *All cost functions are piecewise linear.*

This is a necessary condition when using linear programming methods.

➢ *All demand takes place at the end of each period.*

Since it is not possible to divide the periods into sub-periods in the model, all demand has to take place at the same point in time. Here the decision was made that this point in time should be the end of each period.

➢ *All machines produced within a period are ready in production at the end of that period.*

For the same reason as explained in the previous point, the decision has been made to have all machines finished at period end.

➢ *The number of machines produced in each period must be an integer number.*

This assumption is a consequence of the previous one.

> *The machines are produced in the order in which they are requested.*

This assumption is needed in order to make sure that the inventory situation in the model is the best reflection of reality possible with the current model setup. Assuming that machines are produced in the order they are requested minimizes the risk of machines being taken out of stock (in the model) to fulfill the demand of "the wrong" customers.

> *The machines are dispatched as soon as ready in production.*

The model should only take parameters into consideration that can be affected by production decisions. Therefore, the time that machines are in stock waiting for transport to be arranged or due to postponement or cancellation by the customer should not be accounted for.

> *Shipping instructions and other documentation required are always received on time, so that the goods can be dispatched on the actual ready date of the machine.*

This assumption is needed to make the previous one possible, since a machine cannot be dispatched without the correct documentation.

> *There will be no delays caused by material shortage or production interruptions.*

Since the model should only take into consideration such factors that can be affected by production planning decisions, the effects of delays caused by interruptions or supplier delivery inaccuracy will be overlooked.

> *Machines are not cancelled or postponed after production start.*

In reality it does happen that customers cancel or postpone machines even after they have been taken into production. For modeling purposes, however, these occasions will be overlooked since it is difficult to base production planning decisions on the probability that the RDD is changed.

> *All orders are placed at least 73 days before the requested ETD, and confirmed within the committed lead time. Hence, market companies are always entitled to economic compensation for machine not delivered as per order request.*

This assumption makes it possible to use the penalty cost from Tetra Pak's general conditions as the cost for not fulfilling the customers' requests.

> *A machine that is not requested in the period in which it is produced will be in stock for at least one full time period.*

Since the time periods in the model cannot be divided into shorter sub-periods, it is necessary to assume that production which takes place before the machine is requested will result in at least one period in stock.

> ➢ *A machine that is not produced in the period in which it is requested will be considered backordered for at least one full time period.*
>
> For the same reason as explained in the previous point, it is necessary to assume that production which takes place after the machine is requested will result in the machine being backordered for at least one time period.
>
> ➢ *The monthly forecasted demand is assumed to be evenly spread over the weeks of each month.*
>
> Since the forecasted demand is only available on monthly basis, there is a need to re-calculate it into weekly demands to be able to use the numbers in the model. This will be done by evenly allocating the total forecasted demand of a month over the weeks of that same period, since the customers' behavior does not follow any specific statistical distribution.

6.3 Excel setup

The model described above has been solved by using the Solver function in Microsoft Excel. Due to the limitations of Excel when it comes to speed and capacity, the two production plants have, as mentioned above, been combined into one unit in order to limit the problem size and complexity. This approach also gives Tetra Pak the freedom to allocate the production based on factors such as order intake of other products that require capacity, and the current occupancy of the factories. Moreover, the three products have also been replaced by one average machine to reduce the size of the problem and speed up the calculations in Excel. The planning horizon is set to 20 weeks, due to Excel's capacity limits and the short-term planning horizon within Tetra Pak of approximately 5 months.

In Excel, one separate row has been assigned to each parameter in the model (demand, production output, inventory, backorders, internal and external capacity, number of slots available and number of missed slots). In addition to this, there are rows for cumulative production and demand in order to provide a better overview of how much has been produced over time compared to the total demand during the same time. The row with net cumulative demand represents the demand of the period, D_t, plus the number of backorders from the previous period, B_{t-1}.

Period	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Demand		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Placed orders																					
Forecast																					
Cumulative demand		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net cum. demand		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Production output							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cumulative prod.		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inventory		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Backorders		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Internal capacity		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
External resources		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total slots		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Missed slots		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Constraints																					
Max. capacity																					
Max. inventory																					
Max. tot. backorders	0																				

Figure 9 Model setup in Excel

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There are two ranges of decision variables in the model – the number of machines produced per week and the number of slots per week to be agreed with the module suppliers. These cells have been framed with a thick border, as can be seen in Figure 9, and are the ones that will be the variable cells in the Solver setup. The inventory, backorders, external resources and number of missed production slots, in combination with the total demand for each period, will be results of the values designated to these decision variables.

The problem constraints that have been stated in the Solver are

$$0 \leq P_t \leq S_t \tag{28}$$

$$S_t \leq S_{max} \tag{29}$$

$$I_t \leq I_{max} \tag{30}$$

$$\sum_{t=1}^{T} B_t \leq B_{max} \tag{31}$$

$$S_t \geq 0 \tag{32}$$

$$P_t, S_t \in \mathbb{N} \tag{33}$$

for all periods t in the planning horizon.

Then, the inventory, backorders, external resources and missed slots per period are calculated as per below, through linking of cells in Excel:

$$I_t = \max(0, I_{t-1} - B_{t-1} + P_t - D_t) \tag{34}$$

The inventory level will be greater than 0 if the net demand of the period can be covered by inventory from the previous period and production in period t, and 0 otherwise.

$$B_t = \max\big(0, -(I_{t-1} - B_{t-1} + P_t - D_t)\big) \tag{35}$$

The number of backorders will be greater than 0 if the net demand of the period cannot be covered by inventory from the previous period and production in period t, and 0 otherwise.

$$E_t = \max(0, P_t - R_t) \tag{36}$$

The number of machines produced (partly) by external resources will be the difference between the total production and the number of machines produced entirely by the internal workforce when $P_t > R_t$, and 0 otherwise.

$$M_t = \max(0, S_t - P_t) \tag{37}$$

The number of missed slots will either be 0, when $P_t = S_t$, and have a positive value if the number of machines produced is lower than the number of slots available.

6.4 Input data

Before running the model in Excel, the user has to provide it with the parameters that are known in period 0 and constant throughout the planning horizon T. These fields are shaded in the Excel model, as shown in Figure 9. The value chosen for each of these parameters in the modeling for this project will be presented and discussed below.

6.4.1 Cost parameters

The first cost parameter to be considered is the production cost for regular time production, c_R, which in this case has been set to 0. This is a result of the fact that every hour of production comes at the same cost as long as no external resources are hired, and therefore this cost will not be dependent on the decision whether to produce for stock or not. Hence, it will not have any impact on the result of the model optimization, and will therefore be excluded from the calculations.

The cost parameters representing inventory and backorder costs, i.e. c_I and c_B, have been set to average values of the ones valid for each machine type, based on the total demand of 2014. The reason for basing the average values on the demand of the previous year is that this will give a slightly better reflection of the actual values than an average of the costs per machine type only. With the values from Table 9 the costs were obtained through equations (38) and (39).

Table 9 Parameters used for determination of average costs for inventory and backorders

Parameters	A3/Speed	A3/Flex	A3/CompactFlex
Demand 2014	114	98	147
Holding cost ($/week)	10748	10711	7202
Shortage cost ($/week)	24300	24300	16200

$$c_I = \frac{114 \times 10748 + 98 \times 10711 + 147 \times 7202}{114 + 98 + 147} \approx \$9290/\text{week} \qquad (38)$$

$$c_B = \frac{(114 + 98) \times 24300 + 147 \times 16200}{114 + 98 + 147} \approx \$21000/\text{week} \qquad (39)$$

When it comes to the cost for external resources, c_E, the assumption is made that if demand is lower than 4 machines per week in Modena and below 3 machines per week in Lund, it would in theory be possible to use only internal workforce to perform all production activities. Thereafter, external resources would need to be hired. Even though this assumption is not entirely true in reality, the cost for external resources will be taken as the average of the costs in Lund and Modena when the production rate exceeds 7 machines per week. Here it is also assumed that all the internal capacity at both plants is utilized before external resources can be hired, which is yet another simplification of reality. The value of c_E will be set to:

$$c_E = \frac{31200 + 11255}{2} \approx \$21230/\text{machine} \qquad (40)$$

Finally, the cost per missed slot, c_M, is set to the value stated in section 5.6, and thus

$$c_M = \$59040/\text{missed slot} \qquad (41)$$

6.4.2 Inventory and backorder restrictions

Apart from the cost parameters, there are also restrictions of inventory and backorders to be entered in the model. The inventory in period 0 should be set to the number of already finished machines with requested ETD from period 1 and forward. If there are orders in period 0 that have not been delivered according to the customer's request, these should be entered as the start value of backorders. The start values of both parameters will be retrieved by observing the requested ETD and planned finish dates of open orders at the end of period 0. The initial inventory will be set to the number of open orders with a requested ETD from period 1 and forward which have a planned finish date before period 1.

For the backorders, the start value will be set to the number of open orders with requested ETD before period 1, but with a planned finish date within the planning horizon. Since every machine has a designated customer, it is possible to have a positive inventory and still have unfulfilled requests, unlike the case in make-to-stock production. However, this will not be reflected in the model, due to construction of the formulas used for calculating inventory and backorder levels, and the fact that the model does not keep track of which machine that belongs to which customer.

When it comes to the last time period, it is important to consider that there will be a new planning horizon following the current one, and that the end values of the current planning horizon will be the start values of the next. The cost optimal solution for the first planning horizon might not set out the best possible start for future time periods. Putting restrictions to the end values is one way to handle this issue. However, the interdependency between the demand of the next planning horizon and the end values will still be very strong, and proper determination of the end values in each period would require a rolling planning horizon, which is not possible in the model. Hence, the benefits of setting specific end values for the inventory and backorder levels will in this case be limited. Therefore, the restrictions made will be applicable over the entire planning horizon, and no specific constraints will be set for the last period.

For the backorders, the target of 90% customer order fulfillment of filling machine orders will be used as a basis for the restriction of the end value. The suggestion is that the total number of backorders over the entire planning horizon must not exceed 10% of the total demand, in order to stay on target for this measure.

The maximum level of inventory allowed per period has to be specified taking into consideration that there must be enough space in the warehouses for the machines that are produced for stock. Since the warehouses are used for storage of all Tetra Pak equipment, it is very difficult to determine how much of the space that can be dedicated only to storage of A3-filling machines. Therefore, the target number of filling machines at month end will be used to estimate this number of A3-machines allowed in stock at the end of each time period. Considering a target of an average of maximum 15 filling machines in stock at month end, and that approximately 80% of all filling machine orders are A3-machines, the maximum inventory level dedicated to A3-machines should be approximately 12 machines in total.

Since the model will not take the machines in inventory waiting for transport arrangement into consideration, it is necessary to find out how much of the stock that is related to production planning decisions. After investigating how many of the machines in stock at month end that are in stock due to production prioritizations, it was found that this share was on average around 40% of the total number of filling machines in stock. This result suggests that the maximum number of A3-machines allowed in stock at month end should be set to 5. However, since the target is an average value, and the inventory should be able to fluctuate over the year, the maximum stock level is increased to 8 in the model. In these calculations it

is assumed that the stock situation at month end is not significantly different compared to other weeks.

6.4.3 Capacity and production restrictions

The capacity restrictions for each period t should be set based on the expected capacity availability over the planning horizon. Changes in order intake of other machine types and factory maintenance can be taken into consideration when entering this information, enabling a more correct solution to the optimization problem. The first parameter, which puts the heaviest constraint on the model is the total maximum capacity possible, i.e. the maximum number of slots allowed per period, S_{max}. In the example case (see section 6.5) that will be the basis of the conclusions in this report, this value has been set to 12 machines per week, which is the maximum total production level according to production managers in Tetra Pak. Hence, the number of slots, and thereby the production output, cannot exceed 12 in any time period.

The number of slots per period is further restricted by the TAKT agreement with the module suppliers. Since the time until a new TAKT becomes effective is 72 calendar days, a decision at the beginning of period 1 to change the number of slots will not affect the production output until the end of period 10. Therefore, period 10 will be the first period in the model where the number of slots can be a variable parameter. Hence, the number of slots available in periods 1-9 has to be entered by the user before running the model, and stay fixed in the solution.

Moreover, the TAKT agreement with the suppliers makes it difficult to maintain supply chain efficiency and good supplier relations with frequent TAKT changes. Therefore the TAKT is only allowed to be changed approximately once a month, which means that the number of slots can only be changed every four periods (after period 10) in the model. In the periods in between, the number of available slots will be considered fixed.

Since the external and internal lead times of a machine sum up to 36 working days in total, corresponding to approximately 7 weeks, the production output of periods 1-6 will not be possible to change. Therefore, the outputs of these periods should be set to the number of orders in period 0 that are confirmed with a finish date within each of these periods. A decision made at the beginning of period 1 to produce an additional machine is assumed to generate output in production at the end of period 7, which thus will be the first period in which the level of production can be changed in the model.

The last capacity restriction that has to be entered by the user is the internal resources available in each period. Here it is possible to consider extra activities such as training, which will reduce the time that the internal workforce can spend on actual production activities. In this case, however, the internal capacity has been set to a total of 7 machines per week, based on the assumption that every week 4 machines can be produced in Modena and 3 in Lund without hiring external resources. It is also assumed that all internal capacity in both plants has to be used before external resources can be hired.

6.4.4 Demand

To be able to determine the need of production, the demand for each period has to be known. As the demand forecast is made for each month and not week by week, it is necessary to re-calculate the monthly demands into weekly ones. The weekly demands will consist partly of orders that have already been received and partly of a forecast of orders to come. The share with already received orders will naturally be large at the beginning of the planning horizon, and decrease with time, and the opposite will apply for the forecasted orders. Since the number of already received orders is known, the challenge is to determine the distribution over time of the ones to come. Since there does not seem to be any particular demand pattern over each month, it has been decided to assume an even distribution of the forecasted orders with an ETD within a specific month over the weeks of that same month.

6.5 Example case

To demonstrate the functionalities of the model, an example case will be presented in this section. The planning horizon chosen is a period of 20 weeks, starting in the spring 2015. The input parameters have been selected according to the principles in section 6.4, and hence the cost parameters will be the ones shown in Table 10 below.

Table 10 Overview of the cost parameter values used in the example case

Cost parameter	Value
c_I ($/week)	9290
c_B ($/week)	21000
c_E ($/machine)	21230
c_M ($/missed slot)	59040

The demand over the 20 periods considered is shown in Table 11, where the number of placed orders was taken from the list of open orders at the beginning of the planning horizon, and the forecasted weekly demand was set by evenly allocating the machines from the monthly forecasts for the months within the planning horizon over the 20 weeks studied.

Table 11 Demand over the 20 weeks studied in the example case

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Placed orders	3	6	9	3	7	13	6	7	5	6	1	8	7	6	2	4	1	0	0	0
Forecast	0	0	0	0	0	0	0	0	0	2	2	2	2	3	3	2	3	3	6	7
Tot. demand	3	6	9	3	7	13	6	7	5	8	3	10	9	9	5	6	4	3	6	7

The production output for periods 1-6 is set to the number of open orders with a confirmed ETD within the first 6 weeks of the planning horizon, as demonstrated in Table 12.

Table 12 Production output of periods 1-6 in the planning horizon of the example case

Period	1	2	3	4	5	6
Production output	4	6	6	5	8	11

A decision was made to let the number of slots in periods 1-6 be equal to the production output of these periods, since this output has already been confirmed and therefore the number of slots must cover that level of production. Hence, it is assumed that no slots are missed in these periods. For periods 7-9, the number of slots was set based on the TAKT time defined for those weeks, resulting in an output of 7 machines per week in total during that time. Table 13 shows the connections between the TAKT and the number of machines per week.

Table 13 Total number of slots available in periods 7-9 in the example case

Machine type	TAKT	Machines/week
A3/Speed	3	1.67
A3/Flex	3	1.67
A3/CompactFlex	1.5	3.33
Total number of machines/week		**6.67 ≈ 7**

Among the open orders at the beginning of period 1 (i.e. at the end of period 0) there were 6 orders with requested ETD from period 1 and forward with a planned finish date before the start of the planning horizon. Further, there were no orders with requested ETD before period 1 with planned finish date within the planning horizon. Hence, the initial inventory was set to 6 machines and the initial number of backorders to 0.

The amount of internal capacity is in this example set to the general level of 7 machines per week throughout the entire planning horizon. Thus, in this example case, summer vacations or other events that affect the production capacity have not been taken into account. The maximum number of slots and the maximum inventory allowed per period were also set to the general levels of 12 and 8 units respectively. The total maximum number of backorders allowed was set to 10% of the total demand over the entire planning horizon.

The results of the model calculations with the values presented above are presented in Figure 10. In short, these results show that only in one period (period 7) should it be considered optimal to miss slots instead of producing for stock. Backorders are also suggested as a better option than increased capacity and inventory in just one single period (period 14).

Period	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Demand		3	6	9	3	7	13	6	7	5	8	3	10	9	9	5	6	4	3	6	7
Placed orders		3	6	9	3	7	13	6	7	5	6	1	8	7	6	2	4	1	0	0	0
Forecast		0	0	0	0	0	0	0	0	0	2	2	2	2	3	3	2	3	3	6	7
Cumulative demand		3	9	18	21	28	41	47	54	59	67	70	80	89	98	103	109	113	116	122	129
Net cum. demand		-3	3	12	15	22	35	41	48	53	61	64	74	83	92	97	103	107	110	116	123
Production output		4	6	6	5	8	11	5	7	7	7	6	6	6	7	7	7	7	4	4	4
Cumulative prod.		4	10	16	21	29	40	45	52	59	65	71	77	83	90	97	104	111	115	119	123
Inventory	6	7	7	4	6	7	5	4	4	6	4	7	3	0	0	0	1	4	5	3	0
Backorders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Internal capacity		7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
External resources		0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total slots		4	6	6	5	8	11	7	7	7	6	6	6	6	7	7	7	7	4	4	4
Missed slots		0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Constraints																					
Max. capacity		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Max. inventory		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Max. tot. backorders	12																				

Figure 10 Results of model calculations in the example case

6.6   Scenario analysis

When making decisions on how to optimize the levels of production and inventory, it is important to take the total demand over the planning horizon, and the interdependency between different time periods into consideration. The model presented in this chapter provides a way to take such factors into account when determining a cost efficient production plan. In some cases, however, it might be of interest to just compare single events in isolation, to see which one would generate the lowest cost. Therefore, this section will be dedicated to comparing the costs for inventory, backorders, missed slots and external capacity by analyzing six different scenarios.

6.6.1   Scenario 1 – inventory vs. missed slot.

It could happen that there are enough slots available in a period to produce a machine before it is actually requested by the customer. Doing so would bring costs for keeping the machine in stock for x weeks between the finish date and the requested dispatch date. In this scenario the assumption is made that the alternative to producing for stock is to wait with production, which would result in a missed slot. Using the costs of \$59040/missed slot and \$9290/machine/week in stock, the point of breakeven is obtained as follows:

$$59040 = 9290x \iff x = 6.4 \text{ weeks in stock} \tag{42}$$

This result indicates that if the number of weeks in stock exceeds 6, it is better to miss the slot than to produce the machine in advance, if no other parameters are taken into consideration.

6.6.2   Scenario 2 – inventory vs. backorder

The second scenario is based on the assumption that a choice can be made either to set a higher level of capacity and produce a machine in advance, or to avoid producing for stock at the price of not being able to meet the customer's requested ETD due to lack of capacity in future periods. In such a case, the relevant costs to compare are the ones for holding inventory and for having backorders, assuming that no other parameters are taken into consideration.

Letting x be the number of weeks in stock expected, as in the previous scenario, and y the number of weeks that the machine is backordered, the following equation states the relationship between the two parameters at point of breakeven:

$$9290x = 21000y \tag{43}$$

where \$9290 is the cost per week in stock for a machine, and \$21000 is the cost per week of delay. In Table 14 the corresponding values of x for y between 1 and 5 are presented. x' is the value of x converted into days.

Table 14 Number of weeks in stock (x) corresponding to the cost for a machine being backordered for y weeks

y (weeks)	x (weeks)	x' (days)
1	2.3	16
2	4.5	32
3	6.8	47
4	9.0	63
5	11.3	79

It should be noted, however, that the value of customer service cannot be measured only in monetary terms. Since fulfillment of customer requests is one of the first priorities for Tetra Pak, it is important to evaluate the risk of damaged customer relations and future lost sales before making an active decision not to deliver as requested.

6.6.3 Scenario 3 – inventory vs. need for extra capacity

Here it is assumed that a choice is made between producing a machine in advance with internal capacity or waiting to produce until the machine is actually requested, resulting in a need of hiring extra capacity in a future period. No other parameters are taken into consideration. With a cost of \$21230 per machine where external capacity is needed, and an inventory holding cost of \$9290/week, the following equation is obtained for calculation of the point of breakeven, when x is the expected number of weeks in stock:

$$9290x = 21230 \Leftrightarrow x = 2.3 \text{ weeks in stock} \tag{44}$$

Thus, if the expected number of weeks in stock exceeds 2 weeks, it is more beneficial from a cost perspective to wait with production and hire external resources in the future.

6.6.4 Scenario 4 – inventory vs. missed slot and backorder

In this scenario, a choice has to be made between producing a machine in advance, which will result in the machine being put in stock, or leaving a slot empty and not being able to meet a customer's request due to lack of capacity in future periods. From a strict cost perspective, the

point of breakeven is reached when the cost for inventory is equal to the cost for the backorder and the missed slot. Using the values of $59040/missed slot, $21000/backorder/week and $9290/machine/week in stock, this point is found by solving the equation

$$9290x = 21000y + 59040 \qquad (45)$$

where x represents the number of weeks in stock expected if the machine is produced in advance, and y is the number of weeks a machine is delayed. Table 15 shows the values of x for y between 1 and 5.

Table 15 Number of weeks in stock (x) corresponding to the cost for a machine being backordered for y weeks, taking into consideration the cost for a missed slot

y (weeks)	x (weeks)	x' (days)
1	8.6	60
2	10.9	76
3	13.1	92
4	15.4	108
5	17.7	124

Similar to scenario 2, it is important to consider the soft aspects of customer service, and not rely only on cost comparisons.

6.6.5 Scenario 5 – inventory vs. missed slot and need for extra capacity

In this scenario it is assumed that there is enough capacity available to produce a machine in advance with internal staff, and that if this is not done, a slot will be missed and external resources will be required in future periods to be able to meet the customer's request. The cost balance in such a case is demonstrated by the equation below, where the cost for having external capacity to partly fulfil the production of a machine is $21230, $59040 is the cost for missing a slot, and $9290 is the cost per week in stock. The expected number of weeks in stock is represented by the variable x.

$$21230 + 59040 = 9290x \iff x \approx 8.6 \text{ weeks} \qquad (46)$$

The result of this reasoning is that a machine can have an expected extra time in stock of approximately 8 weeks before it becomes more beneficial from a cost perspective to miss a slot and have to hire external resources to produce the machine in the future.

6.6.6 Scenario 6 – inventory vs. missed slot, backorder and need for extra capacity

This scenario is a combination of scenarios 4 and 5, meaning that if a machine is not produced for stock in a certain period, the result will be a missed slot, an unfulfilled customer request and a need to hire external resources in future periods to produce the machine.

The cost equation to find breakeven is stated as (with the same denotation as above):

$$9290x = 21000y + 21230 + 59040 \tag{47}$$

Table 16 shows the relationship between x weeks in stock and y weeks of a particular machine being backordered, when $1 \leq y \leq 5$.

Table 16 Number of weeks in stock (x) corresponding to the cost for a machine being backordered for y weeks, taking into consideration the cost for a missed slot and need for extra capacity

y (weeks)	x (weeks)	x' (days)
1	10.9	76
2	13.2	92
3	15.4	108
4	17.7	124
5	19.9	140

Again, it should be noted that the soft aspects of customer service have to be taken into consideration in this case.

[Skriv text]

7 DISCUSSION

In Chapter 7 the assumptions, cost parameters, constraints and simplifications of the aggregate planning model developed are discussed in order to point out their impact on the model results. The final section of the chapter brings up the drawbacks of the model and their impact on its usability.

7.1 Discussion of assumptions

The assumptions made for the model naturally limit its accuracy and reflection of reality. This fact is important to take into consideration when interpreting the results of the calculations. Here, the assumptions and their effects on the model results are discussed.

Assuming that demand and finished production always takes place at the end of a period is a simplification made to work around the fact that a period cannot be divided into shorter time units. The result of this, which is also stated among the assumptions, is that each unit of inventory will be in stock for at least one time period, and each backorder will be seen as a delay of at least one week. In reality, the time in stock can be a single day, and delays do not have to be full weeks. Hence, the costs for inventory and delays stated in the model do not provide an entirely true picture of the actual costs. Considering that the average time in stock per machine dispatched during 2014 was approximately 2 weeks, the assumption of at least one week in stock for a machine that is produced in advance is not entirely unreasonable. However, it should be noted that the 14 average days in stock during 2014, unlike the time indicated in the model, included the time in stock caused by delay in shipment arrangements, postponements, cancellations and other events that can prevent a machine from being dispatched and that are not related to production planning decisions. Therefore, the two numbers are not directly comparable to each other.

When it comes to the assumption about orders not being postponed or cancelled, one effect of this constraint is that the possibility that a reallocation of machines among the slots or a reduction of the number of slots available should be done to obtain the true optimal solution is overlooked. Another result of making such a restriction to the model is that the stock time occurring in event of a postponement or cancellation is not taken into account. As mentioned when listing the assumptions, the model should only take parameters that can actually be affected by production decisions into account. A decision from a customer to change the RDD or cancel a machine is very difficult to predict, and not even the most carefully outlined production plan could capture every such possible decision. Therefore, instead of making

attempts to model this kind of events, being aware of the fact that they exist and being prepared to take action when changes occur is a better way of handling these insecurities.

The assumptions about orders and shipping documentation being received on time are also related to the unpredictable behavior of customers. Reality is significantly different, with both orders being placed very close to the requested ETD and shipping instructions received even after the confirmed finish date of the machines. Consequently, the assumption that market companies always have the right to economic compensation in case of unfulfilled requests is not true in reality, which implies that each backorder would not necessarily result in a penalty cost for Tetra Pak. The number of backorders indicated by the model is therefore, if no other parameters affecting this cost are taken into consideration, assumed to be lower than what is actually possible without affecting the total cost in a negative way. Since good customer service is of great importance to Tetra Pak, a low number of backorders would be preferred to a higher one, which is why this result should not be a significant issue. It is, however, important to be aware of the fact that the numbers are, to a certain extent, distorted.

Since the delivery accuracy of module suppliers is currently 99%, the assumption that material shortage does not cause any delays is considered reasonable, and should not have any significant impact on the model result. Regarding production interruptions, it is more difficult to tell how they affect the optimal solution. Considering that such events are usually handled through overtime work, which is not a parameter in the model, it should be possible to follow the plan suggested by the model even in case of unforeseen events of moderate dimensions.

Assuming that the machines are produced in the order in which they are requested can be seen as trivial. Producing a machine that is requested in two months, if there is another one to be produced and that is requested within three weeks, it makes sense to produce the latter one first in order to minimize the time in stock. However, if other parameters are taken into consideration, and if there are different costs for backorders depending on which customer requests are not fulfilled, the situation might be a different one. Since all costs and other conditions are the same for all possible scenarios in this study, the assumption about the order of production should be considered reasonable.

The last assumption to be discussed is the one about evenly allocating the forecasted demand over each month. Attempts have been made to find patterns in the order intake of past years, but these patterns occur with longer time intervals than one week at a time. For weekly time

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intervals, no pattern has been found, which is why an even distribution of the part of the demand that consists of forecasted future orders was considered a feasible option.

7.2 Discussion of cost parameters

The cost parameters used in the model will inevitably have significant impact on the calculation results. Therefore it is important to be aware of how the determination of the costs used in the model has been carried out, and the effects that the simplifications made will have on the solution. This section will be dedicated to discussion of these topics.

Starting with the cost for production by internal resources, this cost has been completely excluded from the model. To get a more correct value of the total cost that is dependent on production decisions, inclusion of the avoidable production costs would have been necessary. The reason why the internal production cost was not taken into consideration in this case is, as mentioned in previous sections, that the cost split of the hourly rate of $1585 could not be obtained and analyzed within the scope of the project. Therefore, the optimal production plan suggested by the model is seen as independent of the internal production cost.

In reality, however, the internal production cost will impact the total cost for production, and thereby also the ideal production plan. Considering the fact that the cost per hour of production is an hourly rate based on the budgeted number of production hours and costs per year, changes in demand, and thereby also the budget, would impact the cost optimal level of internal production. Increasing demand would mean that the overhead costs were spread over more hours, and the total cost would increase only with the extra costs related to the actual production of the increased number of machines. At a certain point, it would from a cost perspective be more beneficial to increase the internal capacity instead of covering the increased demand only with external resources. It could in such case be discussed whether to take the step to increase the internal workforce, or continue to manage a now larger fraction of the production with external manpower in order to stay flexible in case of quick demand fluctuations. From this perspective, the decision not to include the internal production cost in the model is slightly unfavorable for the result. From a strictly operational point of view, however, this decision should not have any significant impact on the optimal solution.

Observing instead the costs for external resources, it was made clear in section 6.4.1 that these are set to an average value based on a simplified view of the real production setups in Lund and Modena. Average values should always be used carefully, since it is easy to overlook factors that would suggest that another value better reflects the actual situation. In this case,

one such factor that is not taken into consideration is the fact that external resources are used for all assembling, dismantling and packing in Lund, independent of the number of machines produced per time unit. Another factor left out is that the production split between the plants is not part of the model. The allocation of production between the two plants affects the cost for external resources, since the cost structures are different in Lund and Modena. Hence, the cost for external resources suggested in the model is not the real one, which means that the ideal solution suggested might not be the truly optimal one from a cost perspective.

When it comes to the storage costs, the first point to be discussed is the machine values. In this project, the machines have been valued to their purchase prices, which means that overhead costs and other costs that are not relevant for the decision on when and how much to produce for stock are included in the value used as a basis for calculations of the capital tied up in inventory. Excluding these costs from the value of machines in stock would make the cost for inventory per time period slightly lower, which could change the cost balance and thereby the location of the cost optimum in the model. The amount of the purchase price comprised by overhead costs is, however, relatively small compared to the total machine value. Considering that the cost for tied up capital is 12.5% per year, and this cost is spread evenly over the weeks, the difference in cost per week will be negligible. If a lower cost for inventory actually would change the time that a machine could be kept in stock in a cost optimal case, the change would most probably not be as large as a full week in stock. Since the model only uses full weeks in the calculations, the relatively small error caused by the inclusion of overhead costs in the machine value should not have a large impact on the suggested production plan.

Similar to the production costs, the inventory cost used in the model is an average of the costs for stock per machine type in Lund and Modena. As the cost difference between Sweden and Italy is very small, less than $100 per week, an average value based on location will not be an issue from a modeling perspective. The difference between the inventory costs per machine type, on the other hand, is larger. Between A3/Speed and A3/Flex, the difference can be neglected, but for A3/CompactFlex, the total inventory cost is approximately 30% lower than for the other machine types. From this point of view, it would have been beneficial to consider separate production schedules for the different machine types in the model in order to get the actual cost for inventory for each kind of equipment, since this would provide a more accurate picture of reality. To minimize the impact of calculating with an average cost

for inventory, the demand split between the machine types was taken into consideration when the average cost was determined.

The cost for backorders has been a challenge to determine, since the value of customer service should not be evaluated from a strict cost perspective. The fact that the order values vary based on machine configuration and amount of accessories and extra equipment ordered also complicates the determination of a fixed backorder cost. This complexity of the backorder cost calculations implies that the results could be significantly distorted because of a misrepresentative cost for insufficient fulfillment of customer requests. A higher cost would mean that less backorders would be allowed in the optimal solution, and a lower backorder cost would allow for more orders to be confirmed with a ready date after the requested one. To make sure that the model does not allow more backorders than Tetra Pak can accept considering their targets for customer order fulfillment, a restriction of a maximum number of backorders allowed over the planning horizon was added in the model restrictions.

The determination of the cost for missed slots has been an ongoing discussion within Tetra Pak for a long time. There are many parameters to be taken into consideration, such as TAKT agreements with module suppliers, unutilized space and resources in production, and module inventory being built up at the supplier sites. Even if a single missed slot might not always result in idling capacity or actual money being paid for space and resources that will not be used, the total effects of missed slots will eventually have a financial impact on Tetra Pak. Therefore, it is considered reasonable to assume a cost for each missed slot in the model, hence overlooking the fact that such costs do not always occur in reality. Whether the financial impact caused by missed slots will be the result of damaged supplier relations, decreased cost efficiency due to resources not being used optimally or other factors is difficult to tell.

It should also be noted that in the long run, the assumption that workers never remain idle when a slot is missed cannot be entirely true. At a certain point in time, if demand stays on a continuously low level, the ideal level of internal capacity would decrease. To then find a cost optimal solution, calculations of the costs for firing employees would have to be compared to the costs for missed slots, idle capacity and the expected increase in cost for external resources at demand peaks. Moreover, the risk of reducing the flexibility in production due to less internal knowledge and resources would have to be considered in such a case.

7.3 Discussion of constraints and simplifications

Several simplifications of reality have been made in order to obtain a model that is easy to interpret and that has an acceptable solution time in Excel. These simplifications will increase the user friendliness of the model, but will also impact the results in different ways. As it is important to be aware of how a simplified model affects the outcome, such aspects will be discussed below.

To begin with, the model does not consider the split of production neither between the plants nor the different machine types. As the cost structures are slightly different for Lund and Modena, and there are also discrepancies between the costs related to each machine type, separate model variables for each plant and machine would improve the model results. Even if the total cost might not change significantly, it would be possible to see in the model how the production orders should be allocated between the factories and how the production plans should be set up for each machine type in order to be as cost efficient as possible. Furthermore, this approach would eliminate many of the negative effects of using average values, since the possibility to use the correct values would increase. One main drawback of involving more variables in the model would be a greater complexity and longer solution time. The input parameters entered by the user would also become more sensitive to errors. Since each parameter would have a lower value than an aggregate value for the two plants and/or three machine types, an error of one unit would have a much larger impact on the overall result.

The internal capacity considered available for production of A3-machines has, as mentioned above, been set to 7 units per week, of which 4 are from Modena and 3 from Lund. The main issue with this simplification is that the internal capacity in Lund is dependent on the capacity need for other machine types produced in the same factory. In many cases, the internal capacity in Lund is higher than 3 machines per week due to resource reallocation between the production teams at the plant, which means that the real need for external capacity cannot be set to a fixed number.

The fact that external capacity is always used for assembling, dismantling and packing in Lund will further complicate the determination of the need for extra resources. Using the estimated maximum of 7 machines per week produced by only internal resources could hence make the model suggest a solution that is not optimal considering that internal capacity could have been used instead of external staff. Moreover, it is possible that external capacity is

bought in one plant before all the internal capacity of the other factory is fully utilized, which is not taken into consideration in the model. Therefore, the internal capacity has to be filled in week by week by the user in the Excel sheet, enabling adjustments depending on order intake, extra activities and other events that are known to impact the need of hiring external resources. This way, the risk of sub-optimal solutions is slightly reduced.

When it comes to the maximum level of inventory allowed in the model, this number has not been based on the actual warehouse space available, but instead on the target maximum inventory level for Tetra Pak filling machines. The fact that it would not be reasonable to reserve the full accepted inventory for A3-machines was taken into consideration, as well as the fact that machines will be in stock for other reasons than production anticipation. It is, however, possible that a higher maximum inventory level could enable a more cost efficient solution to the model.

7.4 Drawbacks of the model

Except from the impact of simplifications and assumptions discussed above, there are a few more drawbacks of the model. The first and most important one is the fact that the solution is optimized from a strictly financial point of view, not taking any soft values such as customer service or supplier relations into account. Before a decision is made to avoid producing for stock, with the result of one or more machines being backordered, it is important that the strategic values of customer service are taken into consideration, and that the risks of losing sales both in a short perspective and over the long term are reviewed. From a cost perspective, the expected financial effects of lost sales should be compared to the cost for the time required in stock if the machine is produced in advance.

Another issue with the model setup is that it does not take any kind of unforeseen events, such as order cancellations or postponements, late receipt of urgent orders or delayed shipping instructions into account. This means that if the production plan is set up exactly according to the results of the model, without leaving space for any flexibility, there is a risk of a significant cost increase in case of events not accounted for. The optimal production schedule suggested by the model will also be changed if the demand pattern is changed.

Furthermore, the model does not recognize the fact that every machine is dedicated to a specific customer, and therefore cannot be used to fulfill the demand of other customers. This means that the optimal solution in the model might not be possible to obtain in reality, if the production plan suggested assumes that the initial stock can be used to fulfill any customer

request. For the production taking place within the planning horizon, however, it is assumed that machines are produced in the order in which they are requested, and therefore the issue of inventory being wrongly allocated among the orders occurs only at the beginning of the planning horizon. The same reasoning can be applied for backorders, i.e. a machine that was requested before period 1 and that has already been confirmed with a finish date within the planning horizon, will be occupying a slot in the period in which it is confirmed.

The fact that other partners in the supply chain, specifically the different module suppliers, are not part of the model increases the risk of sub-optimization from a supply chain point of view. It is possible that the optimal production schedule from a cost perspective within Tetra Pak could be less cost efficient in other parts of the chain. In the model, the cost for missing a slot is the factor that symbolizes the connection between actions within Tetra Pak and effects upstream in the supply chain. It is important to be aware of the risk of under or overestimating these effects if the cost for missed slots is not determined correctly. Furthermore, similar to the customer service aspect, Tetra Pak has to consider soft values in terms of partner relationships and supply chain flexibility when making decisions that affect their partners.

8   CONCLUSIONS AND RECOMMENDATIONS

The final chapter of this report discusses the conclusions of the results obtained in the project as well as recommendations for how these results can be used in practice. Moreover, suggestions for future research and the author's personal reflections on the contribution to increased knowledge of inventory and capacity planning in general are presented.

8.1   Conclusions

In this project, the parameters that affect the cost for finished goods inventory of Tetra Pak filling machines, and the alternative costs for avoiding putting equipment in stock have been investigated. It is concluded that the cost for inventory is dominated by the cost for tied up capital, and that the linear approximation of the holding cost often used in theory could be applied to simplify the calculations. However, since the different parts of the inventory holding cost are relatively easy to determine, they should to the greatest extent possible be included in the calculations of the total cost related to inventory and production decisions, since this enables a better model accuracy.

The costs for alternatives to producing for stock are more difficult to estimate, mainly due to the fact that soft values such as customer service and supplier relations have to be taken into consideration at each decision point. In this case, these cost parameters have been estimated based on the available data, but a more thorough analysis of each aspect and its cost effects would be needed in order to secure the quality and reliability of the model and its results.

The scenario analysis shows that if the different costs are compared for isolated cases, the most cost efficient option is in general to put equipment in stock for at least a few additional weeks rather than not utilizing all the available capacity or leaving the customers' requests unfulfilled. Analyzing possible scenarios, without considering how each decision affects the total production plan, gives an overview of which options can be considered feasible in an isolated decision situation. For an indication of how an overall cost optimal production plan could be set up, however, the interdependency between decisions have to be taken into account, which can be done by using the aggregate planning model.

Apart from the operational applications of the model presented, there are some parameters that can be used as indicators for strategic decisions. The levels of internal and external workforce that are suggested as optimal could imply whether Tetra Pak have chosen to have an amount of internal capacity that is appropriate considering current and future demand.

When making this kind of decisions, factors such as risk of losing internal competences or damaging the relationships with the staffing companies, and thereby putting the flexibility of external resources at risk, have to be taken into account. Moreover, this kind of calculations require more precise determination of internal and external production costs, as well as the costs for hiring and laying off workers, than have been obtained within the scope of this project.

8.2   Recommendations

Taking into consideration the flaws and drawbacks of the model discussed in Chapter 7, Tetra Pak is recommended to assume the following approach when using the results of this project:

➢ *Use the model as an indicator of directions, rather than a way of determining a fixed production plan:*
   The model provides an opportunity to calculate a close to cost optimal production plan and provide an overview of the relationships between the different cost parameters. However, as some features would need to be investigated further in order to give a sufficiently reliable reflection of reality, the solution should not be taken as the absolute cost optimum.

➢ *Keep the soft aspects of customer service, flexibility and partner relations in mind at decision making:*
   Even though having a large amount of backorders could be part of the cost optimal solution in the model, it may not be a feasible solution from a customer service perspective. Hence, Tetra Pak needs to consider their strategic objective of good customer service when making decisions on how much to produce.

➢ *Be aware of how the determination of the cost parameters and other input data affects the optimal plan*:
   If the cost parameters or other input data change, the optimal solution suggested by the model will also be altered. It should be noted that if the ideal solution is not acceptable from a strategic point of view, some cost parameters have most probably not been assigned appropriate values, since the value of each parameter should reflect its real contribution to the total cost.

8.3 Concluding remarks

8.3.1 Re-connecting to the purpose of the study

The purpose of this study consisted of three main parts. To ensure that these have been fulfilled properly, this section is dedicated to linking the results to the different parts of the purpose.

What parameters affect the total cost for keeping a machine in stock?

In the case of Tetra Pak, the cost for holding inventory consists of the costs for tied up capital, for renting storage space and for insurance of the machines in stock. The values and the compositions of these parameters have been discussed in section 5.1. In reality, there should also be a cost for the risk related to damage or deterioration of machines during their time in stock, but a value of this cost has not been possible to find due to the rarity of such events and shortage of historical data.

What are the alternatives to putting equipment in stock, and what are the consequences of these actions?

There are three different parameters that are dependent on the decision whether to put equipment in stock or not: the level of customer order fulfillment, the need for external resources, and the number of missed slots in production. The costs related to each of these parameters have been presented in sections 5.2, 5.4 and 5.6. Moreover, section 6.6 brings up six scenarios where these costs are compared to the cost for holding inventory.

Determination of the most cost efficient balance between inventory and capacity costs

An aggregate planning model for determination of the most cost efficient balance between inventory holding costs and capacity costs has been developed in this project, taking the specific characteristics of Tetra Pak into consideration. The model has been run with the values of a time period of 20 weeks in 2015, and the results of this simulation have been presented in section 6.5.

8.3.2 Validation of the results

The cost structures and relevant parameters found for the case investigated in this project are in many ways similar to the ones suggested by several sources in the literature. All the parameters investigated have in some way contributed to the development of a solution that takes as many company specific aspects as possible into consideration. The result is a model

that aims to find the cost optimal balance between inventory and capacity costs, which was the purpose of this project. Hence, the measurements done actually do measure the parameters relevant for the project, which strengthens the validity of this study.

It should be noted that due to confidentiality reasons, the financial values used in this report have been altered, but the general cost structure has been maintained to the greatest extent possible. The results obtained with these values are not significantly different from the ones where the real values have been used.

8.3.3 General application and reliability of the results

The results of this project are company specific for Tetra Pak, since the model is set up based on factors that are relevant for the particular case studied. This means that the results cannot be directly applied to other situations without modification of the model setup and re-determination of relevant input parameters and constraints. However, if such adaptations are done, the overall structure of the model can be used as a basis for determination of a cost effective balance of inventory and capacity costs in production systems similar to the one described in this report. Hence, there are possibilities of generalization of the results, if they are modified to fit the context in which they will be used.

Regarding the reliability of the study, it is clear that further investigation of the parameters comprising the input data to the model would provide a more robust solution and increase the possibilities to use the model as a basis for decision making within Tetra Pak. This is the reason for the importance of keeping in mind how the determination of the cost parameters and other input data affects the final result.

8.3.4 Suggestions for further research

To improve the reliability and applicability of the model developed in this project, it is suggested that the input cost parameters, and particularly the monetary value of good customer service and order fulfillment, are further investigated. The most unsure cost parameter in this case is the cost for backorders, which has been estimated to a value that is not valid in most real cases. Hence, it can be questioned whether it is a good approximation of the value of customer service or not. When determining the real value of the backorder cost, factors such as the value of lost sales for the short and long-term perspectives should be considered, as well as the value of damaged reputation and customer relations.

Furthermore, adding the split of machine types and capacity allocation between the two plants into the model would increase the possibilities to adapt it to different scenarios and to interpret the results on a more disaggregated level. Therefore it is suggested that one or both of these opportunities are considered for further development of the model. It should be noted, however, that a more powerful tool for solving the equations will be required due to the limited capacity of Excel.

Finally, a suggestion for development of the model is to add the possibility to track which machines are reserved for specific customers, and therefore cannot be taken out of stock until certain periods in time. Doing so would make the model show a solution that is more likely to be fully implementable in reality.

8.3.5 Personal reflections of the author

Although there are elements in the results that would have needed to be investigated further in order to provide a sufficiently reliable and generalizable model, the author is of the opinion that the overall structure of the model developed provides an outline of the interdependencies between different cost factors in a make-to-order environment, which can be applied in production systems similar to the one analyzed in this case. Taking the model drawbacks into consideration, the results should hopefully contribute to an increased understanding within Tetra Pak of which costs should be considered when making production planning decisions, and how these costs impact the total cost of ownership.

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