Ordering and Inventory Control of Raw Materials at AR Packaging Systems

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Preface

This preface ends this master thesis and five years at Lund University, the Faculty of Engineering. It has been a revolving journey with significant impact on both our lives. We are grateful for all the memories and learnings gathered from this experience. A big thank you to the faculty for continuously challenging us with interesting courses, and to our friends who have been supportive in all the ways one can wish for!

We would like to thank AR Packaging for giving us the opportunity to write our master thesis in collaboration with them. Especially a big thanks to Max Ivarsson, who played a crucial part in the realization of this master thesis. With an infinite patience for our many questions, Max has made this thesis possible.

To continue, we wish to direct our warmest gratitude to Jan Olhager, supervisor of this master thesis, for providing us with many learnings and insights. The thesis would not be the same without your expertise, and for that we are deeply grateful.

Lastly, we would like to dedicate our thankful regards to Ingela Elofsson, for enabling us to write this master thesis together. Thank you for all your support in getting us started!

Abstract

Title	Ordering and inventory control of raw materials at AR Packaging Systems
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Examiner	Ph.D. Louise Bildsten, Lund University, Faculty of Engineering, Department of Industrial Management and Logistics
Background	AR Packaging Systems in Lund (ARPS) is relocating to smaller premises and the substantial decrease of available storage space will require sufficient inventory control. As ARPS wishes to maintain low procurement costs as well as reaching a service level at 99% towards their customers, there is a need to formulate an efficient strategy applicable for this specific case.
Purpose	The goal with this master thesis is to develop and formulate a strategy for cost optimal ordering and inventory control regarding raw materials from AR Packaging Flexibles to ARPS' production.
Methodology	This master thesis has been conducted with an abductive approach, where gathering of quantitative and qualitative data has been iterated. This confirms valid, reliable and objective results. Using triangulation, Fisher's model for conducting empirical research has been used as a framework for developing an optimal solution from case studies to be used in practice.
Result	Demand for all raw materials was modeled and showed a great variety in pattern. It was found that all raw materials but three have a large coefficient of variance and relatively low demand. Three different propositions were developed regarding a strategy for how ARPS should tackle these large demand variations considering future space restrictions.
Conclusion	The authors recommend for ARPS to classify products according to coefficient of variance, where no stock should be kept for customers with a value larger than 1. Further, the solution should be tested and implemented under current basis in order to avoid any unexpected operational challenges.

Sammanfattning

Titel	Beställning och lagerstyrning av råvaror hos AR Packaging Systems
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Bakgrund	AR Packaging Systems i Lund (ARPS) ska flytta till mindre lokaler vilket ger en efterfrågan av effektiv lagerstyrning för råmaterial orsakat av ett mindre lagringsutrymme. Då ARPS vill hålla låga inköpskostnader samt nå en servicenivå på 99% gentemot sina kunder finns det ett behov av att formulera en effektiv strategi som är applicerbar för detta specifika syfte.
Syfte	Målet med detta examensarbete är att utveckla och formulera en strategi för kostnadsoptimal beställning och materialstyrning av råmaterial från AR Packaging Flexibles till ARPS produktion.
Metod	Detta examensarbete har genomförts med en abduktiv metod, där insamling av kvantitativa och kvalitativa data har varit iterativ. Detta ger giltiga, pålitliga och objektiva resultat. Med hjälp av triangulering har Fisher's modell för att genomföra empirisk forskning använts som ett ramverk för att utveckla en optimal lösning från fallstudier till att användas i praktiken.
Resultat	Efterfrågan för alla råvaror modellerades vilken visade på stor efterfrågevariation. Det konstaterades att alla råvaror förutom tre har både stor variationskoefficient och relativt låg efterfrågan. Tre olika lösningar utvecklades beträffande hur framtida strategi för ARPS bör hantera dessa stora efterfrågevariationer med åtanke till begränsningar i lageryta.
Slutsats	Författarna rekommenderar ARPS att klassificera produkter enligt variationskoefficienten, där inget lager bör hållas för kunder med en koefficient större än 1. Vidare bör lösningen testas och implementeras under nuvarande bas för att undvika oväntade operativa utmaningar.

Table of Content

1. Introduction

This section provides descriptive background information to establish an understanding of reasons behind this master thesis and the beginning of its journey. Following with a problem formulation, which evolved through a current state analysis. Delimitations and focus followed by target audience finalize the introduction chapter.

1.1. Background

AR Packaging Systems AB (ARPS), which is part of the AR Packaging Group, is a European leading packaging company. Their packaging solutions is a high-tech business area that includes both advanced packaging lines and material components for these. These packaging solutions are mainly used for dry foods and highly sensitive customers, and therefore require high barrier levels. As the packaging business is a highly competitive business area, ARPS has focused on differentiating themselves from their competitors by being best in class at producing packages with very high food safety and hygiene. Still, ARPS focuses on keeping their costs as low as possible to keep their competitive advantage. However, for the manufacturing facility in Sweden, this is quite a challenge since wages are generally higher than for low cost countries.

Currently, ARPS' main supplier is the sister company AR Packaging Flexibles (Flexibles), which is located within the same property as ARPS. Flexibles supplies ARPS with all the materials used for their system customers. These customers are defined by buying a whole product solution from ARPS, where ARPS produces the packaging components and manufactures and sells the accompanying machine that assembles the product. This enables system customers to individually assemble and fill the packages themselves. Consequently, this gives ARPS a competitive edge as transportation to suppliers is made more efficient.

ARPS is currently relocating to smaller and more suitable premises within the same property as today. This thesis is a sub-project of the overall relocation project called 'Apollo'. ARPS' new premises will still be located in direct connection to Flexibles.

1.2. Problem formulation

As ARPS is relocating to premises which are about one third of the earlier ones used, inventory space will be limited for treated raw materials. Currently, the ordering process at ARPS for raw materials cannot meet the new limited storage area with the existing purchasing strategy and inventory control. The inventory area for raw material covers both the new premises dedicated for raw material and inventory designated for raw materials in production. ARPS has stated a wish about streamlining the production process as much as possible. Consequently, it is substantial to investigate how the drawback of inventory space will affect the purchasing strategy. Price levels as a function of ordering volumes is also necessary to take into account. That in order to evaluate the trade-off between achieving price benefits through economies of scale against less tied-up cost in inventory. The total cost perspective for the whole ordering process of raw materials from

Flexibles is critical to take into account, which covers both ordering and inventory costs. Ordering is referred to as ordering point, quantity and frequency.

While reducing inventory levels, ARPS still need to be able to meet the end customers' needs. ARPS puts great effort in achieving a high service level of about 99%, being a major factor that contributes to their competitive advantage and respectable customer relations. It is therefore of importance not to put their customer relationships at risk. However, dispensation between the system customers today vary significantly why possible prioritizations strategies might become relevant to consider as well as the associated risks if compromising the service level.

The forecasts given by the customers to ARPS are often inaccurate which causes complexity in the process for ordering raw materials as this is done based on forecasts. This can result in excess inventory as well as fire-fighting due to rapid demand growth or decrement that initially is not planned for. Out of an optimal cost perspective, the forecast deficiencies will thus be interesting to investigate and if there are any better assessment solutions. However, this would put greater requirements on more transparent communication with a majority of their system customers which in practice is one of the most critical and difficult concerns for supply chain optimization.

The solution for internal storage is to be benchmarked against a possible solution for an external storage with larger inventory area to see what would be most beneficial considering a total cost perspective. The external source is assumed to be through 3PL. This is done as a possible way out if the total costs for optimal ordering at the internal new premises is considered too high.

1.3. Purpose

The goal with this master thesis is to develop and formulate a strategy for cost-optimal ordering and inventory control regarding raw materials from Flexibles to ARPS' production for system customers.

1.4. Focus and delimitations

This master thesis contains research about streamlining the ordering process for printed paperboard laminate supplied from Flexibles used for system customers. Non-printed laminates are not covered in this master thesis. An external storage in combination with large batches is investigated as a possible alternative to internal storage with smaller batches. Inventory levels of WIP (work in progress) after printing presses within ARPS are not investigated. Important aspects which have been considered during this master thesis are that the strategy developed must not jeopardize food safety or personal safety and work environment.

The system customers for ARPS have different components that go through printing presses. This master thesis will only cover the purchasing processes and replenishment regarding system customers and the raw materials shown in Table 1.1. The displayed materials and customers cover all raw materials regarding ARPS system customers and this information is provided by ARPS.

Table 1.1. Relevant raw materials for this master thesis.

Customer	**Denotation**	**Approximate sales** *[units]*
Customer A	RM1	150 M
Customer B	RM2	3-4 M
Customer C	RM3	15-20 M
Customer D	RM4	12 M
Customer D	RM5	12 M

As each component produced towards a specific customer consists of one raw material, this master thesis will specifically cover the procurement and inventory control of five different raw materials towards four different customers.

Cost-related parameters are based on present values and do not take other financial aspects into consideration. Thus, macroeconomic variations or real value changes are not dealt with throughout this report.

1.5. Target audience

This master thesis is aimed for the department of supply chain management at AR Packaging Systems, master students, doctoral students and professors at Lund University, the Faculty of Engineering within the department of Technical Logistics. As this audience should have primary knowledge and studied in the field of logistics, this master thesis is adapted to the level of expected knowledge.

2. Presentation of AR Packaging Systems

This chapter introduces the reader to AR Packaging and its history. It further describes ARPS which is the focus for this master thesis and the products the company specializes in.

2.1. Background

Åkerlund and Rausing was founded 1929 by Erik Åkerlund and Ruben Rausing who had the fundamental idea of restructuring European retailing to the American way, where pre-packed goods were used instead of scooping unpacked products from big sacks. Å&R Carton was eventually founded in 2000, as a result of a merger between Åkerlund and Rausing and the packaging company FCP Group. In 2011, Å&R Carton became part of the AR Packaging Group, which consists of five divisions; branded products, healthcare and beauty, food packaging, flexibles and systems. During the year of 2020, Å&R Carton changed its group name to AR Packaging, where Å&R Carton in Lund was made an individual division where the company draws its name from their primary focus; system solutions, hence AR Packaging Systems. Here, ARPS can draw benefits in differentiating themselves rather than have a low-cost focus, as Sweden with its wages has a hard time competing with pricing for products from production in low-wage countries. Flexibles, ARPS' primary supplier, is also part of the AR Packaging concern and has its focus primarily within flexibles. (ARPS, 2015a)

AR Packaging has geographical presence in 13 different countries with 28 factories. This master thesis focuses on AR Packaging Systems AB and their production of system solutions. (ARPS, 2015b)

2.2. Products and solutions at ARPS

ARPS specializes in making packaging solutions with high food safety and hygiene. As mentioned earlier, the company primarily focuses on producing system solutions for their customers. This means that in addition to producing the packaging material for their customers, they also develop and produce assembling machines for their customers productions, where there exist three different types of packaging; Cekacan®, Sealio® and Boardio®.

ARPS produces all components for these packaging solutions except the plastic components for Cekacan® and Sealio®. The components are sent to the system customers unassembled and are finalized at the customer site. This is possible due to the unique concept of providing system customers with the machinery necessary to complete this manufacturing process. The concept lets the customers finish the assemblance of product components and fill the package with its content. This gives ARPS a competitive advantage as they can benefit from optimizing their transports and thereby minimize costs and environmental impact, both of which are of great importance for the company.

3. Methodology

This chapter presents and describes the applied methodology in this master thesis. A suitable approach is important in order to achieve valid, reliable and objective results. The chapter begins with discussing different types of methodologies and data collection tactics and ends with a motivation for the selected approach.

3.1. Research methodology

While conducting any form of research that adds value to a certain field of study, methodology refers to the fundamental approach of how to perform the specific study. The main purpose and underlying objective are to form guidelines and principles for the research procedure. There are several types of methodologies to utilize that are more or less suitable depending on the study it applies for. Furthermore, depending on the goal of the research and its characteristics, following approaches are applicable (Höst, Regnell and Runeson, 2006. p.29):

- *Descriptive studies*
- *Exploratory studies*
- *Explanatory studies*
- *Problem-solving studies*

Generally, in practice, a broader range of elements must be accounted for while selecting methodology. It is thus difficult to limit the chosen approach to fit with only one certain procedure. The objective with e.g. problem-solving studies is finding a relevant solution for solving an issue, but the problem might however be identified while performing a different sort of study. It is hence realistic to define the procedure as a combination of studies (Höst, Regnell and Runeson, 2006, p.29).

Furthermore, when writing a scientific research paper, the scientific degree and credibility should be addressed in the term's reliability, validity and objectivity. Those three aspects can be considered key measures that evaluate the trustworthiness of a scientific research paper. (Björklund and Paulsson, 2012, p.61)

3.1.1. Qualitative and quantitative approach

Research within operations management has historically and traditionally used a quantitative and normative approach as methodology. Kotzab et al. (2005, p.16-17) argues that there is a need for a more balanced research approach using inductive and qualitative research approaches. This in order to not delimit the scope of inquiry and to be able to contribute to modern research. The choice of research strategy can have a great impact on the outcome of the research, as there exist trade-offs regarding control, realism and generalizability. The reason for this is that the two different research approaches, qualitative and quantitative, have entirely different focuses. While qualitative research maximizes realism, quantitative research maximizes control and generalizability. The choice of research approach should therefore depend on what the researcher wants to know, which should be determined by the nature of the phenomenon at hand and type of research that is to be conducted. (Kotzab et al., 2005, p.19-23)

The aim of a qualitative approach is to understand the phenomenon at hand in its natural setting and gain a close-up view of the topic. The goal is to understand the problem by gaining a close-up view of it, where the level of detail is high. The focus is on internal validity. In contrast, the quantitative approach has its focus on external validity which is gained by building formal theory that explains, predicts and controls the phenomenon of interest. Qualitative and quantitative approaches are not a substitute for one another but should be used to complement each other. (Kotzab et al., 2005, p.19-23)

3.1.2. The balanced approach

Kotzab et al. (2005, p.19-20) suggests a balanced approach which is achieved by integrating the qualitative and quantitative methodologies and iterating between them. The balanced approach is also called abductive, which is a combination of an inductive approach (typically qualitative) and a deductive approach (typically quantitative), see Figure 3.1.

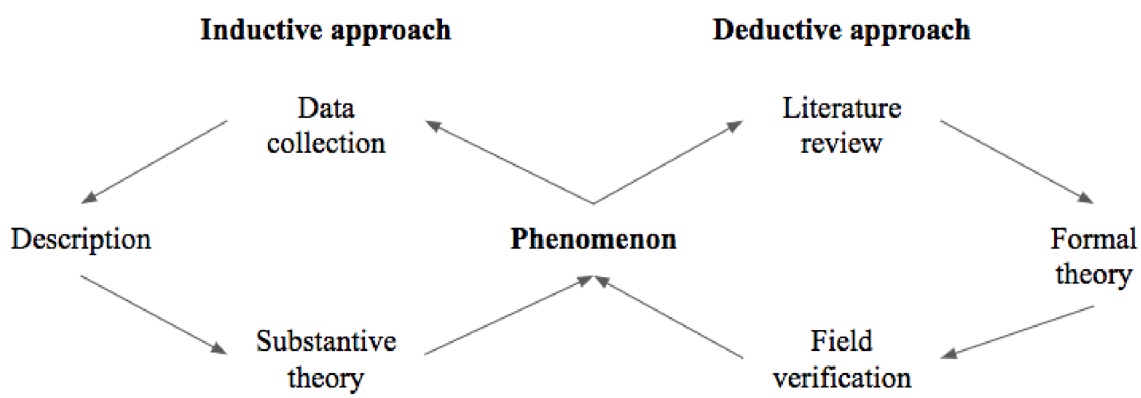

Figure 3.1. The abductive approach, combining inductive and deductive methodology (Kotzab et al., 2005, p.20).

An inductive approach is normally useful in the beginning in order to understand and generate substantive theory on the phenomenon at hand, whereas a deductive approach is more suitable for developing and testing formal theory. (Kotzab et al., 2005, p.19-20)

3.1.3. Matrix for conducting empirical research

Fisher (2007) argues that an approach for conducting empirical research in operational management should start with discussions with the company that is to be studied. This in order to enable a deeper understanding of the issue, and so that research can be guided by accurate questions. Fisher (2007) further highlights the importance of case studies, and how valuable information can be gathered through observations or a comment from the manager over lunch. After the case studies, a hypothesis is developed which should be validated through data. This is then to be implemented in the company and optimized for this specific case. The method of getting from descriptive to prescriptive can be seen in Figure 3.2. (Fisher, 2007)

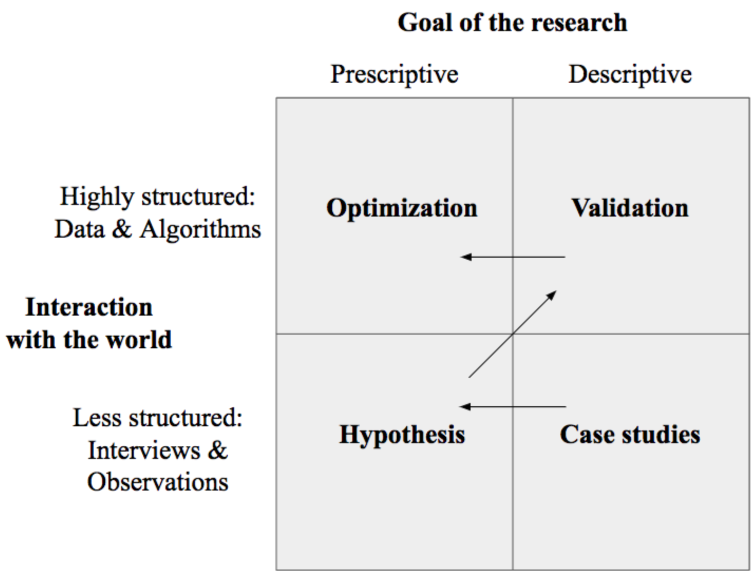

Figure 3.2. Approach for conducting empirical research within operational management (Fisher, 2007)

3.2. Data collection

Data gathering can be performed through several approaches, which all contribute differently depending on what type of information that is sought for. The most feasible way to gather data is very much connected to the choice of methodology, since the latter sets the overall guidelines and policies on how the research should be performed. It is hence relevant to consider what type of information that will be required to proceed with the selected approach (Höst, Regnell and Runeson 2006, p.84; Björklund and Paulsson, 2012, p.67). In the case of ARPS, the study relies on different sources of information but focuses on *interviews*, *observations* and *literature studies*.

3.2.1. Primary and secondary data

Primary data refers to the information that is collected for direct research application. That is for example gathered through interviews or questionnaires. Secondary data is information gathered from sources that do not necessarily address the specific subject, but that still provides valuable information that is applicable for the focal research progress. (Björklund and Paulsson, 2012, p.70)

3.2.2. Interviews

Interviews belong to primary data since it provides information of direct relevance for the research studies. It refers to information gathered by either direct personal contact or through phone and email. Interviews can be designed differently depending on purpose and situation, and the different types of interviews either *structured*, *semi-structured* or *unstructured.* What determines the characteristic and type of interview is the extent of which the questionnaire is pre-decided or rather adjusted during the interview process. (Björklund and Paulsson, 2012, p.70; Höst, Regnell and Runeson, 2006, p.34)

3.2.3. Observations

Fisher (2007) highlights the importance of not underestimating the value less structured data gathering can bring. These inputs can come from something as easy as observations, which refers to the process of studying and notifying different courses of events or phenomenons. The observer can have different degrees of interaction with the phenomena to be studied, from *actively participating* to being limited as an *observer* only. Table 3.1 illustrates the four suggested levels of observers that correspond to different forms of integration when studying a phenomenon.

Observations/participations	**High**	**Low**
High	*Observing participant*	*Complete participant*
Low	*Participating observer*	*Complete observer*

Table 3.1. Four categories of observers (Höst, Regnell and Runeson, 2006, p.93).

3.2.4. Literature review

Literature studies can be explained as every form of written or multifaceted material and refers to literature concepts such as books, research papers or similar sources. What is not to be neglected is the risk of partial or biased studies, why it is important to remain objective and critical while gathering information this way. Literature studies are normally secondary data which explains why the content may be less objective or should be validated with additional sources in order to provide complete support for further analysis. (Björklund and Paulsson, 2012, p.69)

3.3. Reliability

Reliability refers to the credibility of the research, meaning to what extent equal results would be achieved if repetitive measures would be performed. Research reliability can be improved by assessing and questioning gathered information with alternative sources of information. That can for example be comparing literature and reality with interviews or other. (Björklund and Paulsson, 2012, p.61)

3.4. Validity

Validity refers to how well the report measures what is actually relevant for the research. The simplified explanation for validity is that it means to evaluate how well conducted studies fit with the original research plan. Validity can be improved by utilizing multiple perspectives in a study and as with reliability it is favorable with interviews or different forms of inquiries. (Björklund and Paulsson, 2012, p.61)

3.5. Objectivity

Objectivity refers to the extent of which individual perceptions and values are impeding the research process. It further highlights the importance of remaining objective and true throughout the research, meaning that is a key criterion for proving the credibility of a scientific report. The objectivity in a report can be improved by providing clear descriptions of what motivates and drives the report in certain directions. It gives the recipient an opportunity to create its own opinion about the results of the report. Additionally, it is equally important to refer objectively to the sources used in the research. In order for that to be done correctly, one should consider

- Providing correct information and facts
- Avoidance selective information gathering
- Avoidance of expressions that incorporate own values and opinions. (Björklund and Paulsson, 2012, p.61-62)

3.6. Triangularity

To improve the credibility of a study, one can explore more than one methodology to evaluate the results. This approach takes a broader range of perspectives into consideration. A simplified description of this course of action is to utilize two or more methodologies for the same study and most importantly, to achieve identical purposes. The phenomena is called *triangulation* and is visualized in Figure 3.3. (Björklund and Paulsson, 2012, p.80)

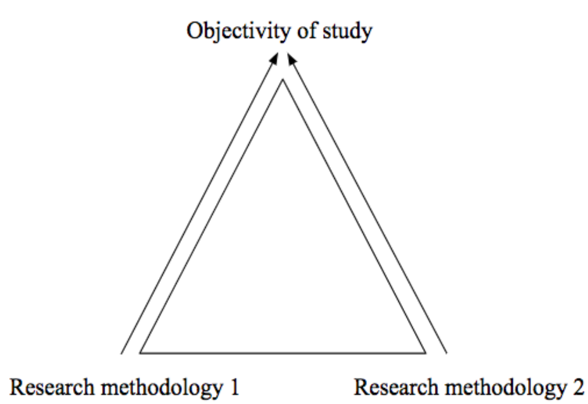

Figure 3.3. Triangularity phenomena (Björklund and Paulsson, 2012, p.80)

3.7. Approach of this master thesis

This master thesis has been conducted with an *abductive* approach, where the focus was first put on the *qualitative* methodology in order to understand the problem at hand enough to go on to the *quantitative* methodology. This was an feasible approach since it has been crucial to consider both qualitative and quantitative factors if the developed recommendation is to be applicable for ARPS. When *quantitative* data has been gathered, this has been cross-checked with the *qualitative* data in order to make sure the results are *valid, reliable* and *objective*. Fisher's model for conducting empirical research has been used as a framework for developing an optimal solution which can also be used in practice. Getting from case studies to optimization has been an iterative process between collecting *qualitative* and *quantitative* data. From collected data, a hypothesis is developed which is cross-checked with both supervisor Jan Olhager and ARPS to make sure it is truthful and applicable. This have helped to validate the hypothesis, and to not proceed in the wrong direction.

The developed hypotheses for this master thesis are the following;

- Customer behavior needs to be changed
- Different raw materials should have different strategies for storage

The validated hypothesis can thereafter be optimized to be suitable for the task at hand, which has been enabled through regular meetings with supervisor Jan Olhager as well as Max Ivarsson combined with relevant theory. Optimizing the hypothesis includes not making the solution too complex, but rather developing recommendations that are feasible for ARPS to follow. Hence, the developed recommendation has required an *abductive,* iterative approach combined with the use of Fisher's model.

Further, the solution for this master thesis relies heavily on data through numbers and calculations, e.g. *quantitative* data. However, the solution needs to be applicable for ARPS, why interviews and observations also are of great importance when developing a feasible and optimal solution that will help ARPS with their ordering and inventory control. The interviews and observations have furthermore helped to *validate* the results and make them *reliable*. The *quantitative* data has provided an *objective* perspective, where discussions with supervisor Jan Olhager have further provided insights in relevant theory for the task at hand.

Primary and secondary data have been collected iteratively depending on what is to be addressed. Information that applies directly on the specific research is gathered mainly from *interviews,* which covers both *qualitative* and *quantitative* data. Interviews have been performed with Jan Olhager, supervisor at the Faculty of Engineering in Lund and with contacts at ARPS that have relevant insights and knowledge regarding the thesis, its problem formulation and associated main objective and purpose. Interview contacts at ARPS include company supervisor Max Ivarsson; Supply Chain Specialist along with Jörgen Olausson; Materials and Production Planner, PO Andersson; Continuous Improvement and Safety Manager, Rosemary Pålsson; Plant Director and retiring Tommy Ericsson; Supply Chain Manager. Meetings have also been held with Magnus Jönsson; Purchasing Director at Flexibles and Jenny Mårtensson; Sales Manager at Flexibles in order to gain insight in additional characteristics regarding production and materials handling at Flexibles. A compilation of asked interview questions can be found in Appendix B1. Since ARPS and Flexibles operate with such close collaboration, production attributes and specifications are relevant in order to make fair assumptions and calculations as well as being able to provide reliable future recommendations to ARPS.

As mentioned, this master thesis relies on both qualitative and quantitative data, why it is of high importance to ensure that gathered information is correct and also applicable for this specific case. Interviews are a great source to achieve this, and also for supporting relevant observations that are gathered along the way. Information gathering through observations is utilized in this research to gain some ad hoc and spontaneous insights from ongoing operations and processes at ARPS. However, observations are mainly gathered through interviews and open dialogue, why the participating observer, exemplified in Table 3.1 applies best.

Validity of this research is desired to evaluate and measure how well conducted studies fit with the actual purpose of the project. To make sure that relevant research is gathered, continuous cross-checks are performed i.e. interviews with both supervisor Jan Olhager as well as with contacts at ARPS. Interviews are either structured and pre-decided or performed spontaneously as questions arise. This approach of keeping regular follow-ups makes sure that the report is moving in the right direction for its purpose.

Throughout this scientific report, emphasis is put on remaining objective and true to research findings. For the trustworthiness of the thesis, the authors own values are not allowed to impede the research process. It is additionally of highest importance that information is derived from its true context and not carefully selected to better fit with one's own interests. To prove the research remains objective throughout the report, focus is put on providing correct information and facts, meaning that references are stated continuously and thoroughly as well as not selectively chosen. That in order to avoid selective information gathering. All information gathered from interviews is treated equally, since the sources are assessed as credible and trustworthy.

There are several types of methodologies to utilize that are more or less suitable depending on the study it applies for. In line with the previous addressed approach, the study can be explained as *problem solving*. That is because a *problem-solving* method generally applies for studies when the main objective is to develop a solution for an identified problem. In this case this approach applies well for determining a solution and recommendation for ARPS on how to streamline their raw material purchases. (Höst et al., 2006, p.29)

Reliability refers to the credibility of the research, meaning to what extent equal results would be achieved if repetitive measures would be performed. Research reliability can be improved by assessing and questioning gathered information with alternative sources of information. That can for example be comparing literature and reality with interviews or other. That also applies for this master thesis, being that all information gathered from either interview or literature is compared to make sure that facts and applied material is reliable and suitable to be utilized in practice (Björklund and Paulsson, 2012, p.61). The triangulation phenomenon was initially considered as a feasible validation method to apply for this master thesis but due to the selected approach, its relevance is considered less important why rather *validity, reliability* and *objectivity* have been considered and applied to ensure research credibility.

References are selected thoroughly, and focus is put on high-quality sources rather than large quantities. Literature is limited to books, research articles or electronic sources that the authors of this thesis have been in contact with before, e.g. sources from master studies or other projects correlated to education. Parts of the chosen literature have also been validated and supported by supervisor Jan Olhager who has provided relevant literature, suitable for the purpose of this master thesis. Trustworthiness and credibility of additional sources has been evaluated based on the number of quotations and the background of its authors.

4. Theoretical framework

This chapter introduces the theoretical frameworks which will enable an analysis of how to improve ARPS' strategy for inventory control. The chapter aims to provide a greater understanding of the underlying theory that later will serve as foundation for continuous procedures. It will also figure as guidance for suggested improvements.

4.1. Process flow analysis

Process flow analysis is a method for documenting all activities regarding a process in detail. This is done in order to gain a better understanding of the process and to gain insights in potential improvements of the value chain. As different analyzes have different purposes, the level of detail and information can vary. A process flow analysis includes the following steps:

1. Identify and categorize process activities
2. Document the process as a whole
3. Analyze the process and identify potential improvements
4. Recommend suitable process changes
5. Implement decided changes (Olhager, 2000, p.91-92)

The process flow is easiest described visually through a scheme or a diagram, where three different types of schemes are presented:

1. Process flow scheme
2. Material flow scheme
3. Layout flow scheme (Olhager, 2000, p.93)

As this master thesis focuses on the procurement and inventory control of raw materials, it is necessary to understand what flows that have a direct impact on these. It is further essential to understand raw material characteristics and define the transaction from raw material to the next value adding step in the manufacturing process. Theory suggests that the transaction between raw materials to the following step in the process occurs when any *value-adding* activity is performed. As the manufacturing process is initialized, the raw material value will increase the further the process proceeds. Consequently, when goods enter a sequence of manufacturing they are no longer classified as raw materials but instead as WIP, i.e. *work in process.* (Gardner and Cooper, 2003, p.44-54; Rother and Shook, 2003, p.31-33; Laguna and Marklund, 2013, p.142)

4.2. Inventory control

Inventory control has lately become of great strategic importance for companies as the total investment in inventories is usually of an enormous size. The recent development of advanced technologies has enabled the use of efficient inventory control methods, which in turn gives the possibility of reducing the supply chain costs substantially. (Axsäter, 2006, p.1)

As inventory cannot be decoupled from other functions in a company such as procurement, production and sales, the goal of inventory control is to balance different objectives against each other. For example, procurement might want to order larger quantities to get discounts. Production wants long production runs to avoid time-consuming set-ups, and also high inventory levels of raw materials to avoid material shortages. Sales normally prefers keeping a high inventory of finished goods to being able to respond quickly to demand changes as well as keeping a high service level. At the same time, reducing inventory levels means freeing up cash which can be used for other purposes. As this balance for inventory control can be hard to achieve, inventory models are used. (Axsäter, 2006, p.46)

An inventory control system is used to determine when and how much to order, which is based on stock situation, forecast of demand and different cost factors (Axsäter, 2006, p.46). The stock situation includes stock on hand, outstanding stock orders and backorders, being that outstanding stock orders are future arrivals of stock and backorders are customer orders that have not yet been fulfilled.

(Eq. 4.1)

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

In contrast, the inventory level is described by the actual stock that is physically available.

(Eq. 4.2)

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

Furthermore, it is the inventory level that has a direct impact on holding costs and potential shortage costs. (Axsäter, 2006, p.46)

4.3. Storage strategies

There exist two different strategies for storing goods; dedicated storage and shared storage. For dedicated storage, each location is reserved for an assigned item. Only the assigned item may be stored in that location. Even if this may be efficient for picking, this strategy can easily cause inefficiencies in usage of the storage space. Shared storage is used as an alternative storage strategy to improve the usage of storage space. Two different strategies can be utilized for shared storage; random storage and zones. For random storage, an item can be assigned to more than one storage location where the idea is that when one location becomes empty, it is available for reassignment, even for a different item. Zones, however, assign a number of items to a specific zone where only these items may be stored. Within the zone however, the storing is random for the specific items. What may be a disadvantage with shared storage is that locations may change on a regular basis for different items, which can cause inefficiencies for put-away and picking of items for the workers. A WMS is therefore critical for random storage. Therefore, zones may be preferred as this causes less change but still utilizes space efficiently. (Bartholdi and Hackman, 2010, p.14; Olhager, supervisor, 2020, interview 2020-03-02)

4.4. Inventory cost factors

4.4.1. Unit value cost

The value of an item should ideally measure the actual amount of money that has been spent on a SKU to make it ready for usage. This includes the price paid to the suppliers including freight and all value-adding costs to the item such as manufacturing and processing. (Silver et al., 1998, p.44)

The unit value is important for measuring two things; the total production costs per year and the cost of carrying inventory.

4.4.2. Inventory carrying costs

Inventory carrying costs (or also called holding costs) consist of many different cost components and is according to La Londe and Lambert (2007) one of the largest costs in a physical distribution system. Theory on calculating inventory carrying costs is currently quite widespread, and there is no general accepted method or framework for determining such costs (La Londe & Lambert, 2007). According to Axsäter (2006, p.44) all costs that are variable to the inventory levels should be accounted for when calculating the holding costs for inventory where the carrying cost is determined as a percentage of the unit value.

La Londe and Lambert (2007) have developed a theoretical framework in order to identify the different cost components that make the inventory carrying costs;

1. Capital costs

Capital costs are made up of two different components, (i) *Inventory investments* and (ii) *Investments in assets required by inventory*. This requires a calculation of a standard cost for each product and inventory levels.

2. Inventory service costs

Inventory service costs contain two different cost positions, (i) *Insurance* and (ii) *Taxes*. Costs for this are usually best derived by historic numbers in budgets.

3. Storage space costs

Storage space costs differ depending on the type of storage that is used; (i) *Plant warehouse*, (ii) *Public warehouse*, (iii) *Rented warehouse* and (iv) *Privately owned warehouse*.

4. Inventory risk costs

These costs can be difficult to calculate but can be estimated from previous years expenses. Inventory risk costs deal with four different cost components, (i) *Obsolescence*, (ii) *Damage*, (iii) *Pilferage* and (iv) *Relocation costs*.

According to Silver et al., (1998, p.45) the true cost of carrying inventory should be based on a weighted average of these rates. Equation 4.3 represents the most common formula used when calculating the inventory carrying costs. (Silver et al., 1998, p.45)

(Eq. 4.3)

$$Carrying\ cost\ per\ year\ =\ \bar{I}vr$$

$\bar{I}$ represents the average inventory in units, *r* represents the carrying charge and *v* is the value unit cost. Olhager argues that the carrying charge for a medium sized company varies between 10-20% depending on the nature of inventory such as obsolescence, demand for workers, special equipment requirements and so on (Jan Olhager, supervisor, 2020, interview 07-02-2020). The percentage calculating carrying costs should in general be considerably higher than the one charged as interest rate by the bank (Axsäter, 2006, p.44).

4.4.3. Ordering cost

Ordering cost is denoted as A and represents the fixed cost associated with a replenishment. This cost is independent from the size of appurtenant replenishment. For a merchant, this cost relates to all administrative work regarding an order and is called ordering cost. (Silver et al., 1998, p.46-47; Axsäter, 2006, p.44-45)

According to Olhager (Jan Olhager, supervisor, 2020, interview 07-02-2020), a medium sized company usually has an ordering cost of approximately 200-500 SEK per replenishment.

4.4.4. Shortage cost

Shortage cost relates to when an item is demanded and cannot be delivered due to shortage. This phenomenon may arise several different costs depending on the situation. If the customer agrees to wait while the order is backlogged, extra costs like administration, price discounts for late deliveries, material handling and transportation may be obtained. However, if the situation occurs when a customer chooses another supplier, the contribution of the sale would be lost. In both cases it usually means a loss of goodwill, which may affect the sales in a long-term perspective. These costs are hard to estimate though, and even more so, the shortage costs incurred in production can be difficult to estimate. Shortage costs in production arise for example if a component is missing, which can cause negative consequences such as delays, rescheduling and so on. (Axsäter, 2006, p.45)

As it is usually hard to calculate shortage costs, a common solution is to replace these costs with a suitable service constraint based on a desired service level towards customers. (ibid)

4.5. Demand pattern modeling

Understanding the demand pattern is crucial for the choice of forecasting and inventory control. demand pattern is estimated through historic sales which provides information about the demand pattern for different products. Historic demand data can be decomposed into five different components which are called time series components, presented below and illustrated in Figure 4.1.

1. Trend - Gradual increase or decrease in demand.
2. Seasonality - A pattern of demand which repeats itself yearly. This could for example be holidays, weather, seasons.
3. Cycle - A pattern which repeats itself after a number of years such as business cycles.
4. Level - The level is the basic average demand over time.
5. Random - These are variations in demand that cannot be explained. (Olhager, 2000, p.152-154)

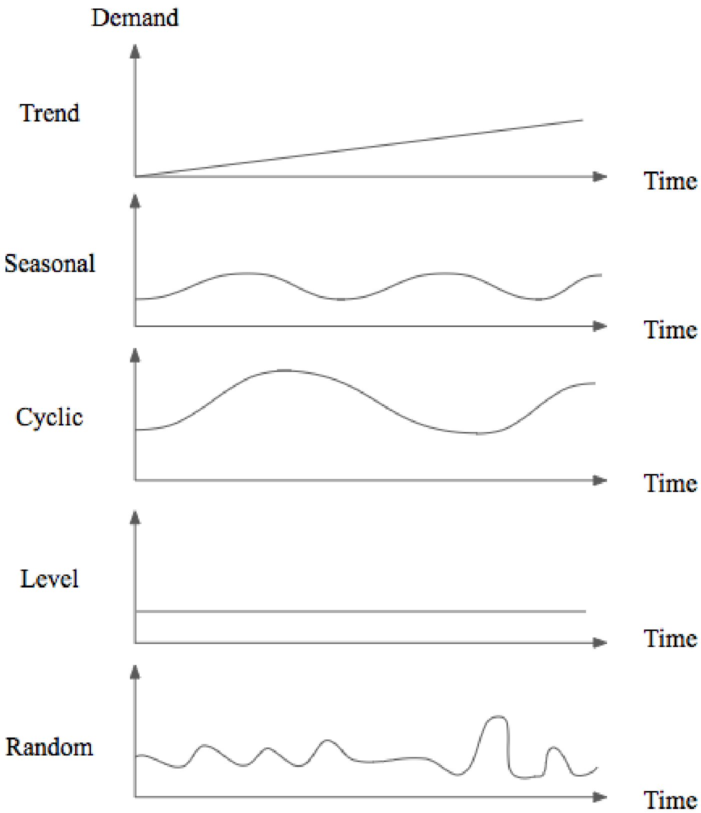

Figure 4.1. Illustration of demand patterns (Olhager, 2000, p.154-156).

Olhager (2000, p.154-156) and Axsäter (2006, p.9-10), suggests three different models for deciding demand pattern; constant model, trend model and combined trend and seasonality model.

4.5.1. Constant model

The constant model contains one constant, time-independent term and one random term. This can be described through

(Eq. 4.4)

$$D_t = a + \varepsilon_t$$

Where
$D_t =$ demand in period t,
a = average demand per period
ε_t = random number in period t.

The random number is an independent stochastic variable with an average value of zero and constant standard deviation. (Olhager, 2000, p.154-155)

$E[\varepsilon_s, \varepsilon_t] = \sigma^2, s = t;\ 0, s \neq t$

As the average value of the random term is zero, can the level be calculated as the value of the average demand. Furthermore, it is most suitable to assume a constant model if trends or seasonal patterns are not expected from the specific product type. The constant demand model is also most applicable for products that are considered mature in their life cycle. (Axsäter, 2006, p.9)

4.5.2. Trend model

A trend model contains a constant level term, a trend term and a random term. It is formulated as

(Eq. 4.5)

$$D_t = a + b \cdot t + \varepsilon_t$$

Where
b = trend per period,
t = period index. (Olhager, 2000, p.155)

The period index marks the number of trend periods after the demand on level a. It is reasonable to assume linear trends if considering a demand that can increase or decrease systematically, for example during specific life cycle intervals in the growth or phase-out stage. It is hence important to consider life cycle characteristics in order to determine suitable demand models. (Axsäter, 2006, p.10)

4.5.3. Combined trend and seasonality model

This formula contains a constant term, a trend term, a seasonality term and one random term. Following is an example of a formula;

(Eq. 4.6)

$$D_t = (a + b \cdot t)\, c_t + \varepsilon_t$$

Where c_t is the seasonal index in period *t.* (Olhager, 2000, p.155)

Seasonal index c_t denotes the expected variation of demand during period t. If the index for example is set to 1.3, it simply means that demand in period t is expected to be 30% higher because of seasonal variation. However, a seasonal model is mainly applicable and useful if demand follows a similar pattern during a longer time interval. (Axsäter, 2006, p.10)

4.5.4. Demand variation

Inventory management is multidimensional in its meaning. However, it often refers to the complex coordination between maintaining a desired service level and replacing inventory with required volume and the right frequency. That in turn requires knowledge and insight in how demand varies, regarding both volumes of demand as well as the frequency of it. This demand modelling is commonly retrieved by assuming that demand follows a certain kind of distribution, usually a statistically standardized distribution that originates from real historical data.

While matching a given demand to a specific distribution, it is possible to compare how well they fit for the given dimensions of storage and the service level which the storage is supposed to serve. It is thus interesting to consider the extent of which the applied distributions can represent the real demand pattern. Normal distribution and Poisson distribution are two of the most commonly applied approximation models for determining demand patterns and are differently used depending on the nature of demand.

4.5.5. Standard deviation

The standard deviation is used to describe the predictability of demand. It measures the deviation between observed numbers and its mean value, thus the variation of data points around the mean value. Standards deviation is derived through Equation 4.7, where *X* describes a stochastic variable with mean *E[X] = m.* (Axsäter, 2006, p.30)

(Eq. 4.7)

$$\sigma = \sqrt{E(X - m)^2}$$

However, the standard deviation does not take volume into consideration, thus products with a higher demand tend to get a higher standard deviation. This is due to greater risk of larger differences in observations than for a product with lower demand. (Olhager, supervisor, interview 2020-04-28)

4.5.6. Coefficient of Variance

D'Alessandro and Baveja (2000) suggest that demand patterns can be examined by the use of a measurement called *coefficient of variance*. They performed a study at the chemical company Rohm and Haas, who experienced a tough situation with dilemmas tangible to the ones at ARPS. Videlicet to balance the two supply chain counterparts; being able to provide the best service to customers while simultaneously operating cost effective. The study was performed during a three-year period and ended in a successful segregation of products into make-to-stock and make-to-order, which makes the case study useful to apply further in this thesis.

The coefficient of variance is similar to standard deviation and functions as a statistical measurement that describes the dispersion of reference points around the mean. The coefficient of variance is calculated through the formula described in Equation 4.8 and is hence derived by dividing the standard deviation by its mean. The mean denotes the average frequency in terms of volume for the specific case. In comparison with the output retrieved by the standard deviation, coefficient of variance takes volume into account which simplifies the comparison between series of data, i.e. different products in a warehouse. By scaling the standard deviation by the average weekly demand, the coefficient makes it possible to compare the variability of products with different demand volumes.

(Eq. 4.8)

$$CofV = \frac{\sigma}{\mu}$$

Since the coefficient of variance is a tool to analyze the demand pattern, it also gives an indication of how to manage inventory most accurately and efficiently. Depending on the values retrieved by the coefficient, different strategies are suitable to apply. D'Alessandro and Baveja (2000) suggest guidelines in how to separate articles with the help of a reference value and the coefficient of variation:

- For $CofV$< 0.52
- For $CofV$> 0.52

The breakpoint between values is set to 0.52, which indicates when different policies should be considered. Continuously, the study verified that products with a coefficient of variation below 0.52 were in fact quite predictable, whilst articles with a coefficient exceeding that reference point were less so. Coefficient of variance is thus a feasible measurement for classifying products into different segments or categories, e.g. which articles that are necessary to store or rather make to order. It is also assumed that products with a coefficient below the reference point follow a normal distribution (Olhager, supervisor, interview 2020-04-28). One can plot the coefficient of variance and the average demand into a diagram that usually will create a similar pattern as shown in Figure 4.2.

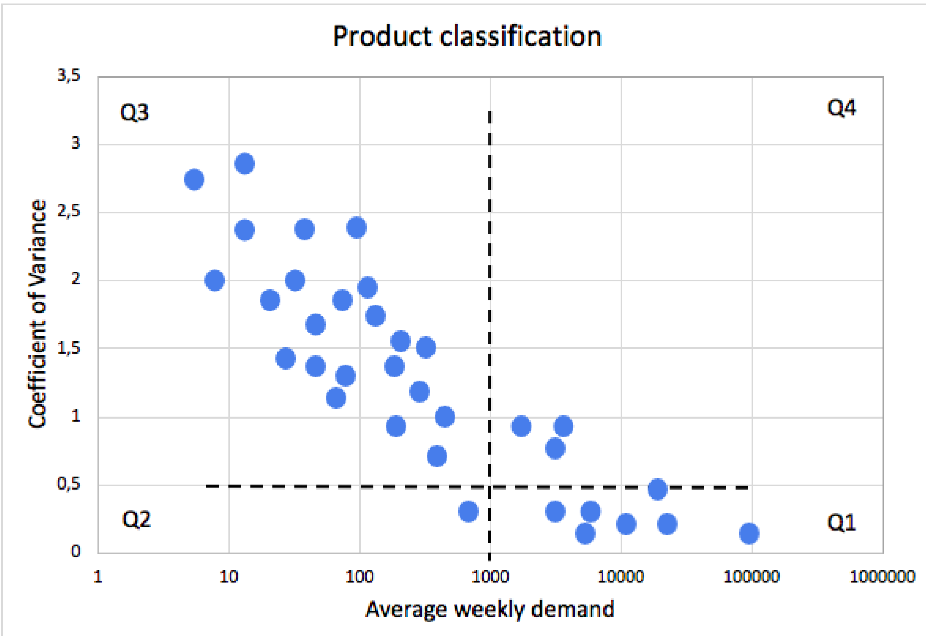

Figure 4.2. Weekly average demand (logarithmic scale). (D'Alessandro and Baveja, 2000)

Figure 4.2 also illustrates how products can be segmented into different zones in the plot, or rather quadrants. Q1 represents high volume and low variability, Q2 is low volume and low variability, Q3 is low volume and high variability and Q4 is high volume and high variability. By dividing the products into separate categories, it allows for treating them differently as well as developing tailored strategies, both regarding sales, storing and manufacturing, see Table 4.1. According to Olhager (interview 2020-06-02) a wide number of industries currently use the coefficient of variance to develop different strategies for storage depending on customer behavior, rather than using volume-based classifications.

Q3 - MTO	Q4 -
Q2 -	Q1 - MTS

Table 4.1. Manufacturing strategies for products that belong to Q1 and Q3 (D'Alessandro and Baveja, 2000).

4.6. Forecasting

Axsäter (2006, p.7-8) means that the reasons behind the necessity of forecasts mainly have two specific reasons. Firstly, the almost inevitable *lead time* caused by delays from the actual order until its arrival. Secondly, the cost aspects that usually vary depending on the *size* of the order. Todays' competitive environment with higher requirements on both price and agility, makes forecasts vital. Demand forecasts can be defined as the average demand estimated for a certain future. However, forecasts are estimates which makes it necessary to address both potential errors as well as uncertainties. Errors are usually measured based on deviation between actual demand compared to estimated forecasts. Depending on forecast uncertainty and the unpredictability of demand, higher requirements are put on inventory level. (Axsäter, 2006, p.7-8)

Demand forecasts can be exploited based on different components and data. Axsäter (2006, p.7-8) implies that forecasts connected to inventory control most commonly provides valuable information one year ahead, but seldom any credible insights if the timeframe is longer. Consequently, inventory forecasts are usually gathered from extrapolation of historical data. It can also be based on factors such as rapid demand fluctuations, i.e. sales promotions or external factors more difficult to predict. For example, demand for spare parts can be difficult to predict and model since it is dependent on external factors such as market variability for the end product.

Depending on the demand pattern, different forecast methods are recommended, which are presented in Table 4.2. Table 4.2 also illustrates a comparison between the methods considering their credibility and accuracy over longer and shorter time horizons.

		Forecast horizon	
Demand pattern model	**Forecasting method**	**Short - middle**	**Long**
Constant model	Moving average Exponential smoothing	2-3 2-4	1 1
Trend model	Exponential smoothing with trend Trend projection	2-4 4	2 3
Trend and seasonality model	Exponential smoothing with trend and seasonality	2-4	2

Table 4.2. Forecasting method depending on demand pattern and evaluation depending on the credibility of the method during short term and long-term time horizons. Ranking based on a numerical scale from 1-5 where 1 = lowest credibility during a certain time frame. (Olhager, 2006, p.156, p.173)

4.6.1. Moving average

Moving average value is a simple forecast method suitable if demand is assumed to be relatively constant over time. This forecast is calculated through the average of a number of periods demand.

(Eq. 4.9)

$$F_{t+1} = M_t = \frac{D_t + D_{t-1} + \ldots + D_{t-N+1}}{N} = \frac{1}{N} \sum_{i=t-N+1}^{t} D_i$$

Where
F_{t+1} = forecast for period t + 1,
M_t = moving average for period t,
D_t= observed demand for period t,
N = number of observations,
i = period index.

For every new month, the latest months demand data is added, and the earliest ones removed. All observed demand data is considered to have the same impact and weight. (Olhager, 2000, p.157-158)

4.6.2. Exponential smoothing

When using exponential smoothing, a constant demand model is assumed. The result is quite similar to moving average, but the forecast is updated differently (Axsäter, 2006, p.12). For exponential smoothing, different demand values are assigned different weights. The following formula is used.

(Eq. 4.10)

$$F_{t+1} = U_t = \alpha\, D_t + (1-\alpha)\, U_{t-1} = \alpha\, D_t + (1-\alpha)\, F_t$$

Where
F_{t+1} = forecast for period t + 1, done in period t,
U_t = exponentially smoothed demand from period t,
D_t = demand in period t,
α = smoothing constant with a value between 0 and 1,
i = period of index.

The forecast is built on previous demand for several time periods. By developing F in the formulation, a new expression can be obtained. (Olhager, 2006, p.159-161)

(Eq. 4.11)

$$F_{t+1} = \alpha\, D_t + (1-\alpha)\, F_t = \alpha\, D_t + (1-\alpha)\, [\alpha\, D_{t-1} + (1-\alpha) F_{t-1}] = \sum_{i=0}^{\infty} \alpha\, (1-\alpha)^i\, D_{t-i}$$

The forecast for the next period of time is obtained as the exponentially smoothed demand, which is calculated through all earlier observations D_i with weights α and 1- α. The weights will subside exponentially, where the choice of the value for the smoothing constant will have an impact on how fast the weights will subside. A larger α-value will have a faster reaction to changes but will be more sensitive random changes. In contrast, a lower α-value gives a more stable forecast but has poorer reaction to systematic changes. (ibid)

4.6.3. Forecasting errors

In order to develop a suitable formula taking safety stock and inventory level into consideration, it is sufficient to know the accuracy of the demand forecast. A well-known approach that describes how the forecast deviates from its mean value is through the *standard deviation* formula. here meaning how much demand can be expected to deviate from the forecast. Assign X as a stochastic variable and let mean $m = E(X)$, which illustrates the expected value of X. The standard deviation, σ can thus be derived from Equation 4.12. (Axsäter, 2009, p.29)

(Eq. 4.12)

$$\sigma = \sqrt{E(X-m)^2}$$

One additional way to address potential forecast errors is to estimate the *Mean Absolute Deviation*, abbreviated as *MAD*. *MAD* yields the expected value of the absolute deviation of the mean and is derived from Equation 4.13. (Axsäter, 2009, p.29-30)

(Eq. 4.13)

$$MAD = E|X-m|$$

However, the standard deviation σ and *MAD* yield similar results of the variation around the mean. Continuously, (Axsäter, 2009, p.29-30; Olhager, 2000, p.168-169) suggest that it is common to assume that forecasting errors are normally distributed, which thus results in a simple relationship between the two measurements seen in Equation 4.14.

(Eq. 4.14)

$$\sigma = \sqrt{\frac{\pi}{2}} MAD \approx 1{,}25\ MAD$$

4.6.4. Forecast monitoring

Problems caused by less accurate forecasts can be avoided by continuous follow-up and monitoring. Techniques can thus be applied to evaluate the accuracy of new forecasts, so that updated forecasts are more adequate. The most usable techniques are for evaluating the reliability of the new updated forecast and to test if its average is representable. (Axsäter, 2006, p.34-35).

Olhager (2000, p.170-171) confirms the benefits of forecasting monitoring and implies that one of the most applied techniques are relating the *absolute deviation* in the focal period to the previous addresses *mean absolute deviation,* i.e. MAD. The relation is compared according to Equation 4.15, and the reasonability can hence be evaluated based on the deviation between the two measurements. It is highly unlikely that the current periods *absolute deviation* deviates drastically from MAD.

(Eq. 4.15)

$$TSD_t = \frac{|D_t - F_t|}{MAD_{t-1}}$$

Where

TSD_t= Tracking Signal during period *t*

MAD_{t-1}= Exponentially smoothed *mean absolute deviation* during period *t-1*

F_t =Forecast during period *t*

4.7. Demand distribution

In order to determine the optimal reorder point for a stochastic demand, a suitable demand model is required. Further, the appropriate demand model to apply can usually be determined by examining the nature of product demand. If the demand is low, e.g. only a few pieces per year, it has been found that a discrete model is more suitable such as Poisson distribution. In contrast, if demand is relatively large, an approximate continuous demand model such as Normal distribution is theoretically more suitable. (Axsäter, 2006, p.77)

Literature suggests different guidelines to support the election of distribution type. The most commonly used and also the most attractive one for real practice application is the normal distribution (Olhager, supervisor, interview 2020-04-28). A massive body of research and studies support the simplicity of using normal distribution while the objective is to find appropriate dimensions for safety stock (Silver et al., 1997, p.719; Olhager, supervisor, interview 2020-04-28; Mattson 2003). However, there are some deficiencies in its application, i.e. for articles with less frequent turnover rate and low demand. That is since the normal distribution is symmetric around its mean. Different guidelines are suggested in literature regarding the feasibility of normal distribution for a certain demand pattern. An important measure to consider is the number of existing standard deviations in the interval between 0 and its mean. Different quotas between standard deviation and the mean is thus suggested to indicate how well the distribution fits with reality (Mattson, 2011).

On the other hand, there exist additional approximation models that better suit demand of different nature than what fits normal distribution. Poisson distribution is a non-symmetric model which better depicts real demand variations while considering articles with less frequent demand and high variability (Mattson, 2011; Marklund, 2019). In accordance with (Axsäter, 2006, p.80), it is suitable to use Poisson distribution as long as the condition below is true.

- $0{,}9 < \frac{\sigma^2}{\mu} < 1{,}1$

This condition must be valid in order to approximate demand with the Poisson model.

4.7.1. Poisson distribution

Theory implies that a common assumption when applying stochastic demand models is to illustrate demand as a nondecreasing process with stationary and mutually independent increments. Further, all such processes can be described as a sequence of suitable compound Poisson processes (Axsäter, 2006, p.77; Marklund, 2019). When applying the Poisson process, it is assumed that arrivals occur according to a Poisson distribution. If the corresponding size of demand is stochastic, the distribution is called the compounding Poisson. Compound Poisson means that the size of customer demand is independent of previous demand from other customers and also independent of customer arrivals.

Definitions:

- Let arrivals occur according to the rate λ and thus, the time between arrivals is denoted as ~exp ($1/\lambda$), meaning that time between arrivals is exponentially distributed.
- Assume that each arrival orders J units, where J is a stochastic variable and has a compound distribution.
- Let f_j^k denote the probability that k customers demand a total of j units.
- Let D(t) denote the stochastic demand during time interval t.
- Let P(k customers arrive during time interval t) = $\frac{(\lambda t)^k}{k!} \cdot e^{-\lambda t}$ denote the probability that k customers arrive during time interval t.

This is finalized in Equation 4.16 which renders the probability that k customers arrive during time interval t and demand a total of j units.

(Eq. 4.16)

$$\sum_{k=0}^{\infty} \frac{(\lambda t)^k}{k!} \cdot e^{-\lambda t} \cdot f_j^k$$

Assign the following denotations:
μ = average demand per time unit, where;

(Eq. 4.17)

$$\mu = \lambda E[J] = \lambda \sum_{j=0}^{\infty} j f_k^j$$

σ = standard deviation of demand per time unit, derived from the variance;

(Eq. 4.18)

$$\sigma^2 = \lambda E[J^2] = \lambda \sum_{j=0}^{\infty} j^2 f_j^k$$

When Poisson distribution is applied for inventory control it is normally necessary to measure the distribution of demand over a certain time, that can e.g. be lead time. In that case, let $\mu' = \mu t$ and $\sigma' = \sigma t$ denote the mean and standard deviation of demand during that specific time period *t*. (Axsäter 2006, p.77-80; Marklund, 2019)

4.7.2. Normal distribution

Research implies it is more suitable and convenient to model demand with continuous distribution if the size of demand is higher than what suits to be modelled according to Poisson distribution. Given the mean $\mu'$and the standard deviation $\sigma'$of the demand during a time period *t*, it is always possible to fit a unique normal distribution to these parameters as illustrated in Equation 4.19. Normal distribution fits well when considering a sum of several independent variables since their distribution will be approximately normal. Furthermore, the normal distribution is beneficial in the meaning of simplicity as well as being used for long and is therefore well-known and applied in practice. (Axsäter 2006, p.85-86)

(Eq. 4.19)

$$\varphi(x) = \frac{1}{\sqrt{2\pi}\,\sigma^2} \cdot e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

4.8. Lot sizing modeling

Lot sizing modeling is done in order to determine the optimal batch quantity in replenishment considering cost factors as well as end customer demand. The fluctuations in inventory levels for a constant demand is represented in Figure 4.3.

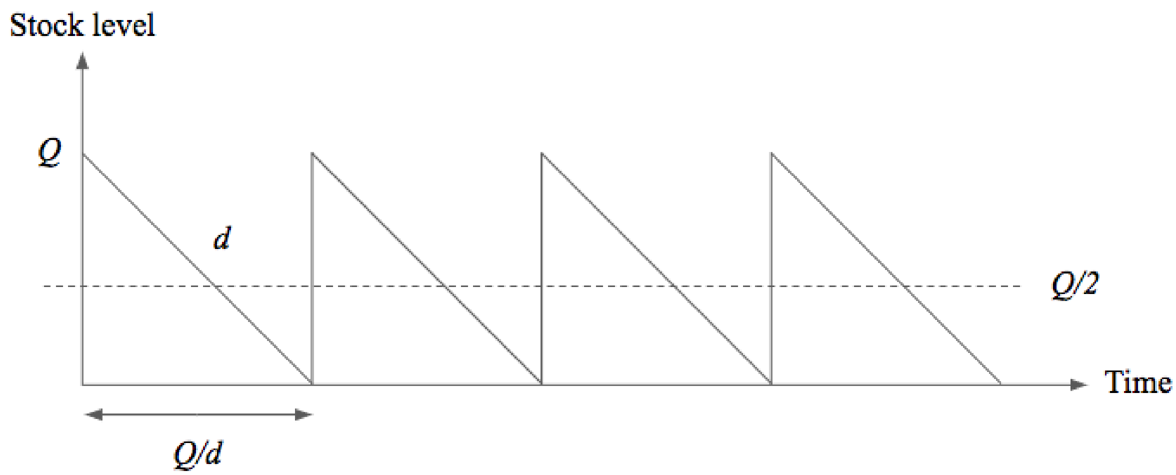

Figure 4.3. Fluctuations in inventory levels for a constant demand (Axsäter, 2006, p.53).

4.8.1. Economic Order Quantity

According to Axsäter (2006, p.52-54) the Economic Order Quantity-model figures as one of the best-known models in inventory control for determining optimal order quantity. The formula is based on following assumptions:

- Demand is constant and continuous
- Ordering and holding costs are constant over time
- The batch quantity does not need to be an integer
- The whole batch quantity is delivered at the same time
- No shortages are allowed. (Axsäter, 2006, p.52-54)

Following notation is used;
$h = rv$ = carrying cost per unit
A = ordering or setup cost
d = demand per time unit
Q = batch quantity
C = cost per time unit.

Depending on the batch quantity, the ordering and holding costs will vary. Based on this, the following equation is obtained;

(Eq. 4.20)

$$C = \frac{Q}{2} h + \frac{d}{Q} A$$

The first term represents the holding costs where *Q/2* is the average stock, and the second term the ordering costs per time unit. By deriving the previous equation, the optimal ordering quantity *Q** can be obtained. (Axsäter, 2006, p.52-54)

(Eq. 4.21)

$$\frac{dC}{dQ} = \frac{h}{2} - \frac{d}{Q^2} A = 0 \rightarrow Q^* = \sqrt{\frac{2Ad}{h}}$$

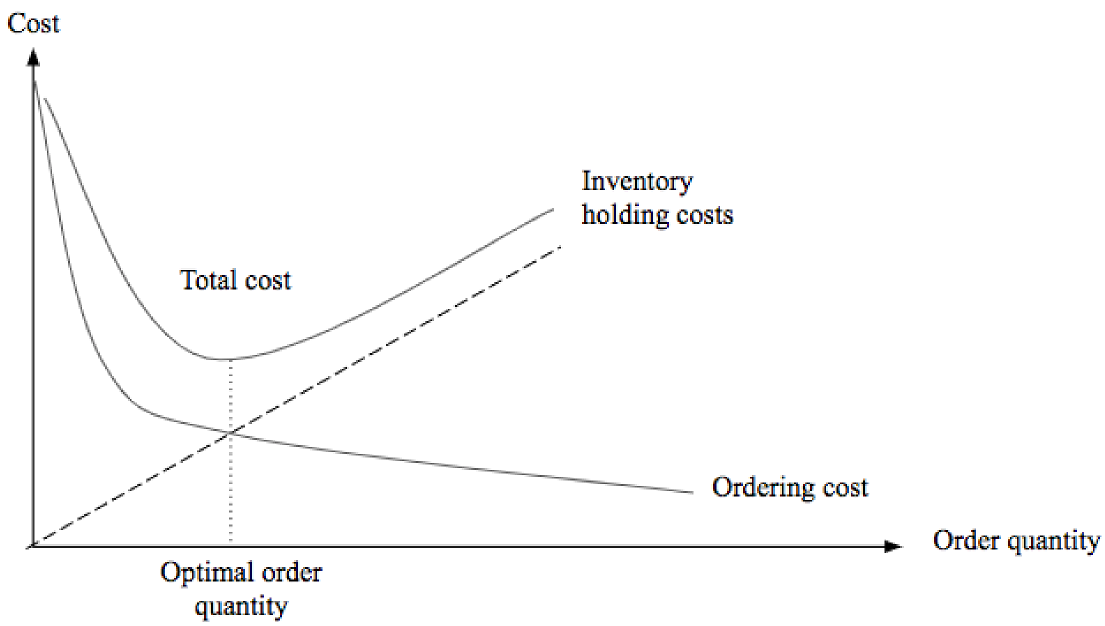

Figure 4.4. The optimal order quantity as function of lowest total cost (Olhager, 2000, p.212).

The lowest total cost can be seen in Figure 4.4 as a function of ordering cost and inventory holding cost. However, this assumes a constant cost per unit and takes no consideration to eventual discounts for larger batches.

4.8.2. Economic Order Quantity with quantity discounts

When considering quantity discounts, the EOQ-model needs some adjustments as the procurement cost so far has been assumed to be linear. In reality, larger quantities often result in a lower price per unit. There exist two different types of quantitative discounts:

1. Discount for the whole order,
2. Incremental discount, different prices for different quantity ranges.

However, as incremental discount rarely occurs, a model for discount on the whole order is used. (Olhager, 2000, p.216-219)

Let us assume an all-units discount is provided if the purchased order quantity exceeds a certain amount. It is hence relevant to investigate the optimal quantity that yields the lowest price per unit. To determine the most beneficial order quantity in terms of receiving the lowest cost per unit, let

v = value per unit given normal price setting and $Q < Q_0$
v' =value per unit given volume discount and $Q \geq Q_0$

Where Q denotes the volume yielding quantity discounts and Q_0 denotes the volume corresponding to normal price setting, i.e. initial price per unit. Consequently, the unit-cost declines as the quantity increases. The ultimate goal function thus includes the variable cost associated with quantity discounts, order set-up costs and the inventory carrying cost (holding cost). The latest is assumed to be affected by the volume discount as below:

$h = rv$ for $Q < Q_0$, carrying cost with normal price setting
$h = rv'$ for $Q \geq Q_0$, carrying cost with discount price

It is reasonable to assume that the carrying cost h consists of one capital cost, which depends on the interest rate and the value per unit. Let C denote the initial cost-equation considering different price settings depending on volume. (ibid)

(Eq. 4.22, 4.23)

$$C = dv \cdot \frac{Q}{2}(rv) + \frac{d}{Q}A, \qquad Q < Q_0$$

$$C = dv' \cdot \frac{Q}{2}(rv') + \frac{d}{Q}A, \qquad Q \geq Q_0$$

Equation 4.21 in the previous section renders the standard formula for optimal economic order quantity. By applying the modified version considering volume discount, the equation will change according to new cost-components. The optimal solution can be obtained by two different calculations. First, the optimal quantity and its associated cost are derived from Equation 4.23 without considering $Q \geq Q_0$. (ibid)

(Eq. 4.24)

$$(Q')^* = \sqrt{\frac{2Ad}{rv'}}$$

Which renders the cost equation;

(Eq. 4.25)

$$C' = \sqrt{2Ad(rv')} + dv'$$

If $(Q')^* \geq Q_0$, Equation 4.24 yields the optimal order quantity and Equation 4.25 the lowest cost that can be obtained. That is because the equations are considering v'which already denoted the lower price setting. However, if $(Q')^* < Q_0$ it is sufficient to optimize the cost Equation 4.22 according to the structure without any volume discounts:

(Eq. 4.26)

$$(Q'')^* = \sqrt{\frac{2Ad}{rv}}$$

Which renders the cost equation;

(Eq. 4.27)

$$C'' = \sqrt{2Ad(rv)} + dv$$

Since we know that *v* > *v'*, this mathematically makes Q'' less than Q'. Consequently, Equation 4.26 and 4.27 render the smallest quantity and lowest cost without a discount. However, the formula yielding the lowest cost with a discount is introduced below, where *A* is the order set-up cost and *d* denotes constant demand per time unit.

(Eq. 4.28)

$$C(Q_0) = dv' + \frac{Q_0}{2}(rv') + \frac{d}{Q_0}A$$

An illustration of this can be seen in Figure 4.5. (Axsäter, 2006, p.56-58; Olhager, 2000, p.216-219)

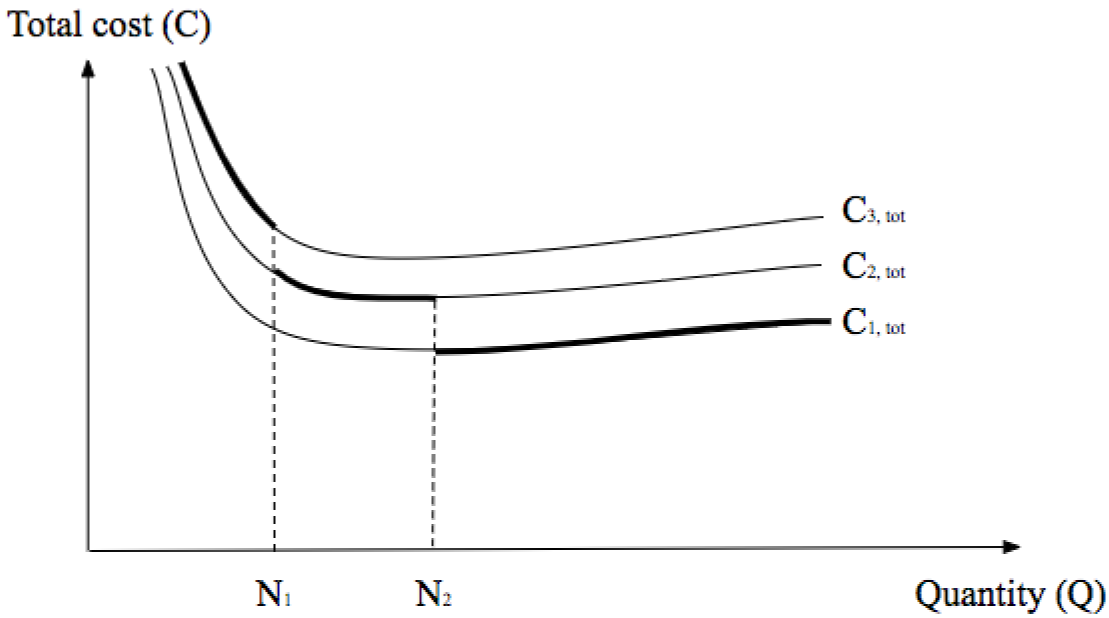

Figure 4.5. Comparing total costs for larger and smaller batches with quantity discounts (Olhager, 2000, p.219).

Potential benefits that discount arrangements can yield to individual players are present and confirmed by research (Monahan, 1984; Dolan, 1987). However, it remains interesting to question the actual benefits for the total supply chain with such agreements. Quantity discounts naturally incentivizes supply chain members to procure larger volumes, but fails to address the consequences this might result in. Olhager (2020) means that this pricing strategy seldomly benefits the supply chain as a complete entity, but rather contributes to local optimization and silos across business units. Consequently, a widespread result of agreements that drive up volumes over the supply chain can usually be detected in higher inventory levels, which in turn contribute to increased tied-up capital.

4.8.3. Economic Order Quantity with restrictions

Standard formula for economic order quantity takes only the cost of replenishing and carrying inventory into consideration. However, it is realistic that other factors affect the feasible order quantity. Additional factors covering other aspects than financials are physical constraints. Shelf life and storage capacity are also restrictions that can impede on the optimal order size. The general problem formulation taking any sort of restriction into consideration is described in Equation 4.29. (Olhager, 2000, p.219-220)

(Eq. 4.29)

$$Min\ C_{tot} = \sum_{j=1}^{n} C_j(Q_j)$$

Where

g($Q_1 \ldots Q_n$)= M

C_{tot}= total cost

$C_j(Q_j)$= relevant cost for article j

Q_j= order quantity for article j

M = limited condition

g = conditioning function

4.8.4. Finite production rate

In practice, it is not unusual to split orders into smaller batches that are delivered according to the speed of production intervals. In other words, this concept applies when deliveries do not take place instantaneously but are replenished as the articles are produced (Olhager, 2000, p.214). Batches thus arrive continuously depending on the suppliers' production rate, which requires a modified version of the economic order quantity taking successive arrivals into consideration. Adjusting the standard equation accordingly, it yields the following:

(Eq. 4.30)

$$C = \frac{Q(1 - d/v)}{2}h + \frac{d}{Q}A$$

Let *v* = production rate and *v* > *d*. This yields the optimal order quantity;

(Eq. 4.31)

$$Q^* = \sqrt{\frac{2Ad}{h(1 - d/v)}}$$

Figure 4.6 illustrates the modified model taking successive arrivals into consideration. Using a finite production rate will result in larger batch sizes. Note that the production occurs during time interval *Q/v* whilst inventory increases with the rate of *d/v*. This renders a maximum inventory level of *Q(1-d/v).* As illustrated, the inventory decreases with rate *d* after passing the time *Q/v*. (Axsäter, 2006, p.55)

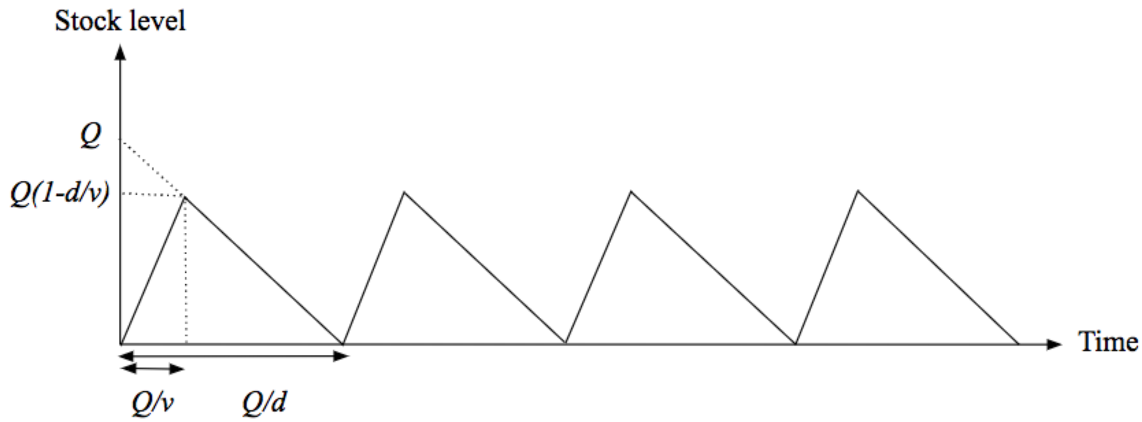

Figure 4.6. Development of inventory level with finite production rate (Axsäter, 2006, p.56; Olhager, 2000, p. 214).

4.9. Safety stock

As replenishment of raw materials is based on probabilistic values, there exists two different scenarios of risk;

- Not being able to satisfy customer demand due to stockout as demand is larger than anticipated.
- High inventory levels due to lower demand than anticipated leading to higher inventory carrying costs. (Silver et al., 1998, p.241-243)

The safety stock exists to cover up the random variations in demand during lead time, from reorder point until the products are disposable for customers (Olhager, 2000, pp. 227). According to Olhager (2000, p.227-228) there exist two different models for deciding a suitable safety stock, either through a wished service level or through a shortage cost model. The first described model is the most common and will be used in this master thesis.

Olhager (2000, p.227) describes two different service measurements;
1. SERV1, the probability of no stock outs during an order cycle, i.e. that an order arrives in time before the stock is finished.
2. SERV2, the fraction of demand that can be satisfied immediately from stock on hand.

When calculating SERV1, the following formula is used;

(Eq. 4.32)

$$SS = k\,\sigma_L = k\,\sigma\,L^{\gamma}$$

Where
k = safety factor,
σ = the standard deviation of the errors of forecasts of a total demand over a period,
σ_L= the standard deviation of the errors of forecasts of a total demand over a period of duration L,
L = lead time over a period,
γ = constant.

The constant γ is dependent on the correlation between forecast errors for different periods. If no correlation exists, the value for γ is 0,5 whereas this value will grow with a growing correlation. The safety factor is calculated through a perspective of no stock outs using the formula:

(Eq. 4.33)

$$SERV1 = P[x_L \leq SS] = P\left[\frac{x_L - 0}{\sigma_L} \leq \frac{SS - 0}{\sigma_L}\right] = \Phi\left[\frac{SS}{\sigma_L}\right]$$

where Φ describes the distribution function (Olhager, 2000, p.227-230). The safety factor corresponding to the desired service measurement can be seen in Table 4.3. This is obtained from the forecasting error probability distribution.

Table 4.3. Safety factors for different values of service measurement (Axsäter, 2006, p.97; Olhager, 2000, p.229).

SERV1	0.5	0.75	0.80	0.85	0.90	0.95	0.99
k	0	0.67	0.84	1.04	1.28	1.64	2.33

If there would exist insecurities and variations for the lead time, the following formula should be used instead;

(Eq. 4.34)

$$SS = k\sqrt{L\sigma^2 + D^2[\sigma(L)]^2}$$

where
D = demand per period,
$\sigma(L)$ = standard deviation per period. (Olhager, 2000, p.230)

What is important to acknowledge with SERV1 is that it does not take the batch quantity into consideration, which according to Axsäter (2006, p.94-95) is a drawback on using this model when calculating an appropriate safety stock. The total probability of stockouts depends on the amount of total number cycles, which in turn is decided by order quantity (Olhager, 2000, p.230).

When using the second service measurement, SERV2, the batch quantity is taken into consideration. The estimated size of a stockout is first calculated during an order cycle.

$E[stockout] = \int_{SS}^{\infty}(x - SS)\frac{1}{\sigma_L}\varphi\left(\frac{x}{\sigma_L}\right)dx$

Using variable substitution

$z = \frac{x}{\sigma_L}$

the following formula can be obtained;

(Eq. 4.35)

$$E[stockout] = \int_{SS}^{\infty}(\sigma_L z - SS)\varphi(z)dz = \sigma_L\varphi\left(\frac{SS}{\sigma_L}\right) - SS\left(1 - \Phi\left(\frac{SS}{\sigma_L}\right)\right)$$

In order to obtain the fraction of demand that can be delivered immediately from stock, this stockout should be related to the demand during one order cycle which is the same as the batch quantity Q. The service measurement SERV2 can thereby be derived as;

(Eq. 4.36)

$$SERV2 = 1 - \frac{E[stockout]}{Q}$$

where the safety stock can be decided from a given service level and batch quantity. (Olhager, 2000, p.230)

Figure 4.7 illustrates how a safety stock affects inventory levels for a constant demand.

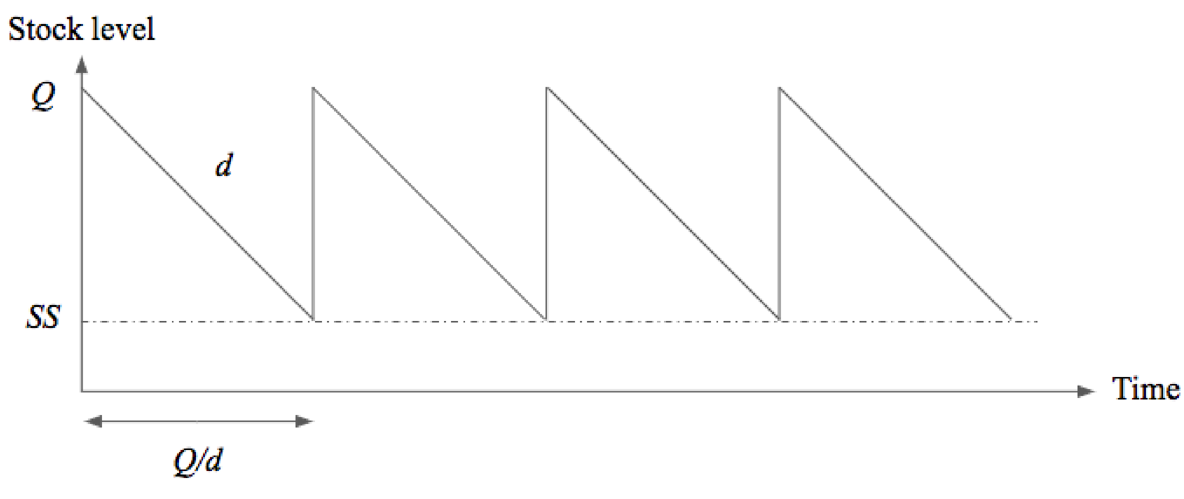

Figure 4.7. Illustration of a safety stock for an inventory with constant demand (Olhager, 2000, p.321)

4.10. Reorder point modeling

When considering reordering policy for an inventory control system, this can be designed to be either continuous or periodic review. A continuous review will trigger an order depending on the inventory position. The triggered order will be delivered after a specific lead time, denoted as L.

Periodic review, however, only considers the inventory position at specific time periods, with a set time period T between the reviews. This causes less administrative work, but greater risks of out-stocks than a continuous review which leads to a higher safety stock that needs to be kept when only considering periodic review. (Axsäter, 2006, p.47)

4.10.1. (R, Q) policy

By using the (R, Q) policy, an order of size Q is triggered when the inventory position declines to or below the reorder point R. The inventory position is not affected by the lead time L, whereas the inventory level can move as illustrated in Figure 4.8. The (R, Q) policy is applicable for both continuous review and periodic review. In case of continuous review, the reorder point will be hit quite precisely and that also applies for continuous demand. The reorder point will be reached exactly. In terms of periodic review or if the triggered point depends on multiple units, the inventory position usually falls below the reorder point R. That is because this policy considers inventory level depending on time intervals, why the level more commonly falls below the reorder point. When this occurs, inventory position R+Q will not be reached since the starting point is lower. Further, the (R, Q) policy mainly applies when an order consists of multiple batch quantities. (Axsäter, 2006, p.48)

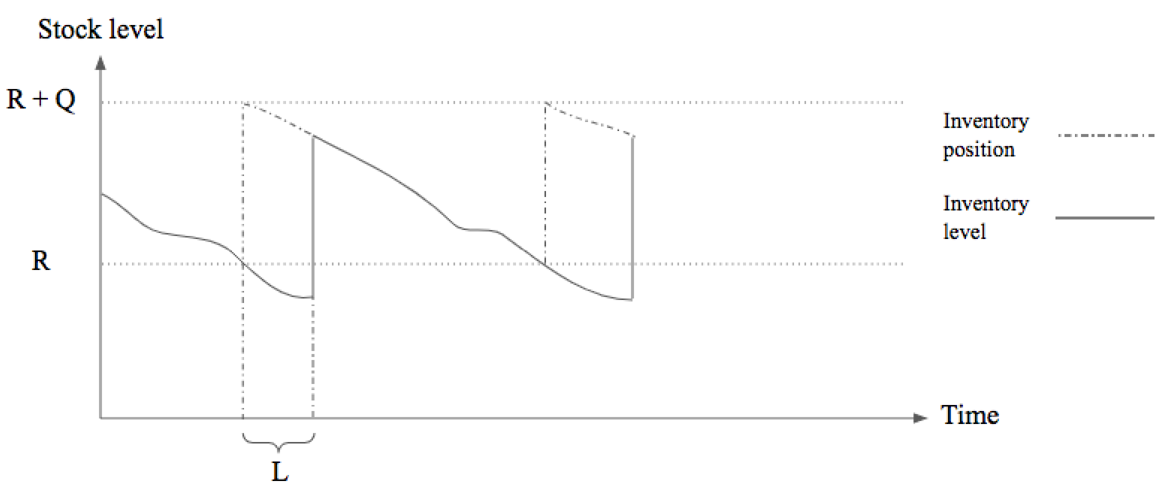

Figure 4.8. Illustrating an (R, Q) policy (Axsäter, 2006, p.48).

The reorder point R can be calculated through Equation 4.37, where $x_L$describes the mean demand during lead time of replenishment. (Olhager, 2000, p.231)

(Eq. 4.37)

$$R = SS + \bar{X}_L$$

4.10.2. (s, S) policy

For an (s, S) policy, an order is triggered by the reorder point, *s*. In this case, *s* is the reference point instead of *R* that applies to the (R, Q) policy. Capitol *S* refers to the maximum level to order up to after the inventory position has declined to or below *s*, illustrated in Figure 4.9. The (s, S) policy differs from an (R, Q) policy since it cannot be applied when ordering multiples of a given batch quantity. The (s, S) policy does not require any specific inventory position in order to trigger an order, it instead builds on ordering up to S independent of the inventory position. The S policy also enables immediate ordering of the demanded number of units, but in that sense, it is usually denoted (S-I, S) policy. Comparing the two policies against each other, the (R, Q) policy is in general easier to use in practice, preferably with fixed batch quantity. (Axsäter, 2006, p.49)

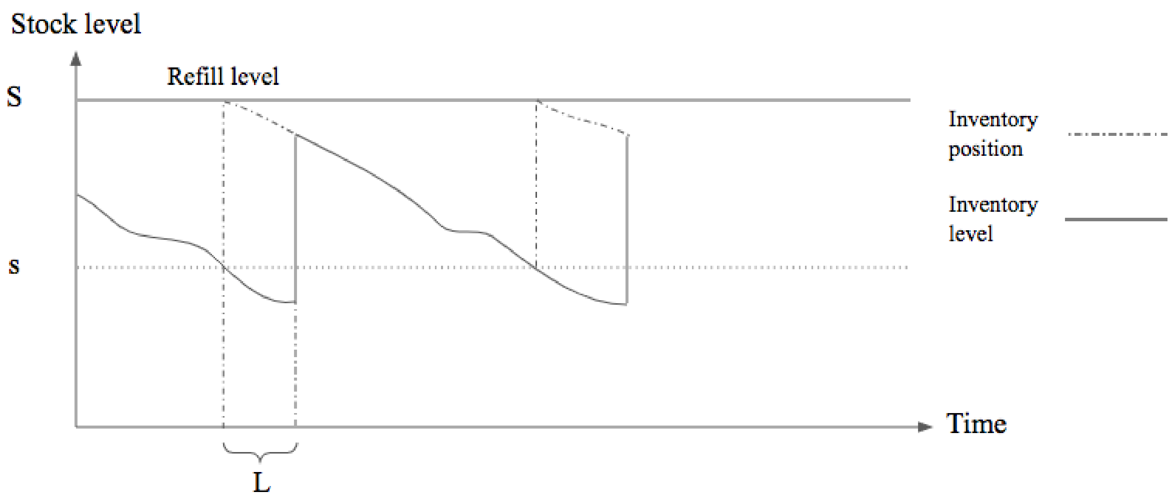

Figure 4.9. Illustrating a (s, S) policy where S is the maximum refill level (Axsäter, 2006, p.50).

4.11. Synchronized replenishment

4.11.1. Periodic order system

If the order frequency is performed during specific periods and determined by periodic review of inventory levels, the policy is called a periodic order system. Order quantity is based upon a specific level of refill taking following inventory parameters into account; the sum of safety stock, demand during lead time and demand during an inspection interval. Complexity arises along the supply chain, meaning that specifications and policies differ depending on actors and position in the supply chain. The inspection intervals should be adjusted according to feasible production cycles both taking suppliers and the actual production entity into consideration. In terms of the safety stock, it should cover demand uncertainty during lead time as well as during the inspection interval. (Olhager, 2000, p.233-234)

Inspection intervals can be decided taking two aspects into consideration:

- Adjustment of production intervals according to supply entity
- Translation of economic order quantity to time between orders

When the periodic order system applies for raw material planning, external actors are normally responsible for the supply part. It is thus feasible to synchronize order intervals according to the suppliers' production points.

Production intervals can also be calculated by translating the economic order quantity into time units.

(Eq. 4.38)

$$I = \frac{EOQ}{\bar{D}} = \sqrt{\frac{2A}{HD}}$$

I= Specific inspection interval
$\bar{D}$= Average demand during specific time interval

In the periodic order system, the average order quantity is converted to expected demand during the specific inspection interval. (Olhager, 2000, p.233-234)

4.11.2. Cyclic purchasing

Cyclic purchasing is a process where the objective is to order less frequently and to reach benefits from coordinated transportation between the production company and suppliers. It is mainly based upon coordinating purchasing activities to benefit from synchronized material flow.

$$Minimizing\ C = \sum_{i=1}^{n} \left(A_i \frac{1}{I} + H_i \frac{D_i I}{2} \right)$$

A_i= Order set-up cost
H_i= Inventory carrying cost
D_i= Production demand per time unit for article i
I= Inspection and order interval

By deriving the formula with respect to decision parameter I, the minimum cost can be calculated. Derived formula for parameter I is presented below;

(Eq. 4.39)

$$I' = \sqrt{\frac{2\sum A_i}{\sum H_i D_i}}$$

Periodic order system is characterized by keeping a constant time between orders, which is suitable if certain lead times are required or if the aim is to synchronize supplier procurement. (Olhager, 2000, p.234)

4.12. Supply chain risks

Risks and uncertainties in the supply chain are rarely avoidable, and research suggests that the appearance of these varies depending on the nature of products. Products with a stable demand which thus becomes easier to predict are, according to Fisher 1997, *defined as functional products* while the opposite demand characteristics apply for *innovative products.* Theory emphasizes the importance of considering the nature of products when assessing potential risks that may occur on the journey from extraction of raw material to eventually become finished goods. Theory suggests that key variables driving uncertainties in the supply chain are demand and supply related to the product (Lee, 2002; Fisher, 1997). Consequently, factors that impact supply risks are e.g product availability, number of available potential suppliers and geographic distance (Van Weele, 2009 p. 163), while risks associated with product demand considers the outbound flow i.e. demand variability, new product adoptions or short product life cycles (Johnson, 2001, p.110-112). Addressing the operational criticalities that may arise from disrupted supply chains, Simatupang and Sridharan (2005) suggest contributors that drive uncertainties. Continuously, they suggest that indicators of inefficient operations involve task duplication, long lead time, excessive/insufficient stock and distorted information, whilst pricing distortion, unnecessary inventory costs and risk pooling pertain to commercial inefficiencies. Figure 4.10 illustrates a generalized breakdown of risk elements associated with supply, operations and demand in the value chain.

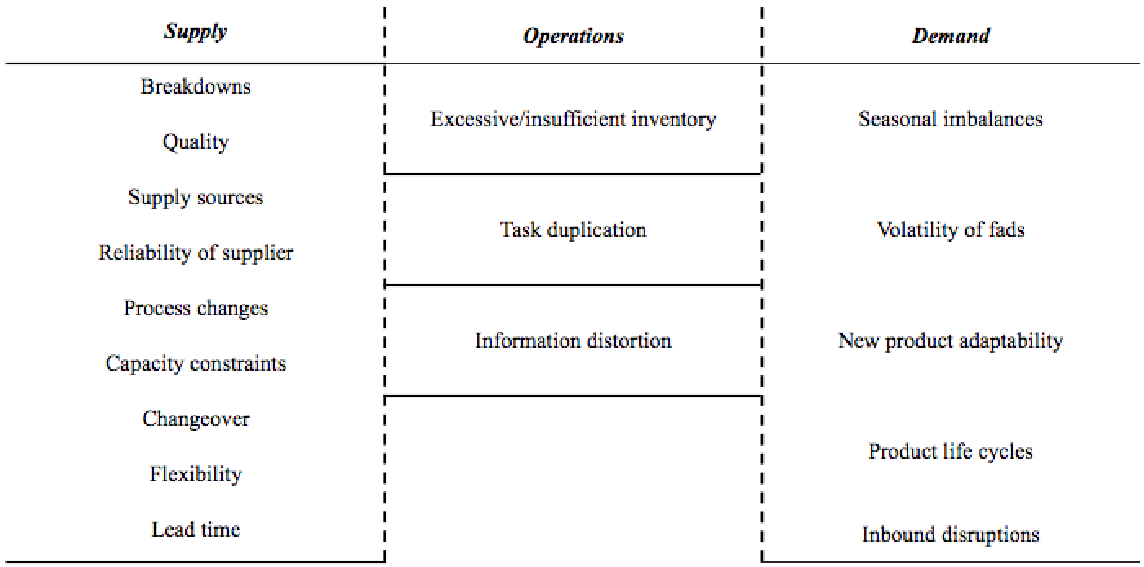

Figure 4.10. Supply chain risks (Simatupang and Sridharan, 2005; Lee, 2002; Fisher, 1997).

The importance of risk mitigation and assessment is addressed in a research article by Simatupang and Sridharan (2005). The study suggests that supply chain discontent between members within the supply chain usually occurs due to misaligned incentives and a lack of mutual business goals, appearing both over internal business units as well as externally over involved players. It is further implied that discrepancies in supply chain processes are caused by members who misunderstand the value of viewing the supply chain as a whole rather than focusing on local optimization. Consequently, fragmented intercompany/supply chain business processes commonly contribute to wastes in the supply chain which lead to poor profitability.

Supply chain risks can further be assessed through the risk matrix, which measures impact and probability of an identified risk. The risk can thereafter be assessed and managed accordingly. Figure 4.11 shows a typical risk matrix, where the red represents major risk level and green minor. (Olhager, 2019)

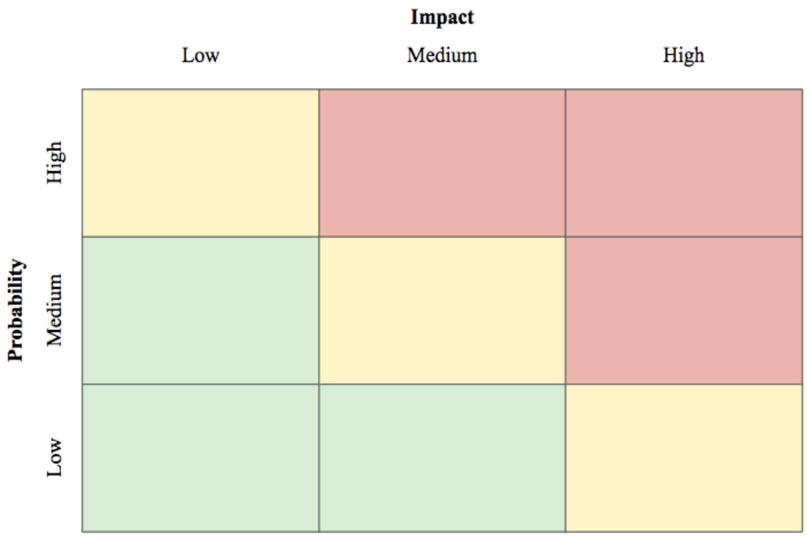

Figure 4.11. Risk matrix (Olhager, 2019).

5. Empirical study of ARPS

The empirical study describes the current situation at depth and will be used for the analysis and recommendation. The data described in this chapter is provided by ARPS, and mainly focuses on historic values over one year. The empirical study covers both quantitative and qualitative data.

5.1. New premises

The new premises will be located nearby ARPS' current facility, in direct connection to Flexibles. There are two available locations where raw materials can be stored;

- Storage next to the printing press - 150 sqm,
- Raw material storage - 50 sqm.

ARPS has expressed a wish of using only the storage next to the printing press to as much extent as possible. Furthermore, there will be a change in the process flow when relocating to the new premises. Instead of sheeting the raw materials in ARPS' production, the rolls will be sheeted at Flexibles and delivered on pallets to ARPS. The palletized version makes it possible to store double stacked, which makes better use of space in comparison to rolls.

5.2. Procurement strategy

Currently, the common factor that serves as foundation for all purchasing activities at ARPS is the aim towards operating as cost-efficiently as possible. Hence, the procurement planning depends greatly on circumstances and requirements set further up the supply chain. However, the previous inventory capacity has put little requirements on ARPS' inventory planning due to the excess space that has been available for storage. ARPS' target has been to not have more raw material in stock than for two months, yet a lower batch price has been prioritized, i.e. quantity discounts. Thus, the collaboration between ARPS and Flexibles has proceeded without complications, seeing that both parties' interests have been mutual. Flexibles has been able to deliver large quantities and ARPS has received a favorable price. What has not been taken into consideration is the cost tied up in inventory and risks this strategy results in, which proves to be a potential problem when relocating to new premises with a size of about one third of the original ones.

5.3 Process flow analysis

5.3.1. Process flow scheme

Figure 5.1 presents the process flow for the value chain of the raw materials, from receiving at Flexibles to out-loading from ARPS to customers. This gives an overhead picture of the value-adding steps the components relevant for this master thesis goes through.

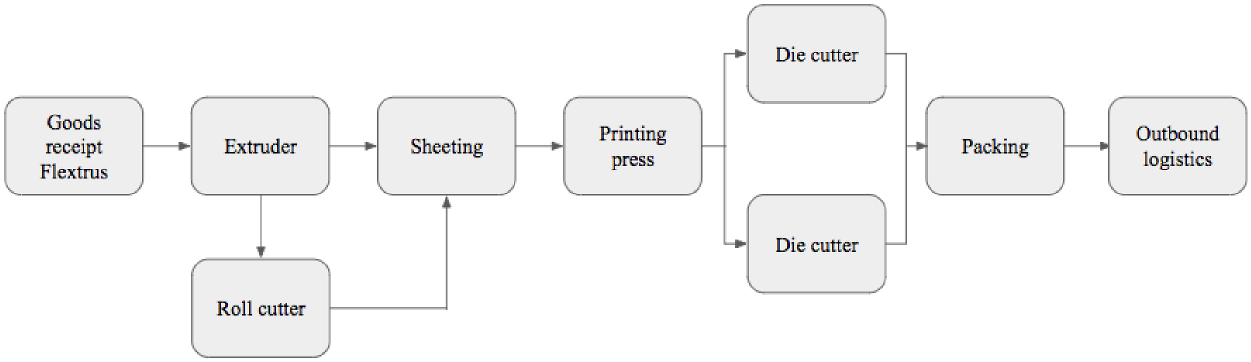

Figure 5.1. Process flow scheme for the value chain of relevant raw materials.

5.3.2. Material flow scheme

The material flow is presented in Figure 5.2. Flexibles provides ARPS with raw materials every week, and depending on the size of the delivery, it can take from one day up to several days to deliver the whole order. All of the raw materials are currently delivered on rolls except RM5, which is ordered on pallets and already sheeted when delivered. When a customer ordered is laid, the rolls are sheeted and put on pallets by ARPS, where RM1, RM2 and RM4 have two different cut-off lengths depending on component and design. After the sheeting, the materials will go through the printing press which will give the sheets the design assigned by the customer. After the printing press, the sheets go through a die cutter. Depending on the shape each component is supposed to have, different amounts of units are obtained from each sheet. The components are palletized and sent to the finished goods warehouse before they are sent to the customer. The components are considered by ARPS to be raw materials until they go through the printing press. According to theory, this is not accurate as the sheeted materials should be considered to be WIP-items. However, as this is how ARPS currently defines its process, all material up until the printing press will be considered as raw material and accounted for in this master thesis.

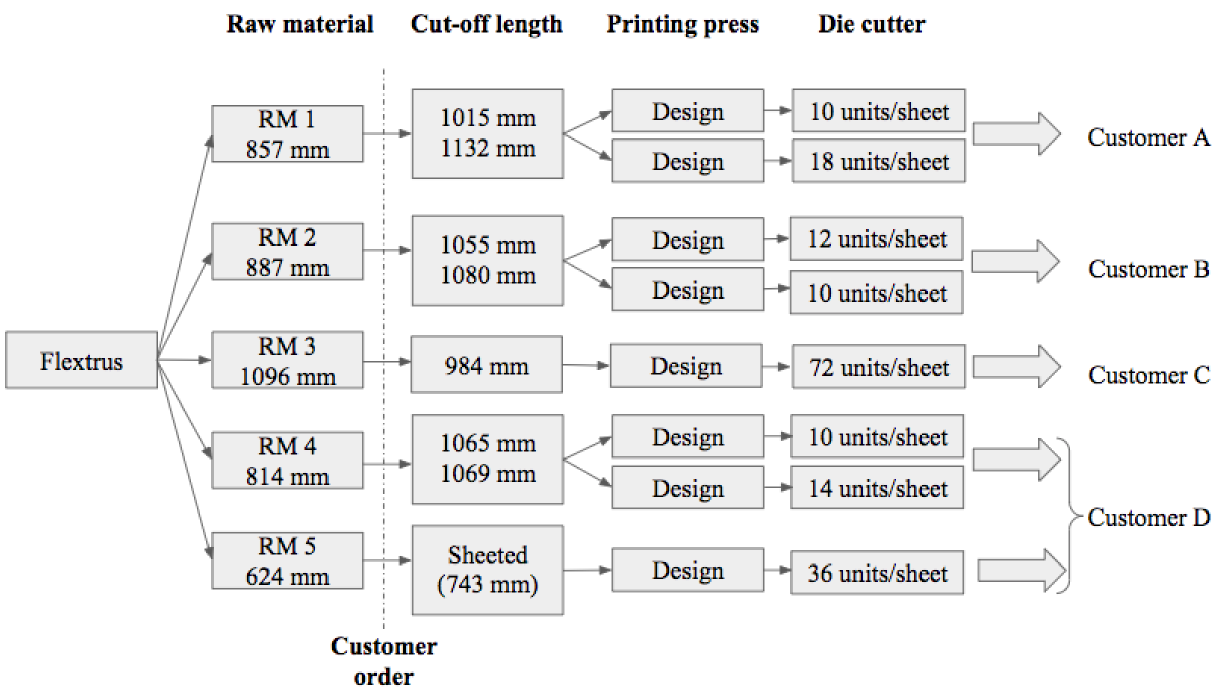

Figure 5.2. Old material flow scheme of the relevant raw materials for this master thesis.

The process described has been the material flow up to this point. When moving to the new premises, the sheeter will be relocated to Flexibles premises and the raw materials will instead be delivered sheeted on pallets. This causes changes in the material flow, as ARPS will have to deal with eight different raw materials instead of five, since the sheeted products have two different cut-off lengths for three of the raw materials. Sheeted materials will hence be defined as the only raw material dealt with. The value-adding processes which will be located within ARPS' premises are the printing press and the die cutter before delivery to customers. The new material flow scheme can be seen in Figure 5.3.

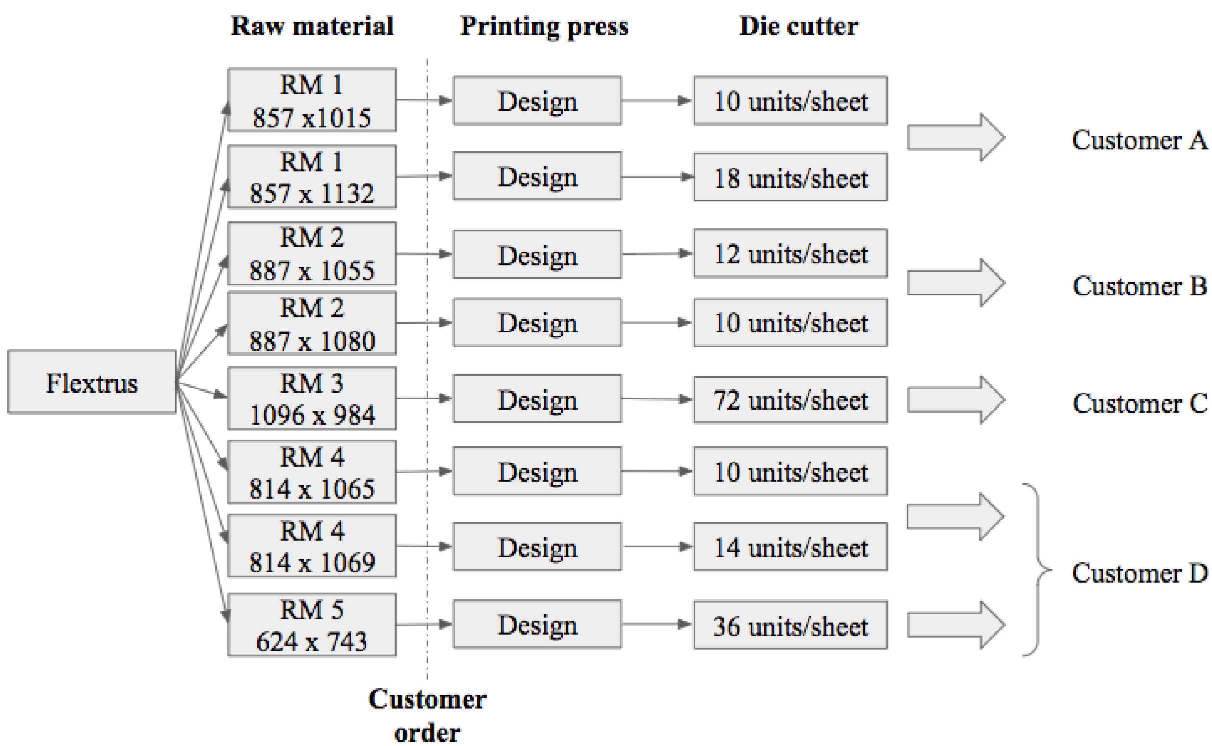

Figure 5.3. New material flow scheme considering the new premises.

5.3.3. Production line characteristics

The material alterations begin in the sheeting machine and are further refined as the value-adding activities proceed. Favorably, the characteristics of this production line supports a frictionless and smooth material flow as the sheeting machine and printing press operates at the same speed. However, the printing press has a somewhat longer set-up time than the sheeter, as a production run of one raw material can contain different printing designs. As for the die cutter, it runs at a similar pace as the printing press and sheeter.

The printing press has a given pace of 5 pallets per hour and runs 24 hours per day during the weekdays. Downtime and production errors must although be considered, since it can impede on output. Extra shifts are conducted during the weekends if there would be a need for it.

5.4. Demand pattern and data

ARPS specializes in commodity products with a stable demand. Consequently, these products are less exposed to seasonal patterns or trends that otherwise might cause disruptions in supply chain activities. However, fluctuations are difficult to avoid and especially when forecasting errors commonly occur early in the supply chain. In this case, fluctuations can usually be derived from misjudged planning or sudden changes from the customer side, where orders often are laid ad hoc. The historic demand pattern over the last year can be seen in Figure 5.4. Complementary figures can be seen in Appendix A5, where demand pattern is shown per week for all raw materials separately.

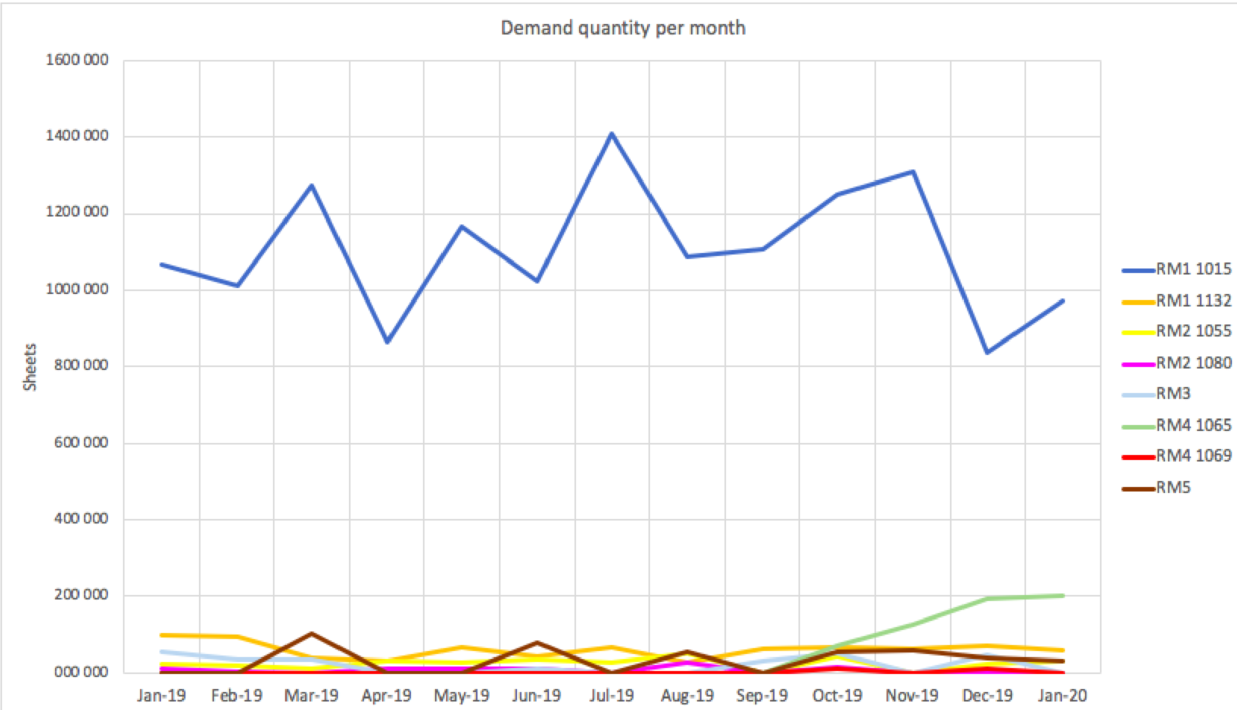

Figure 5.4. Historic values of sheets through printing press, during January 2019-January 2020.

The demand data for each raw material is derived through data from the printing press, as a production order for the printing press is dependent on an order from a customer. Thus, one can see how much material that is refined through the machine and its associated frequency. Table 5.1 shows the average demand data per week, month and year. For historic demand data, see Appendix A2.

Table 5.1 Derived average demand per week, month and yearly from extraction of data from printing press.

Raw Material	**Avg demand per week** *[sheets/pallets]*	**Avg demand per month** *[sheets/pallets]*	**Avg demand yearly** *[sheets/pallets]*
RM1 1015	255 379 / 128,2	1 106 231 / 553	13 331 695 / 6 665,8
RM1 1132	13 897 / 7	61 164 / 30,6	722 647 / 361,3
RM2 1055	5 702 / 2,9	25 002 / 12,5	261 518 / 148,3
RM2 1080	1 654 / 0,8	7 378 / 3,7	85 994 / 43
RM3 984	5 215 / 2,6	20 391 / 10,2	271 201 / 135,6
RM4 1065*	43 078 / 21,5	149 117 / 74,6	2 240 056 / 1 120
RM4 1069*	1 680 / 0,84	6 300 / 3,2	87 360 / 43,7
RM5 743	7 183 / 3,6	37 876 / 18,9	373 536 / 186,8

**RM4 has limited data, causing greater uncertainties in calculations.*

RM1 1015 is by far the material with largest demand volume, produced to Customer A where it represents approximately 77% of the total demand volume. This causes its high frequency in production, where it is produced several days per week, every week. Additionally, RM1 1132 follows a quite similar production pattern as RM1, i.e. approximately scheduled to run every week. According to Ivarsson, RM4 1065 is the third material with constant frequency, where there is a booked slot time for the material every second week. However, historical data implies otherwise, namely that this article runs either more often or seldom. In terms of the remaining raw materials, they are produced in significantly smaller batches and very infrequent. Considering RM4 1069, it is nearly impossible to recognize any production pattern. That is since this article lacks relevant historical data on customers' orders and thus the frequency of which it is produced. There is definitely a need to incorporate more data points in the calculation to better derive information regarding this article. The average time between production runs for remaining raw materials is presented in Table 5.2

Table 5.2. Average time between production cycles. Values derived through data from the printing press.

Raw Material	Time between production runs
RM1 1015	Every week
RM1 1132	Every week
RM2 1055	3,5 weeks
RM2 1080	5,9 weeks
RM3 984	4,9 weeks
RM4 1065	1,8 weeks
RM4 1069*	--
RM5 743	7,4 weeks

**Not enough data points for RM4 1069 to calculate a frequency.*

Every sheet has a number of units per sheet which is extracted through the die cutter before delivered to customers, see Table 5.3. The raw materials ordered on a roll have a material length of 4000 m. Using the known cut-off lengths, the number of sheets obtained from one roll is derived. Through calculating the number of units per sheet the number of finished components per roll and pallet can be obtained, see Appendix A3.

As this master thesis focuses on the control of raw material, demand in unit measures is neglected, but could easily be translated if so wished.

Table 5.3. Units per sheet obtained through the die cutter.

Raw Material	Units per sheet
R1 1015	10
R1 1132	18
R2 1055	12
R2 1080	10
R3	72
R4 1065	10
R4 1069	14
R5	36

In order to calculate the setup waste for each material, the average size of one job order is calculated for each raw material. Firstly, the average setup waste from the sheeter and the printing press can be assumed as a total of [redacted] sheets per job order. Additionally, [redacted] per roll is thrown away as the [redacted] layers of each roll are removed due to hygiene reasons. These [redacted] layers account for approximately [redacted] waste per roll. All pallets are assumed to contain 2000 sheets per pallet. The total setup waste per raw material can thus be seen in Table 5.4, where consideration is taken both to the waste of two layers per roll and the setup waste. For more detailed information, see Appendix A.4.

Table 5.4. Total setup waste per raw material.

Raw Material	**Total setup waste**
R1 1015	[redacted]
R1 1132	[redacted]
R2 1055	[redacted]
R2 1080	[redacted]
R3	[redacted]
R4 1065	[redacted]
R4 1069	[redacted]
R5	[redacted]

5.5. Forecasting

ARPS receives annual forecasts from their customers which they share with Flexibles. These forecasts contain information about the estimated customer demand for a whole year. Monthly updates are received from Customer A and Customer C, while the remaining system customers do not send any updated information. Mentioned forecasts are seldom trustworthy, why ARPS themselves make approximate forecasts for their largest customer, Customer A. Replenishment of raw material from Flexibles is done based on these forecasts, but the manufacturing of components is not done until an order is final. However, as the orders from Flexibles cannot be altered later than 4 weeks before delivery, demand variability can be problematic. That is e.g. if the customer needs much larger or less quantities than anticipated. Also, Flexibles ability to respond to order alterations depends on if they have sufficient amounts of raw materials in their own pipe. Consequently, it seems to be a lot of potential to develop a better, more standardized and efficient forecasting method for ARPS to use internally.

5.6. Inventory characteristics

5.6.1. Inventory levels

Each roll is approximately 1900 mm in diameter. As materials before the printing press currently concerns both rolls and sheeted material, the storage area each material occupies through either of these alternatives needs to be calculated. The rolls are not stored on pallets, which the sheeted material is. Calculations for the dimensions of both rolls and sheeted materials can be seen in Table 5.5.

Table 5.5. Dimensions for raw materials.

Raw Material	**Roll size** *[sqm]*	**Dimensions per sheet** *[mm]*	**Sheet size** *[sqm]*	**Pallet size** *[sqm]*
RM1 1015	1,63	857 x 1015	0,87	0,89
RM1 1132	1,63	857 x 1132	0,97	1,4
RM2 1055	1,69	887 x 1055	0,94	1,4
RM2 1080	1,69	887 x 1080	0,96	1,4
RM3	2,08	1096 x 984	1,08	1,4
RM4 1065	1,55	814 x 1065	0,87	1,4
RM4 1069	1,55	814 x 1069	0,87	1,4
RM5*	-	624 x 743	0,46	0,49

**Ordered sheeted on pallets.*

Figure 5.5 shows weekly snapshots of the inventory levels in storage space for the considered items before the printing press. As the data are only snapshots per week, values for maximum, average and minimum inventory could potentially be different. The inventory levels cover, as stated before, both raw materials on rolls and sheeted material on pallets.

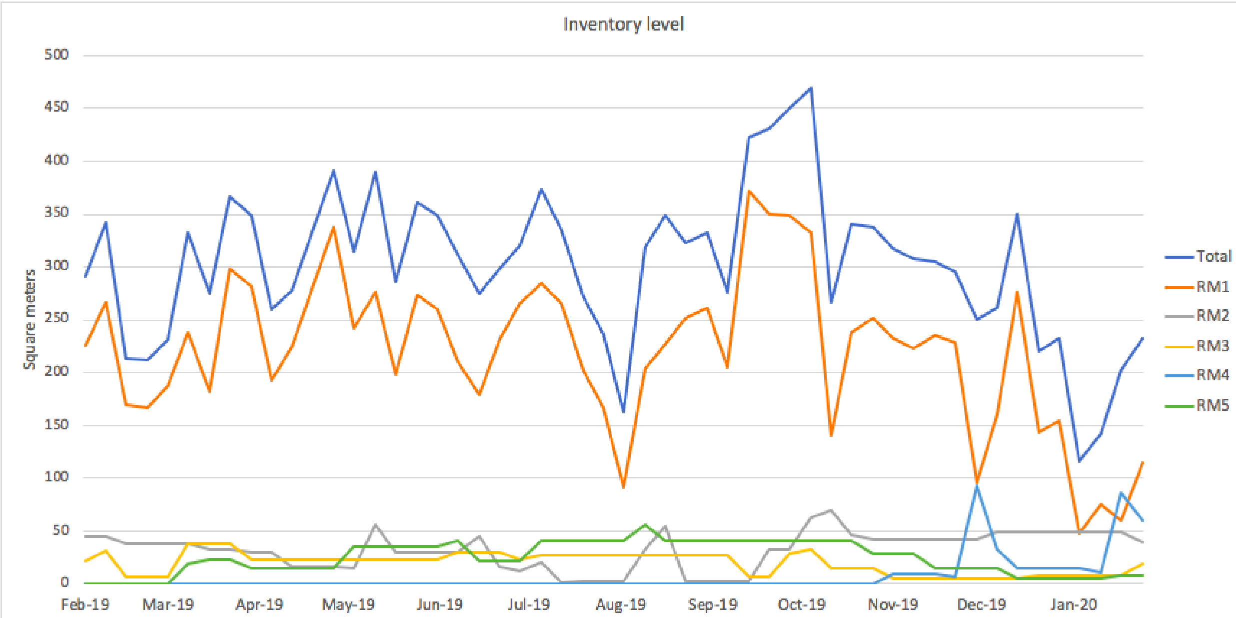

Figure 5.5. Storage space used in sqm for raw material from 2019-02-02 until 2020-01-25.

From Figure 5.5 it is obvious that inventory levels for RM1 has by far the largest impact on the total inventory levels, which is expressed in Table 5.6 in square meter (sqm). For these calculations it has been assumed that no inventory is double stacked, which in reality can be done for sheeted materials.

Table 5.6. Maximum, minimum and average inventory over the period between 2019-02-02 until 2020-01-25.

Raw Material	**Min space** *[sqm]*	**Max space** *[sqm]*	**Average space** *[sqm]*
RM1	47,5	372,5	219,5
RM2	1,5	69,2	32,4
RM3	4,8	37,6	19,1
RM4*	6,5	93,2	29
RM5	4,9	55	27,1
Total	**116,3**	**469**	**302**

**Values during the period 2019-02-02 until 2019-10-26 are not accounted for in the calculations for RM4 as there is no data for this period.*

5.6.2. Inefficiencies in storage

The current palletized material causes inefficiencies in usage of space. This inefficient usage has previously not been considered, but with limited storage space, this matter becomes of greater importance. Table 5.7 below illustrates with red or green color how effective the pallets are used.

Table 5.7. Inefficiencies in storage space from palletizing.

Raw material	**Sheet Dimensions** *[mm]*	**Pallet dimensions** *[mm]*	**Pallet space not used**
RM1 1015	1015x857	1020x870	2%
RM1 1132	1132x857	1400x1000	30,7%
RM2 1055	1055x887	1400x1000	33,2%
RM2 1080	1080x887	1400x1000	31,6%
RM3	984x1096	1400x1000	23%
RM4 1065	1065x814	1400x1000	38,1%
RM4 1069	1069x814	1400x1000	37,9%
RM5	743x624	750x650	4,9%

The first and last pallet has already been optimized by ARPS and has great space usage why these cells are colored as green. However, approximately one third of the remaining pallets are used inefficiently, which causes waste in storage and are thus colored with red for better visualization. As ARPS exchange their pallets often due to high food security and hygiene reasons, this inefficiency in storage could easily be eliminated.

5.6.3. Safety stock

ARPS try to always satisfy their customer’s needs, and especially Customer A due to them being the largest customer. They are therefore dependent on keeping a good relationship between one another. Consequently, ARPS has set a target of always having 1-1,5 weeks in safety stock toward Customer A. This is not a calculated reference, but has been set by ARPS as a reasonable stock level for being able to meet demand fluctuations experienced from Customer A.

The new premises will cause a change in material flow and require that procured materials arrive palletized rather than on rolls. It is thus interesting to translate what space the current policy for safety stock would need. Table 5.8 is a compilation of only RM1 and the storage space that would be required to cover for a safety stock of 1-1,5 weeks.

Table 5.8. Values for RM1 when having 1-1,5 weeks of mean demand in safety stock.

Safety stock	**Storage space** *[sqm]*	**Pallets**	**Sheets**
1 week	114,5	128,2	256 379
1,5 weeks	171,7	192,3	384 568

As Customer B, C and D have significantly lower yearly demand than Customer A, the only expressed safety stock in place is having a stock covering a monthly mean demand, see Table 5.9. The storage space is calculated through the pallet sizes that correspond to each raw material, where all articles are assumed to be palletized and not on rolls for simplistic reasons.

Table 5.9. Safety stock, average demand per month for RM2-RM5.

Raw Material	**Storage space** *[sqm]*	**Mean demand per month** *[sheets/pallets]*
RM2 1055	18,2	25 002 / 12,5
RM2 1080	5,6	7 378 / 3,7
RM3	15,4	20 391 / 10,2
RM4 1065	105	149 117 / 74,6
RM4 1069	5,6	6300 / 3,2
RM5	9,3	37 876 / 18,9
Total	**159,1**	

The total safety stock requires 273,6 sqm in efficient storage space for a safety stock of 1 week for RM1, and 330,8 sqm in the case of 1,5 weeks.

5.6.4. Stock turnover rate

In order to calculate the turnover ratio for raw materials, ARPS uses the following formula:

$$\frac{3\ months\ of\ average\ RM}{3\ months\ of\ average\ DM * 12} \cdot 365\ =\ Turnover\ ratio\ for\ RM \qquad (Eq.\ 5.1)$$

Where RM is denoted as Raw Materials and DM as Direct Material, which means consumption. Data from the printing press is also now used as values for consumption. The values are expressed in stock value, SEK.

Given the historic demand data and inventory levels, the turnover rate can be derived which is calculated in Table 5.10.

Table 5.10. Historic turnover ratio calculated through Equation 5.1 from 2019-01-01 until 2020-01-31.

Raw Material	**Monthly avg stock RM** *[SEK]*	**Monthly avg stock DM** *[SEK]*	**3 months avg stock RM** *[SEK]*	**3 months avg demand DM** *[SEK]*	**Turnover rate** *[days]*
RM1	4 964 025	11 938 935	14 892 076	31 422 272	14,4
RM2	541 521	343 494	1 624 563	1 030 483	48
RM3	343 059	212 857	1 029 178	638 570	49
RM4*	606 632	832 643	1 819 897	2 497 929	22,2
RM5	513 606	185 148	1 540 818	555 444	84,4

**RM4 lacks sufficient data for an exact analysis.*

5.7. Cost parameters

5.7.1. Stock value

Figure 5.6 shows weekly snapshots of the inventory tied-up capital for approximately one year in raw material. However, this is not entirely accurate if one is considering only raw materials. That is because ARPS defines all items in stock before the printing press as raw material, even though value adding activities occur in earlier steps, which contradicts theoretical suggestions. This includes both items delivered directly from Flexibles as well as items that ARPS sheet themselves, which reasonably rather would be defined as WIP-items.

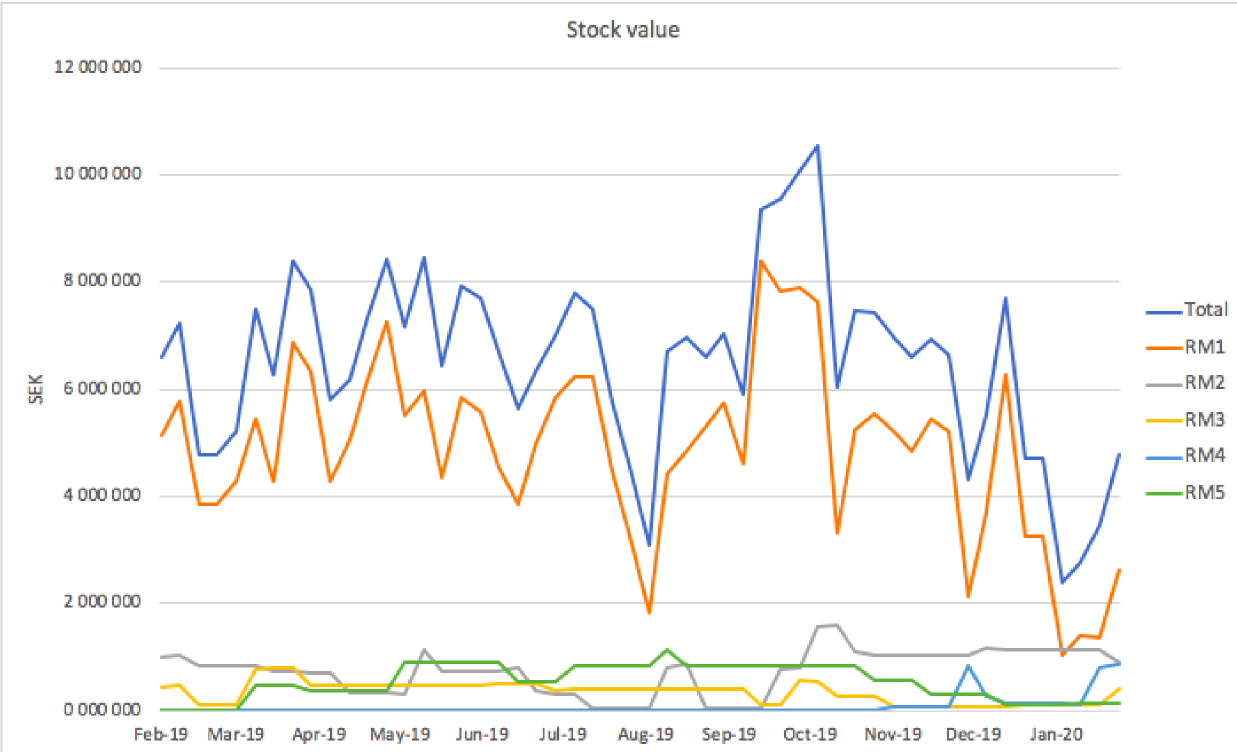

Figure 5.6. Inventory tied-up capital in stock during the time period between 2019-02-02 and 2020-01-25.

ARPS have defined the stock value through following formula;

$$Stock\ value\ roll\ =\ procurement\ cost\ \cdot\ exchange\ rate$$

The exchange rate is set to the specific value it is defined to the date of the procurement.

For pallets, the rolls have been refined by the sheeter which is seen as a value-adding process. The value of this processing is added upon the stock value and is based on ARPS' perspective the cost for refining raw materials in the sheeter. The material in itself is not of more value than before, but in order to sheet the rolls, there will be a cost from the machine and workers. This cost is called conversion cost.

$$Stock\ value\ pallet = \ procurement\ cost\ \cdot\ exchange\ rate\ +\ conversion\ cost$$

Stock value is defined in SEK.

The tied-up capital will fluctuate depending on inventory level. Minimum, maximum and average tied-up capital for respective raw material can be seen in Table 5.11.

Table 5.11. Fluctuations of tied-up capital in inventory for different raw materials.

Raw material	**Min tied-up capital** *[SEK]*	**Max tied-up capital** *[SEK]*	**Avg tied-up capital** *[SEK]*
RM1	1 038 716	8 389 994	4 877 744
RM2	23 717	1 591 828	730 710
RM3	71 951	784 684	340 006
RM4*	57 915	872 288	284 809
RM5	101 352	1 117 730	589 246

**Values during the period 2019-02-02 until 2019-10-26 have not been accounted for RM4 as there is no data on stock levels for this period.*

Table 5.12 gives a better picture the total inventory value, describing fluctuations through max, min and average tied-up capital.

Table 5.12. Tied-up capital in total inventory.

Min tied-up capital *[SEK]*	**Max tied-up capital** *[SEK]*	**Avg tied-up capital** *[SEK]*
2 399 599	10 552 748	6 533 831

5.7.2. Inventory carrying cost

When deciding the inventory carrying rate r, this percentage depends highly on the nature of the producing company. ARPS is a middle-sized company with low obsolescence and long shelf life for their products, which could argue for a lower carrying rate. However, considering the nature of products in storage, this number is suggested by ARPS to be increased. As the products are voluminous and in ratio to their volume, have a low value, ARPS suggests that a carrying rate of 20% should be used. The value unit cost v will be based on ARPS' own calculations for stock value, see section 5.6.1 where min, max and average values are calculated in Table 5.13.

Table 5.13. Minimum, maximum and average carrying costs in raw material before printing press.

Min carrying cost *[SEK]*	**Max carrying cost** *[SEK]*	**Avg carrying cost** *[SEK]*
479 920	2 119 550	1 306 766

5.7.3. Ordering cost

The ordering cost, which only are the costs directly related to an order, have been defined by ARPS as 30€ per order, which in this master thesis will be converted to 300 SEK for simplicity. No regards will be taken to fluctuations in exchange rate.

5.7.4. Shortage cost

ARPS do not have any direct shortage penalties in their contracts with their customers but are keen on having a high service reliability at 99%. ARPS also replaces costs that can be incurred for the customer if the delivery from ARPS fails to meet the contract agreement. That could for example be material shortages or delayed deliveries, which could possibly result in food going to waste at the customer site. As ARPS has a high focus on maintaining a good relationship with their customers, they occasionally cover other costs that the customer may incur due to late deliveries.

5.7.5. Price lists and quantity discounts

As Flexibles deals with relatively high production set-up costs, this results in a wish of selling larger batches to ARPS. Consequently, Flexibles will give quantity discounts for ordering larger quantities, resulting in a lower cost per unit. These quantity discounts have a greater impact on RM2-RM5, as RM1 is already ordered in very large quantities. The present quantity discounts decrease at an exponential degree, where the alterations for smaller quantities cause greater differences in price per unit than for alterations with larger quantities.

Appendix A1 illustrates how the price per unit declines exponentially as the volumes increase, until reaching a quantity when the price setting has smaller changes. This point is reached when the curve starts to flatten. Figures in Appendix A1 yield a price per sheet, with the minimum batch quantity demanded in order to get this price.

The complexity of supply chains is present while considering optimal order sizes, taking different perspectives and parameters into account. In this specific case, ARPS can be defined as the third tier from a total value chain perspective, while Flexibles is the second and in turn has their supplier of raw material to consider. Consequently, one critical factor that limits the order sizes, and thus affects the price structure, is the actual impact of the first player in the supply chain. Being that Flexibles must adapt according to the production cycles of their suppliers, resulting in less flexibility in their procurement strategy. One additional aspect is the nature of these products that are dealt with. Carton and paper-based products imply bigger volumes and thus larger batches.

The capability of squeezing down order sized for ARPS remains critical and problematic since their offerings from Flexibles, in turn, are dependent on the batch sizes they receive. If Flexibles are offered volume discounts from their supplier, this pricing structure applies for ARPS as well.

5.7.6. Change in price lists

Since the raw material will be delivered on sheets rather than rolls when relocating to new premises, there will be a change to earlier price lists. This change is calculated through the average conversion cost for sheeting per raw material, see Table 5.14, and added to the original ordering cost.

Table 5.14. Average conversion cost for sheeting per raw material.

Raw Material	**Cost for sheeting** *[SEK/1000 sheets]*
RM1 1015	370,9
RM1 1132	411,6
RM2 1055	404,8
RM2 1080	409,2
RM3	336,7
RM4 1065	342,3
RM4 1069	342,3
RM5	Delivered on pallets

5.8. Characteristics of supplement

Flexibles has one dedicated machine for ARPS, where ARPS represents approximately 80% of the demand of produced materials. As Flexibles has limited storage area, the finished materials produced for ARPS are consequently transferred from Flexibles premises to ARPS' simultaneously with the production. Therefore, can deliveries from Flexibles take place several days a week for some of the raw materials where larger batches are produced.

The frequency between delivery and average batch sizes can be seen in Table 5.15. Values are approximate as they are average but can however figure as guidelines.

Table 5.15. Approximate values for frequency per delivery and batch sizes.

Raw Material	**Avg frequency per batch delivery** *[weeks]*	**Average batch size per delivery** *[running meters/rolls]*
RM1	1	214 468 / 53,6
RM2	7,5	69 786 / 17,5
RM3	6	45 000 / 11,3
RM4	2,3	105 279 / 26,3
RM5	5,6	50 600 / 25,3*

**[sheets/pallets]*

RM1 is the most produced raw material out of the five different raw materials. Hence, supplements from Flexibles arrive weekly and the arrivals can span over several days. The aim is to have the raw material delivered from Flexibles the week before it is planned to go into production.

The lead time for an order from Flexibles, from ordering point to delivery, can be assumed as 10-12 weeks. The order size can be altered up to 4 weeks until delivery, but to what extent depends on Flexibles possibility to alter considering their own inventory and production planning. However, it is estimated that an order can be changed approximately 10-20% in volume up to 4 weeks before delivery. Correspondingly, the double amount 8 weeks before delivery.

Flexibles receives a stable inflow of raw materials i.e. carton rolls, that is dedicated for ARPS, which is stored approximately one to three days before being ready to enter the production. This is due to certain material conditions that must be considered before it is being processed, e.g. long shipping activities makes the temperature drop whilst it must recover before entering production.

A breakdown of raw material components from Flexibles to ARPS results in three elements that are carton, PE plastic film and aluminum. These three components are assembled in one dedicated machinery specifically for materials ordered by ARPS.

Flexibles' machinery has the capacity to produce 2,5 finalized rolls per hour which indicates 60 rolls per day if production runs frictionless, which can be assumed to be roughly 120 pallets. Pace-wise, production speed at Flexibles fits well with production at ARPS, being that the outputs from sequential machinery correspond with one another. That is since production capacity for the sheeting machine, which is the next operation the components enter, has larger capacity than the previous operator. Consequently, the internal flow from Flexibles to ARPS should be possible to run in time without intermediary stock keeping.

A potential barrier for smooth information exchange between Flexibles and ARPS is their different IT-Systems. ARPS uses Radius as an ERP-system and Flexibles uses SAP.

6. Analysis

This chapter will provide a deeper analysis on how the theoretical framework is applied on ARPS from the empirical findings. The analysis is modeled with three different propositions, where a conclusion and recommendation will be based on these and their yielding.

6.1. Process flow

The new process flow causes changes in the material flow scheme which results in greater risks and insecurities associated with the material flow. Since the materials will already be refined into sheets when delivered to ARPS, and not be delivered on rolls, this results in eight different raw materials that will need to be ordered and controlled instead of five. As ARPS intends on keeping a service level at 99%, this puts tough requirements on forecasting and control of inventory in relation to demand. However, the palletized material is more efficient to store than rolls, which is beneficial considering the new limited storage area. With the new material flow it becomes even more urgent for ARPS to gain greater control and accuracy over their inventory levels and replenishment of raw materials. Especially so when considering the new storage constraint.

6.2. Setup waste

As the calculated setup waste is very small, it can presumably be neglected. The setup waste is therefore not accounted for in all further calculations.

6.3. Storage optimization

6.3.1. Storage strategies

In order to maximize the usage of the storage space available, it is recommended for ARPS to use shared storage with zones. Thus, will the space assigned for the raw materials serve as one zone, with random storage within the zone.

The assigned storage space accounts for a total of 200 sqm which can be double stacked, resulting in 400 sqm. However, due to lost space between stacked pallets, it is reasonable to assume that less than 100% of available space will be of effective use. In calculations it is thus assumed that 10% of the total space is unavailable which ultimately renders a total space of 360 sqm. This assumption is made as dimensions for length and width for the storage area has not yet been decided by ARPS. Triple stacked has not been investigated, as current trucks are not fit for this, but could potentially be updated if ARPS would wish to invest in new trucks.

6.3.2. New sheet and pallet dimensions

As ARPS frequently buys new pallets due to food safety and hygiene, different pallet dimensions could be used without causing any major additional expense for ARPS. Currently, used pallet dimensions cause inefficiencies in storage space. It is therefore suggested that these should be exchanged to new pallet dimensions, where the pallets are adapted to the dimension of the sheets in a more optimized way. See Table 6.1 for such a suggestion, where Ivarsson has certified that such pallet dimensions would be feasible.

Table 6.1. Suggestion of new pallet dimensions.

Raw material	**Sheet Dimensions** *[mm]*	**Pallet dimensions** *[mm]*	**Pallet space not used**
RM1 1015	857 x 1015	870 x 1020	2%
RM1 1132	857 x 1132	1200 x 900	10,2%
RM2 1055	887 x 1055	1200 x 900	13,4%
RM2 1080	887 x 1080	1200 x 900	11,3%
RM3	1096 x 984	1200 x 1000	10%
RM4 1065	814 x 1065	1200 x 900	19,7%
RM4 1069	814 x 1069	1200 x 900	19,4%
RM5	624 x 743	750 x 650	4,9%

However, while the analysis was developed, new information was provided regarding the relocation for ARPS. Namely that new production machines will be acquired which consequently will require new sheet dimensions. See Table 6.2 for new preliminary dimensions.

Table 6.2. New preliminary sheet dimensions.

Raw material	**New sheet dimension** *[mm]*	**Units per sheet**
RM1 1015	843 x 610	6
RM1 1132	843 x 738	12
RM2 1055	875 x 699	8
RM2 1080	875 x 650	6
RM3	963 x 740	48
RM4 1065	802 x 640	6
RM4 1069	802 x 640	8
RM5	628 x 907	44

The new sheet dimensions will be smaller which results in less units obtained per sheet for all materials but RM5. However, when calculating the ratio of smaller dimensions in comparison to the number of units per sheet, it was found to be quite similar, implying that old calculations are still applicable since the resulting space and demand will be similar.

Table 6.3. Change in ratio of dimensions and units for one sheet.

Raw material	**Change in dimensions** *[%]*	**Change in units per sheet** *[%]*
RM1 1015	41%	40%
RM1 1132	36%	33%
RM2 1055	35%	33%
RM2 1080	41%	40%
RM3	34%	33%
RM4 1065	41%	40%
RM4 1069	44%	43%
RM5	-23%	-22%

However, to be considered is that with smaller dimensions, more pallets will be required where more space will be lost due to space inefficiencies between pallets. This as each pallet demand space between the next one and so on, meaning that more but smaller pallets will demand more space than large and few pallets. However, 360 sqm, which is 90% of maximum storage area, is still assumed to be a feasible storage space to use as an upper storage boundary.

Pallet dimensions have not yet been decided for the new sheet dimensions. However, these should be optimized as much as possible according to the sheet dimensions while striving towards using as few different pallet sizes as possible to reduce complexity.

As new pallet dimensions and unit measures are preliminary, this analysis will use the old dimensions given for the sheets with the new suggested pallet dimensions displayed in Table 6.1, which are optimized according to how it should be future-wise. However, the calculations can easily be redone using the new ratios, which will increase the number of pallets needed in storage and decrease the space each pallet will need equally.

6.4. Demand pattern

The demand pattern is derived from data of quantities through the printing press for each week and from each raw material. Through demand data and standard deviation, the coefficient of variance can be calculated, see Table 6.4.

No values for dates between 2019-12-23 until 2019-12-30 have been accounted for as the production is assumed to be closed between this period.

Table 6.4. Standard deviation and coefficient of variance for all raw materials.

Raw Material	**Mean demand, $\bar{x}$** *[sheets/pallets]*	**Standard deviation, σ** *[sheets/pallets]*	**Coefficient of Variance**
RM1 1015	256 379 / 128,2	86 080 / 43	0,34
RM1 1132	13 897 / 7	13 188 / 6,6	0,95
RM2 1055	5 702 / 2,9	13 207 / 6,6	2,3
RM2 1080	1 654 / 0,8	4 892 / 2,4	2,96
RM3	5 215 / 2,6	11 920 / 6	2,29
RM4 1065	43 078 / 21,5	43 854 / 21,9	1,02
RM4 1069	1 680 / 0,8	4 434 / 2,2	2,6
RM5	7 183 / 3,6	20 675 / 10,3	2,9

6.4.1. Classification according to coefficient of variance

Figure 6.1 illustrates mean demand per week and coefficient of variance for RM1 to RM5. Referencing back to section 4.5.6, one can see that the majority of articles are positioned in Q3. Only RM1 accounts for Q1 where the reference point is set to 0.5 and a weekly demand exceeding 10 000 sheets.

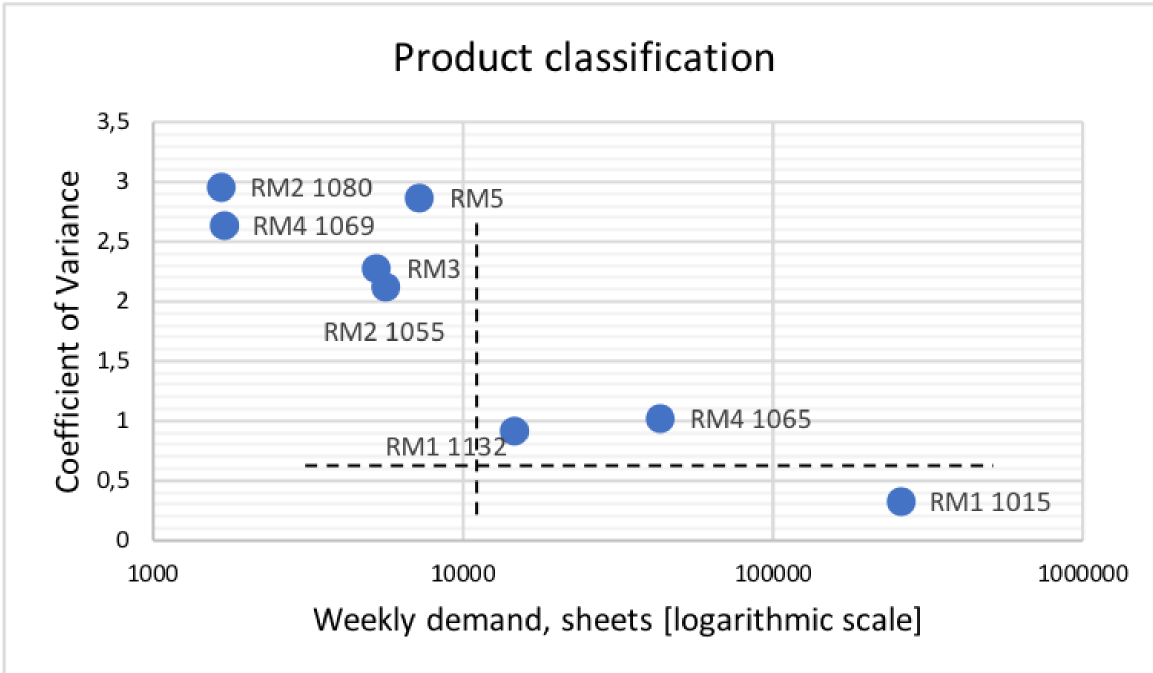

Figure 6.1. Demand variability by coefficient of variance and average weekly demand (sheets).

According to theory, it is only recommended to keep inventory of products within Q1, where products are deemed to have a constant demand. However, the reference point can be stretched to a coefficient of variance of value 1 in order to include RM1 1132 and RM4 1065. As RM1 1132 is produced from the same raw material as RM1 1015 and delivered to the same customer, it would be a reasonable approach. Further, as RM4 has a slotted production cycle of 2 weeks where RM4 1065 is by far the most often produced comparing RM4 1065 and RM4 1069, it could be reasonable for it to be stored due to its frequency.

As presented, the rest of the raw materials receive a higher coefficient of variance which implies great variety in demand. Such variance in demand is tough to model and forecast and needs to be treated differently than constant demand. For example, a coefficient of variance between 2 and 3 implies that products should be offered to customers make-to-order, *MTO*, not make-to-stock, *MTS*. For ARPS, a make-to-order strategy would mean that after a customer order is placed, ARPS orders raw materials from Flexibles. A make-to-stock strategy would mean having the required raw materials in stock. Hence, theory suggests no storing of remaining raw materials due to a high coefficient of variance and low demand.

As such, considering the new limited storage area, ARPS may have to rethink how they serve their customers. With an earlier aimed service level at 99% and lead time of 2-3 weeks, all customers regardless of size have been able to lay orders ad hoc, not adhere to forecasts or not share updates in forecasts with ARPS. ARPS has proven to be able to tackle almost all obstacles presented, which has put no pressure on the customers communication or performance toward ARPS. In this relationship, it is only ARPS who pays the costs of poor communication and ordering. Therefore, this relocation is an opportunity for ARPS to restructure how they serve their customers.

6.4.2. Propositions according to classification

The authors suggest three different proposals for ARPS when communicating new conditions for their customers with a coefficient of variance exceeding 1, see Figure 6.1. This are based on the hypothesis stated in section 3.7, where it assumed that ARPS needs to change customer behavior and storage strategies depending on raw materials. The propositions have been developed through applying theory on ARPS current situation. Thereafter, the propositions have been iterated and validated with supervisor Jan Olhager as well as discussed continuously with Max Ivarsson, supervisor at ARPS, who have approved of these proposals to be feasible. Hence, three different proposals will be presented and developed more in detail in following sections.

The first proposal would be for ARPS to put greater requirements on customers for a more frequent ordering where updated forecasts are shared regularly and continuously. A more frequent ordering would yield a lower standard deviation. This would in turn result in lower stocks since less pressure on hedging demand uncertainties is needed. This would further lead to ARPS being able to keep high service levels and short lead times at a lower cost.

The second proposal would be for ARPS to let customers continue ordering as today, keep high service levels and favorable lead times but have the customers pay extra for ARPS keeping this extra storage. This could potentially demand an external storage of raw materials, which the customers then would have to pay for.

Last but not least, the third proposal would be for ARPS to not keep any raw material inventory between orders and communicate longer order lead times to customers. This would apply for Customer B to D, except for eventually RM4 1065. When a customer order is laid, ARPS would put an order of raw materials to Flexibles. This would put greater pressure on the customers planning toward ARPS, and greater communication would be needed between customers and ARPS. Moreover, as RM1 1015, 1132 and RM4 1065 accounts for approximately 93,5% of total demand on a volume basis considering sheets, it can be concluded that the remaining 5 articles account for a quite small volume which may not offset the actual cost to serve.

The three suggested proposals give ARPS the advantage of having different propositions for their customers, where all would improve ARPS current situation remarkably. The rest of the analysis is developed based on the foundation of these three alternatives.

6.5. Forecasting method

As ARPS relies on forecasts performed by their customers, an internal forecasting system would be beneficial for greater accuracy in replenishment of raw materials from Flexibles. However, an internal forecasting system is only suitable for products with constant demand, alas only products with a low coefficient of variance or known production cycles is suitable. Therefore, forecasting is only suggested to be used for RM1 1015, RM1 1132 and possibly RM4 1065 due to current demand patterns. If the coefficient of variance were to decrease for remaining raw materials, forecasting for these could be applicable.

As forecasting is only done for products deemed to have a relatively constant demand, either moving average or exponential smoothing is considered as most suitable. The different forecasting methods are applied to historical demand data in order to decide which follows the demand data best and has the least MAD, comparing the forecast to the demand data.

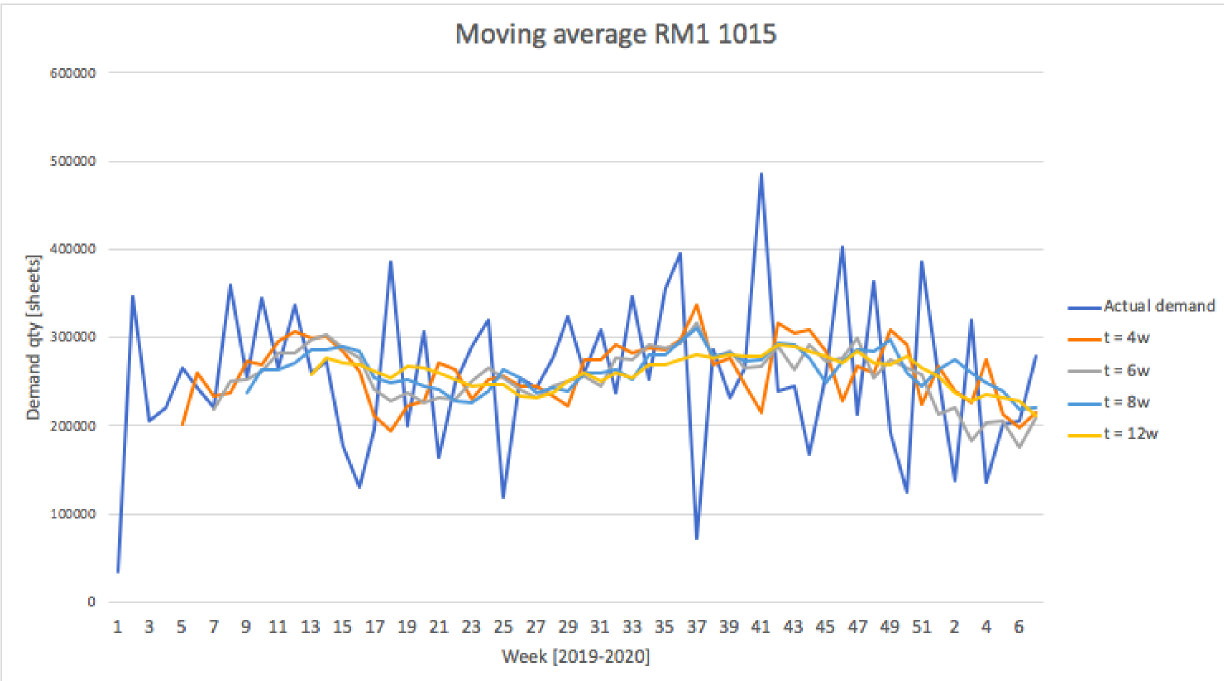

Figure 6.2. Applying moving average for t=4, 6, 8 and 12

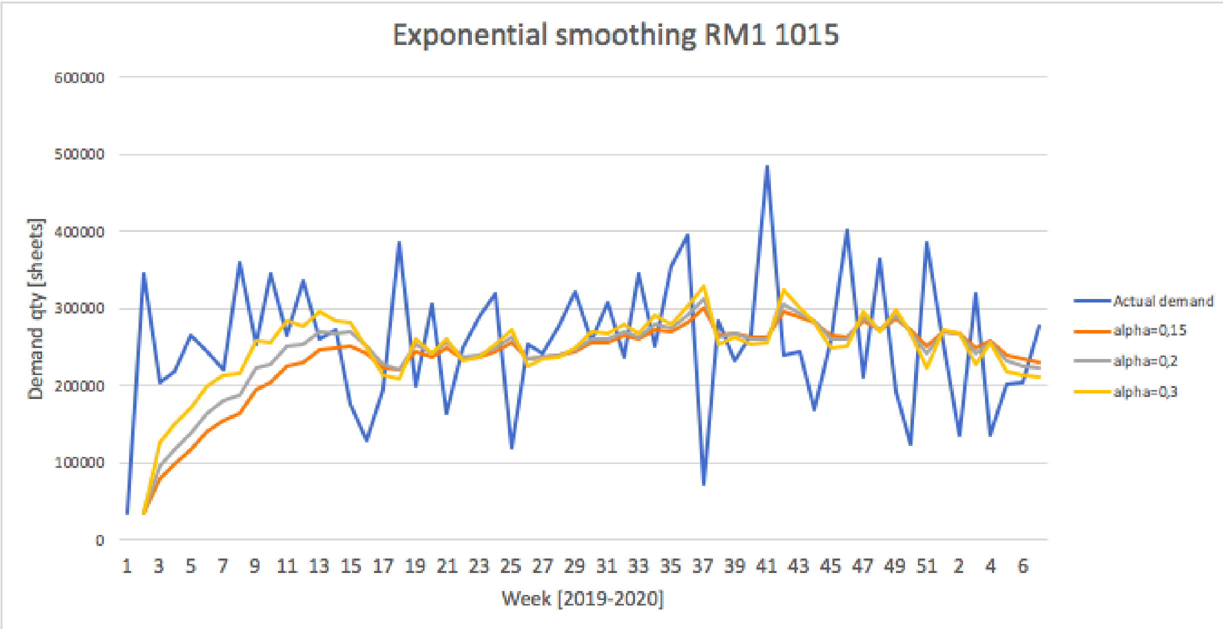

Figure 6.3. Applying exponential smoothing for coefficient 0.3, 0.2 and 0.15.

Figure 6.2 and 6.3 visualizes the application of the forecasting methods with different values. Different values are investigated in order to determine which are most suitable for each forecasting method. For moving average, the time periods 4, 6, 8 and 12 weeks are applied. For exponential smoothing, values for α of 0.3, 0.2 and 0.15 are applied where the larger the coefficient is, the more sensitive it will be to changes in demand, see Figure 6.3. The forecasting methods are then evaluated against each other, see Figure 6.4, where the values providing the best result for respective methods are used.

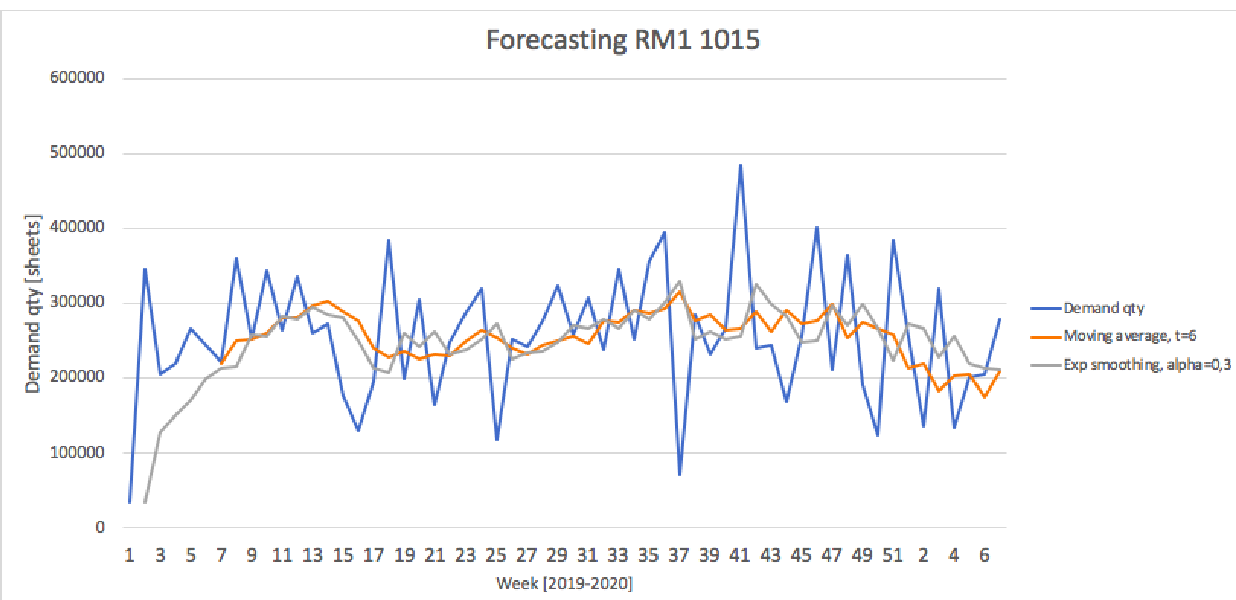

Figure 6.4. Comparison of moving average and exponential smoothing for RM1 1015.

Figure 6.4 shows moving average where 6 earlier time periods have been used as well as exponential smoothing, where the coefficient is set to α= 0,3. These values are chosen to represent the respective method as they have the lowest MAD where MAD is derived from comparing demand data with forecasting data.

Table 6.5. Average MAD for moving average and exponential smoothing for RM1 1015.

Moving average	**MAD** *[sheets/pallets]*	**Exponential smoothing**	**MAD** *[sheets/pallets]*
t = 4 weeks	77 242 / 38,6	α= 0,15	82 473 / 41,2
t = 6 weeks	68 879 / 34,4	α= 0,2	79 332 / 39,7
t = 8 weeks	69 590 / 34,8	α= 0,3	78 039 / 39
t = 12 weeks	69 667 / 34,8		

As can be seen in Table 6.5, does moving average give the lowest value for MAD but has a slower response to change in demand. In comparison, is exponential smoothing more responsive to changes, but has a higher value for MAD. This is caused by the demand fluctuations. If the demand fluctuations are large, they can be hard to follow why a moving average is deemed as most suitable for ARPS to use with a time period of 6 earlier values, where the forecasting is done per week

In order for forecasting to be efficient, forecast monitoring is recommended to be done continuously where the authors suggest that this is conducted weekly.

6.6. Demand distribution

Considering the demand pattern, histograms for all raw materials are presented in Appendix A6. Initially, the idea was to appoint each raw material a feasible demand distribution model. However, modeling demand according to an approximation model turned out as irrelevant since the patterns failed to indicate any interesting insights that are not already familiar. Although, plotting demand for each article with the corresponding number of observations, rather confirmed the difficulties in recognizing certain demand patterns. Exceptionally, since RM1 1015 and 1132 are ordered relatively frequent with stable and constant demand, it is arguable to assume a normal distribution. That is even though the diagrams in Appendix A6 for these raw materials indicate otherwise and follow a pattern that theoretically would be considered as Poisson or Logarithmic. For the rest of the raw materials however, a discrete model for distribution was initially considered as demand is lower and infrequent, but the randomness and few data points made it difficult to model them, anyhow. Regarding RM4 with cut-off length 1069, no diagram is plotted due to too few data points available in order to perform such an analysis.

Plotting the frequency of a certain demand can however provide information regarding the most commonly ordered quantities. Thus, indicating both the “normal” volume of an order as well as peaks in demand that occasionally occurs. This will later be referred back to when evaluating reasonable stock quantities, as there is no reason to have a stock quantity less than a normal order size.

6.7. Safety stock

When calculating the safety stock, only SERV1 is applied and not SERV2, as it is usually not used in reality by organizations due to it being a more complex model. ARPS have earlier expressed a desired service level of 99% toward all of their customers, however considering the new space constraint, this may not be feasible and customers like Customer A may have to be prioritized. A high standard deviation is further a driver of safety stock, which is a result from random demand. The question thus arises whether ARPS should consider not keeping safety stocks for products with high coefficient of variance.

A lead time of 4 weeks can be assumed for RM1 1015 and 1132 as material is replenished every week. Also, for RM4 1065, a lead time of 4 weeks is assumed due to a lower coefficient of variance and a production cycle of 2 weeks. However, for remaining raw materials, a lead time of 12 weeks will have to be assumed due to infrequent orders from customers and deliveries from Flexibles.

Table 6.6 displays the calculated standard deviation during lead time, which is needed in order to calculate the safety stock according to SERV1 and Equation 4.32.

Table 6.6. Standard deviation during lead time.

Raw Material	**Standard deviation during lead time, σ_L**	σ_L *[weeks]*
RM1 1015	185 969 / 93	4
RM1 1132	20 489 / 10,2	4
RM2 1055	28 471 / 14,2	12
RM2 1080	12 368 / 6,2	12
RM3	27 371 / 13,7	12
RM4 1065	44 494 / 22,2	4
RM4 1069	17 819 / 8,9	12
RM5	22 228 / 11,1	12

6.7.1. Proposition 1

The first alternative for ARPS is an alternative that would treat a more constant demand with shorter intervals between production cycles. That is since the first proposition suggests for ARPS to rewrite their ordering policies to receive orders more frequently. Such a proposal is modeled according to a production cycle of once per month for all raw materials except RM1 and RM4 1065, which are modeled with a frequency of once per week respectively every second week.

As the wish is to keep inventory levels as low as possible, the service level is modeled at a target of 90% for RM2-RM5, this in order to be able to keep the stock internally. In terms of RM1, replenishment occur on a weekly basis. Therefore, service level can be ignored, and safety stock is set to one week, nevertheless. Since the standard deviation is currently relatively large due to random demand, a service level of 99% would drive up stock levels and is therefore not used for this alternative.

Table 6.7 thus provides calculations for such an alternative, where the modeled demand during lead time is set to 1 week for RM1, 2 weeks for RM4 1065, and 4 weeks for all remaining raw materials.

Table 6.7. RM1 1 week of safety stock, all else 90%.

Raw material	**Safety stock** *[sheets]*	**Safety stock** *[pallets]*	**Safety stock** *[weeks]*	**Safety stock** *[sqm]*
RM1 1015	256 379	128,2	1	114,5
RM1 1132	13 897	7	1	7,6
RM2 1055	36 443	18,2	6,4	20,5
RM2 1080	15 831	7,9	9,6	8,6
RM3	35 034	17,5	6,7	21,6
RM4 1065	56 952	28,5	1,3	31,3
RM4 1069	22 808	11,4	13,6	13
RM5	28 452	14,2	4	7,3
Total				**224,4**

Table 6.7 shows a high usage rate of the available storage area for safety stock; however, ARPS would be able to keep such a stock within the premises. Thus, there seems to be no need for outsourcing if this proposition were to be applied, but it could however impact the service level kept toward customers.

6.7.2. Proposition 2

The second alternative evaluates and yields the necessary safety stock required if ARPS were to maintain a 99% service level and continuing with the same order routines as before. However, this alternative is only realistic and applicable if Customer B, C and D can accept paying extra for storing their raw materials externally. The condition for this would be for ARPS to act responsively on these customers' demand patterns. Maintaining the 99% service level yields a service constraint of $k=2,33$ and corresponding safety stock is presented in Table 6.8.

Table 6.8. Safety stock according to calculated SERV1 and service level of 99%.

Raw material	**Safety stock** *[sheets]*	**Safety stock** *[pallets]*	**Safety stock** *[weeks]*	**Safety stock** *[sqm]*
RM1 1015	433 308	216,7	1,7	192,6
RM1 1132	47 739	23,4	3,5	25,9
RM2 1055	66 337	33,2	11,6	36,7
RM2 1080	28817	14,4	17,4	16,2
RM3	63 774	31,9	12,2	38,4
RM4 1065	103 671	51,8	2,4	56,2
RM4 1069	41 518	20,8	24,7	22,7
RM5	51 792	25,9	7,2	12,7
Total				**401,4**

As illustrated in Table 6.8, high standard deviation with a 99% service level drives up safety stock, which will make the current storage insufficient. Storage boundaries is set to 360 sqm, given that 90% of the available storage will be used efficiently. Therefore, would a safety stock modeled with 99% service level, as previously mentioned, require the additional space from an external storage.

6.7.3. Proposition 3

The third alternative is for ARPS to not keep any safety stock for raw materials with a coefficient of variance larger than 1, and only keep safety stock for raw materials such as RM1 and RM4 1065 where there is a frequent and cyclic production. This would consequently result in a better usage ratio of the available storage area. A safety stock of 1 week is used toward RM1 and a service level of 90% for RM4 1065. As this alternative is built upon only dedicating storage to RM1 and RM4 1065, no storage would be given towards the remaining ones. This could possibly result in poorer service and longer lead times towards these customers, which one should be aware of. Table 6.9 presents the safety stocks that this alternative would account for. Service level for RM1 is neglected as for alternative 1 since it is more reasonable to set a timeframe of one week due to the weekly replenishment. See Table 6.9 for calculations.

Table 6.9. Safety stock of 1 week for RM1 and 90% for RM4 1065.

Raw material	**Safety stock** *[sheets]*	**Safety stock** *[pallets]*	**Safety stock** *[weeks]*	**Safety stock** *[sqm]*
RM1 1015	256 379	128,2	1	114,5
RM1 1132	13 897	7	1	7,6
RM4 1069	56 952	28,5	1,3	31,3
Total		**178,2**		**153,4**

However, if demand was to become more constant, standard deviation would decrease which could reduce the safety stocks considerably. Such reasoning is only applicable to proposition 1 and 3, however. In order to calculate future safety stocks, these should be remodeled and overlooked continuously. The standard deviation can also be calculated through looking at how forecasting matches relative to customer orders. Hence, there is value to unlock and benefits to retrieve if ARPS were to internally use a suitable forecasting method.

6.8. Lot sizing

6.8.1. Economic order quantity

Assuming an ordering cost *A* of 300 SEK, carrying rate *r* of 20% and average demand derived from yearly demand, the Economic Order Quantity is calculated and can be seen in Table 6.10. The value unit cost *v* is derived from a historic average price per sheet. The optimal time between arrival of an order is calculated through dividing the optimal order quantity with total demand for one year multiplied with 365 to obtain the number in days.

Table 6.10. EOQ for all raw materials and time interval between deliveries.

Raw Material	**Order qty** *[sheets/pallets]*	**Time between deliveries** *[days]*
RM1 1015	67 268 / 33,6	1,8
RM1 1132	14 831 / 7,4	7,5
RM2 1055	9 525 / 4,8	11,7
RM2 1080	5 071 / 2,5	21,5
RM3	9 276 / 4,6	12,5
RM4 1065	33 038 / 16,5	5,4
RM4 1069	6 513 / 3,3	27,2
RM5	15 050 / 7,5	14,7

6.8.2. Economic order quantity with discounts

As Flexibles and ARPS operate with quantity discounts, lot sizes should be modeled accordingly. Initially, the minimal batch size corresponding to the new pricing was derived, and these calculations indicated large differences in order volumes. Meaning that in order to receive the lower price setting, volumes would need to be increased sufficiently. That is, in order for ARPS to benefit from quantity discount and volume-based pricing, it would require them to order higher volumes than what is recommended and optimal. If doing so, there is a risk of unrealistically large batches which the storage capacity will fail to swallow.

Continuously, the price picture per order also remained relatively stable as the volumes increased, and no tangible gains were detected. This implies that ARPS should care less about a volume-based price structure and rather order based on suitable quantities that fit their storage capacity. As for that, a greater variance in optimal order quantities was expected than the ones retrieved while testing for different unit values. These unit values were derived from the given pricelist and based on these values; the EOQ-model indicated very similar suggestions on optimal order size.

6.8.3. Economic order quantity with space restriction

Looking at space restrictions, the available space for the batches can be derived using different the different alternatives. If calculating the available storage space from total space minus space needed for calculated safety stock, where the safety stock is set to 90% for all raw materials except for RM1 where safety stock is one week, the available space would be 120 sqm. The calculated EOQ batches would allow for such a restriction with a needed storage space of 80,1 sqm. Consequently, there is no need to calculate further on EOQ for space restrictions, as an alternative with a higher service level for safety stock would rather demand an external storage.

6.8.4. Adjusting EOQ according to supplements prerequisites

As EOQ assumes a constant demand, the results cannot be seen as accurate for the raw materials with a coefficient of variance larger than 1. Hence, the calculated order quantities and frequencies between deliveries must be altered to fit with the ordering frequencies for these raw materials. As many of the raw materials have infrequent demand, this causes a challenge to calculate optimal order quantity.

Further, since raw materials are ordered on a weekly basis from Flexibles, this needs to also to be considered when deciding the optimal batch quantity. For instance, Flexibles has expressed no possibility of delivering one raw material every second day as this would demand too much time in change of production setup. Therefore, all quantities are altered to at least a weekly frequency. However, this could be a possible discussion for the future with Flexibles as smaller batches would lead to a reduced inventory, which would be beneficial for ARPS.

6.8.5. Proposition 1

Alternative 1 is based on the suggestion that ARPS renegotiates their ordering policies and requires a more frequent ordering for RM2-RM5 except RM4 1065. These are all the materials with a coefficient of variance exceeding 1. A suggestion is to increase the ordering for these materials to once per month. Raw materials would then be replenished with the same frequency as their production cycles.

As Flexibles can produce up to 60 rolls per day when the production is running smoothly, a maximum of 120 pallets delivered per day is assumed. Table 6.11 renders the lot sizes that would be obtained from alternative 1.

Table 6.11. Adjusted lot sizing to customer order frequencies.

Raw Material	**Order qty** *[sheets/pallets]*	**Time between deliveries** *[weeks]*
RM1 1015	255 676 / 127,8	1
RM1 1132	13 859 / 6,9	1
RM2 1055	22 477 / 11,4	4
RM2 1080	6 596 / 3,3	4
RM3	20 804 / 10,4	4
RM4 1065	85 919 / 43	2
RM4 1069	6 702 / 3,4	4
RM5	28 655 / 14,3	4

6.8.6. Proposition 2

If ARPS do not require their customers to order more frequently, they will likely end up needing external storage, even more so if they wish to achieve a higher service level than 90%. The batches would then be ordered based on customer and internal forecasting.

6.8.7. Proposition 3

However, if ARPS were to only keep stock of the raw materials with a lower coefficient of variance, only RM1 and RM4 1065 would be ordered with a certain frequency. All other raw materials would then be replenished depending on a customer order. Table 6.12 displays calculations for lot sizes of RM1 and RM4 1065.

Table 6.12. Adjusted order quantities.

Raw Material	**Order qty** *[pallets]*	**Order qty** *[rolls]*	**Frequency deliveries** *[weeks]*
RM1 1015	127,8	64,8	1
RM1 1132	6,9	3,9	1
RM4 1065	43	23	2

6.8.8. Finite production rate

Since the most critical aspect for ARPS is to hold inventory levels as low as possible although still being able to maintain high quality on their customer service, finite production rate will not be further investigated. A finite production rate was suggested to illustrate the variety of inventory levels for RM1 due to its highly frequent arrivals from Flexibles. However, as the model is better suitable for organizations that aim towards slowly building up inventory rather than keeping it low, this model is not feasible due to the space constraint.

As the sheeter located at Flexibles premises has the same pace as the printing press located at ARPS, there are significant prerequisites for production to run frictionless, effective and smooth. Thus, Flexibles and ARPS can possibly operate synchronized, and this could allow for an optimized material flow between the two of them. Arriving materials from Flexibles to ARPS could theoretically therefore be directly transferred into their next value adding activity, i.e. the printing press. In theory, this would imply that no additional space is required for intermediate storage, exceptionally when articles are being queued before entering the printing press.

However, if considering a frictionless production flow, adherence is not taken to eventual break downs, production errors, downtimes, or discrepancies between laid orders from Flexibles and the actual customer order. Further, as the set-up time is longer for the printing press than the sheeter, this causes disruption in the production flow and can possibly prove to be a bottleneck.

Also, as the standard deviation for all raw materials is relatively high, one cannot expect the forecast to exactly match the customer order with the risk of either building stock or stock-outs. If the wish is to buy bigger batches due to quantity discounts rather than small batches, this causes further discrepancies for a frictionless flow. Therefore, can one only rely so much on a frictionless production flow as this will reasonably be extremely sensitive to any external factor.

6.9. Coordinated purchasing

Coordinated ordering could be an option for ARPS since they purchase some of their raw materials, i.e. RM1, RM2 and RM4 from the same material source but with different cut-off lengths. Hence, one can evaluate if it is a reasonable solution to coordinate these purchases belonging to the same raw material. In regards of RM1, both specifications have as previously argued for, a quite stable and continuous demand, why it makes sense to synchronize these orders. However, since RM1 1015 yields the highest volumes with most frequent orders, it is fair to adapt the ordering of RM1 1132 accordingly.

Equal reasoning is applied for RM2 and RM4 as they also have different dimensions. Apart from being more time efficient since the workload would be consolidated, it would also require less handling and be less costly. The cost parameters considered are ordering cost, quantity discounts as well as handling costs. In terms of RM4 1065, it could be favorable to have it ordered every second week due to its high volumes and relatively frequent demand. RM4 1065 also renders a comparatively low coefficient of variance which indicates a smoother demand pattern, why it is reasonable for it to be ordered on a shorter interval basis. RM4 1069 has not yet followed a similar pattern why order consolidation with RM4 1065 can be a favorable solution.

Ordering intervals has thus been further assessed and computed, which indicates that the reasoning above is realistic and applicable. If synchronizing the purchasing for RM4, calculations for optimal ordering intervals *(Equation 4.39)*, suggests that orders for this material should be laid every second week. In terms of RM2, equal calculations rendered the same order interval of every second week, if purchases were to be synchronized and demand constant. It is hence discussable for ARPS and Flexibles to rewrite their production routines and schedule according to a better fit for suggested order intervals.

However, a risk worth mentioning is to what extent a synchronized ordering would affect inventory levels. Such strategy might lead to a significant increase in inventory levels if no other requirements are put on ARPS customers. Therefore, if this alternative and solution were to be further investigated, it would mean that ARPS must invoke orders from relevant customers to fit with the suggested ordering intervals. Realizing this suggestion could yield several benefits for ARPS, it would hopefully bring a continuity in their ordering cycles and also improved collaboration with their customers.

6.10. Reorder point modeling

As the computer system at ARPS allows for continuous updates of inventory level, a continuous review of inventory is recommended rather than a periodic one. This, since inventory levels are to be kept as low as possible. In order to have an easy and applicable reorder point model for ARPS, the (R, Q) policy is recommended. As (s, S) policy tend to be more complicated to use, this is not further investigated. Thus, will the reorder point R trigger an order of size Q. The reorder point is calculated through safety stock and mean demand during lead time.

6.10.1. Proposition 1

The following section is based upon the suggestion of keeping all raw materials in stock but have customers order more frequently. Historically, ARPS has had 4 weeks of average demand in storage for all materials except RM1. However, Table 6.13 shows that having four weeks of average demand in stock does not satisfy historic orders, not even the average customer order size (except for RM2 1055). Therefore, such a solution seems insufficient and is not recommended to proceed with. However, if ARPS wishes to store all of the articles nevertheless, the lot size should be modeled with a reorder point dependent on safety stock plus mean demand during lead time as explained in Equation 4.37.

Table 6.13. Comparing 4 weeks of average demand with avg and max size of customer order.

Raw Material	**4w mean demand** *[sheets/pallets]*	**Avg size per prod. run** *[sheets/pallets]*	**Max size per prod. run** *[sheets/pallets]*
RM2 1055	22 416 / 11,2	19 119 / 9,6	52 173 / 26
RM2 1080	6 615 / 3,3	9 592 / 4,8	28 043 / 14
RM3	20 862 / 10,4	27 494 / 13,7	43 366 / 21,7
RM4 1069	6720 / 3,4	12600 / 6,3	12600 / 6,3
RM5	28 734 / 14,4	52 080 / 26	101 630 / 51

It is difficult to approximate lead times due to the highly infrequent ordering that is experienced. However, the suggested approach for alternative 1 is to improve these uncertainties by scheduling customer orders and have them make orders more frequently. If proposition 1 was to be pursued, it would mean for RM2-RM5 (RM4 1069 excluded) to be ordered and delivered once per month from Flexibles. The calculations for demand during lead time, $\bar{X}_L$ would then cover 4 weeks. Safety stock would still be modeled through a standard deviation of 12 weeks, with a 90% service level. The batch Q is decided through EOQ-modeling, with deliveries every fourth week. This is, however, only an example. In reality, Q should be modeled through forecasts.

Continuously for proposition 1, mean demand during lead time for RM1 is assumed to be one week, and safety stock is also calculated to one week. This is due to weekly replenishments of this raw material and also to maintain low inventory levels. Regarding RM4 1065, the safety stock is modeled according to a service level of 90%, and mean demand during lead time is calculated to 2 weeks.

Table 6.14. (R, Q) modeling for a more frequent ordering.

Raw Material	**Reorder point, R** *[sheets/pallets]*	**Batch size, Q** *[sheets/pallets]*
RM1 1015	512 758 / 256,4	255 676 / 127,8
RM1 1132	27 794 / 13,9	13 859 / 6,9
RM2 1055	59 252 / 29,6	22 354 / 11,2
RM2 1080	22 446 / 11,2	6 597 / 3,3
RM3	55 896 / 27,9	20 804 / 10,4
RM4 1065	143 108 / 71,6	85 920 / 43
RM4 1069	29 528 / 14,8	6702 / 3,4
RM5	57 186 / 28,6	28 655 / 14,3

Table 6.14 displays how a (R, Q) policy could be modeled according to such an alternative. The determined service level could be increased if so wished but would cause extra storage and space required.

Table 6.15. Average and max inventory for raw materials with (R, Q) policy.

	Average inventory		**Max inventory**	
Raw Material	**Batch** *[pallets]*	**Space** *[sqm]*	**Batch** *[pallets]*	**Space** *[sqm]*
RM1 1015	192,3	171,3	256,4	228,1
RM1 1132	10,4	11,3	13,9	15,1
RM2 1055	23,9	26,7	29,6	32,8
RM2 1080	9,6	10,4	11,2	12,2
RM3	22,7	27,8	27,9	34
RM4 1065	50	54,5	71,4	77,7
RM4 1069	13,1	14,8	14,8	16,6
RM5	21,4	10,8	28,6	14,3
Total		**327,6**		**430,8**

Table 6.15 shows average and maximum inventory levels for the modeled (R, Q) policy. However, if customer orders would remain infrequent, inventories would likely build up, causing the storage available to be insufficient. Therefore, it is only recommended to keep an (R, Q) policy for items

with a low coefficient of variance or known frequency of ordering, where it can be modeled accordingly.

Table 6.16. Total space used with a (R, Q) policy for all raw materials and frequent ordering.

Average inventory		**Max inventory**	
327,6 sqm	91%	430,8 sqm	120%

As can be seen in Table 6.16, calculations from the (R, Q) policy would test the limits of inventory capacity. However, important to keep in mind is that a more frequent ordering from customers would cause the standard deviation to decrease. Thereby would also the modeled safety stock decrease, and thus the space required. For example, if the standard deviation would be lowered by 20%, the safety stock would also be lowered by 20%. If such a decrease were to happen for RM2-RM5 the average space required with the modeled batches would instead be 307,1 sqm. Furthermore, batches will never arrive simultaneously from Flexibles, why it is not realistic to reach maximum inventory. This is further supported by ARPS printing press which has the same capacity as the sheeter, and hence materials will theoretically be produced through the printing press at the same pace as they arrive.

The modeled policy would need close monitoring in order to avoid inventory buildup and stretching beyond the capacity of inventory space. A further possibility to lower inventory for this alternative is to have customers ordering even more frequently, say every second week, where batches are modeled accordingly. One further alternative is to negotiate new agreements with Flexibles regarding RM1, to arrive in smaller batches and with shorter intervals. Possibly even discuss the opportunity to split large orders from Flexibles to receive smaller batches separately, where peaks in inventory levels would be avoided.

6.10.2. Proposition 2

If ARPS were to continue to let their customers order ad hoc and have a 99% service level for all raw materials, this would require an external storage. Table 6.17 displays how such a policy would be modeled, where Table 6.18 shows the space required. The batch quantity Q is assumed to cover an average customer order size for all raw materials except RM1 and RM4 1065 where the batch is modeled as earlier, with a frequency of one week respectively two weeks of mean demand. The demand during lead time, $\bar{x}_L$, is modeled to twelve weeks for all raw materials except RM1 and RM4 1065 since no decided production cycle exists, and therefore no determined frequency in replenishment. This time would hence account for the lead time from Flexibles.

Table 6.17. (R, Q) modeling with 99% service level and infrequent ordering.

Raw Material	**Reorder point, R** *[sheets / pallets]*	**Batch size, Q** *[sheets / pallets]*
RM1 1015	689 687 / 344,8	255 676 / 127,8
RM1 1132	61 636 / 30,8	13 859 / 6,9
RM2 1055	134 764 / 67,4	20 864 / 10,4
RM2 1080	48 662 / 24,3	8 720 / 4,3
RM3	126 358 / 63,2	25 208 / 12,6
RM4 1065	143 108 / 71,6	85 920 / 43
RM4 1069	61 678 / 30,8	12600 / 6,3
RM5	137 992 / 69	52 079 / 26

Table 6.18. Space required for an inventory with 99% service level and infrequent ordering.

Average inventory		**Max inventory**	
511,7 sqm	142%	622 sqm	172%

As earlier stated, having a 99% service level is a large driver for inventory levels. This solution would thus result in a need for external storage.

6.10.3. Proposition 3

RM1 and RM4 1065 is modeled as in proposition 1, where RM1 has a modeled safety stock and demand during lead time of one week. RM4 1065 has a calculated service level of 90% and modeled demand during lead time of two weeks. Table 6.19 presents the reorder points and batch sizes if only RM1 and RM4 were to be kept in stock.

Table 6.19. (R, Q) modeling for RM1 and RM4 1065 only.

Raw Material	**Reorder point, R** *[sheets / pallets]*	**Batch size, Q** *[sheets / pallets]*
RM1 1015	512 758 / 256,4	255 676 / 127,8
RM1 1132	27 794 / 13,9	13 859 / 6,9
RM4 1065	189 827 / 95	85 920 / 43

Through (R, Q) policy, the average and maximum inventory can be calculated, see Table 6.20.

Table 6.20. Calculating storage space with (R, Q) policy.

	Average inventory		Max inventory	
Raw Material	**Batch** *[pallets]*	**Space** *[sqm]*	**Batch** *[pallets]*	**Space** *[sqm]*
RM1 1015	192,1	171,3	256	228,1
RM1 1132	10,4	11,3	13,9	15,1
RM4 1065	64,5	69,7	86	92,9
Total		**237,1**		**320,9**

As mentioned earlier, as the batches for the different raw materials never will be delivered at the same time, the maximum inventory will never be reached. This is further strengthened by the pace of the printing press, which is the same as the sheeter delivering the inbound material. Table 6.21 shows the average and max inventory in percentage of total inventory, where it is further proven that this could be a feasible solution.

Table 6.21. Total space used with a (R, Q) policy for RM1 and RM4 1065 only.

Average inventory		Max inventory	
237,1 sqm	66%	320,9 sqm	89%

However, in order to keep peaks low and a steadier inventory level, it is recommended to have smaller batch quantities delivered with a higher frequency. As Flexibles has stated earlier that they do not produce the same material at two different production cycles for one week, this will not be further investigated in this master thesis. It is, however, recommended by ARPS to have a discussion with Flexibles regarding this matter, as it should be in both company's best interest to keep a smooth production line and low inventory levels.

6.11. Cost savings

6.11.1. Proposition 1

Given the alternative of a more frequent customer ordering, Table 6.22 displays average tied-up capital in inventory and average carrying costs. The costs are based on one customer order per month for all raw materials except RM1 and RM4 1065. The safety stock is set to one week for RM1, and 90% for remaining raw materials.

Table 6.22. Stock value and carrying costs if customers were to order more frequently.

Raw Material	**Avg tied-up capital** *[SEK]*	**Avg carrying costs** *[SEK]*
RM1 1015	3 259 930	651 986
RM1 1132	197 031	39 406
RM2 1055	477 819	95 564
RM2 1080	195 585	39 117
RM3	460 866	92 173
RM4 1065	588 534	117 707
RM4 1069	157 044	31 409
RM5	219 643	43 929
Total	**5 556 452**	**1 111 291**

A more frequent ordering would decrease the average stock value with ~1 MSEK, and the average carrying cost by ~200 KSEK. Prices used are derived from price lists dependent on batch size. However, it must still be considered that this storage only holds a safety stock with a service level of 90% for RM2-RM5 respectively 1 week of safety stock for RM1 and is based on a potential scenario.

6.11.2. Proposition 2

If ARPS wishes to keep a modeled service level of 99%, this would mean higher inventories that would demand an external storage and result in increased capital tied-up costs and carrying costs.

Table 6.23. Costs when keeping a service level at 99% for all raw materials.

Raw Material	**Avg tied-up capital** *[SEK]*	**Avg carrying costs** *[SEK]*
RM1 1015	4 761 104	952 221
RM1 1132	456 299	91 260
RM2 1055	767 145	153 429
RM2 1080	339 215	67 843
RM3	774 701	154 940
RM4 1065	863 731	172 746
RM4 1069	287 074	57 415
RM5	399 611	79 922
Total	**8 648 879**	**1 729 776**

As can be seen in Table 6.23, the cost this service level would require would mean that the average inventory tied-up capital would increase by ~2 MSEK and a carrying cost increase by ~300 KSEK. Further, if an external storage is to be considered, it is important to take into consideration the extra costs this would cause. Besides the capital invested in inventory, there would also be extra costs such as rent and handling of the raw material. The handling covers both machines needed and labor. Such handling, transporting raw material to an external storage, to then have it transported back to production when a customer order is laid, can be seen as double handling and should be avoided if possible. However, if customers are willing to pay for the extra service in order to be able to keep low lead times, high service level and ordering ad hoc, it could be done. But if ARPS is the one who would stand with such costs, external storage should by all means be avoided.

6.11.3. Proposition 3

If ARPS were to choose to only have RM1 and RM4 1065 as items in stock, and rather order the remaining raw materials when a customer order is laid, Table 6.24 shows the average stock value with the approximate carrying cost this storage would demand.

Table 6.24. Calculating stock value and holding costs for RM1 and RM4 1065.

Raw Material	Avg tied-up capital *[SEK]*	Avg carrying costs *[SEK]*
RM1 1015	3 259 930	651 986
RM1 1132	197 031	39 406
RM4 1065	588 534	117 707
Total	**4 045 495**	**809 099**

This would result in a decrease of ~2.5 MSEK in tied-up capital and a little less than 500 KSEK for holding costs compared to earlier costs.

Worth noting is that when comparing alternative 1 to alternative 3, where RM1 and RM4 1065 is handled similarly, alternative 1 contributes with an additional tied-up capital cost of ~1.5 MSEK and carrying cost of 300 ~KSEK. This cost regards only the serving of remaining 5 raw materials, which accounts for approximately 6.5% of the total demand on a volume basis.

All calculations in Tables 6.22, 6.23 and 6.24 are based upon purchasing values for raw materials, derived from price lists according to batch size.

6.11.4. Costs for external storage

Keeping an external storage was investigated as a feasible solution as this was proposed by ARPS. After conversing with a third-party supplier that offers complete solutions of storage, a cost proposition was gathered, and approximate expenses could be investigated. As the external storage most likely would be credited a variable fee for both times spent on inbound activities as well as a unit cost per pallet during departures, products with high activity would drive up costs. Therefore, if ARPS were to store articles externally, this would only be recommended for RM2-RM5 with exception from RM4 1065. The calculations are based on previous information regarding ARPS production frequency for the different articles. In terms of RM4 1069, no specific interval could be gathered from previous data due to the lack of reference points, why it was assigned a frequency of 4 weeks.

Yearly cost *[SEK]*	194 097

External storage was only investigated for a service level of 99%. However, being that only the materials who account for a lower demand would be kept externally, the calculated expenses can be seen as relatively large. Further, the expenses could potentially become larger if investigating this alternative further and more accurately. For example, handling and labor needed from ARPS is currently not included in these calculations. Moreover, this handling can be seen as double handling and should be avoided in order to keep an efficient workflow.

6.12. Collaboration between ARPS and Flexibles

Through observations and interviews has the cruciality of close collaboration between Flexibles and ARPS been highlighted with the relocation. A close collaboration needs information transparency, where the two different IT-systems, Radius and SAP may prove troublesome. This further highlights the importance of developing routines for close communication in order to improve the collaboration.

Moreover, it has been noted that even though Flexibles and ARPS themselves highlight the close communication and collaboration they have as sister companies, there arises disjoint incentives as they report to different departments and therefore have their own separate financial goals. Through streamlining and greater information sharing, they have the potential of unlocking a better position towards competitors by not looking at one another as a separate unit. This will however be tough as long as there are no incentives for closer collaboration or engagement from top management to do so.

A clear example of how the collaboration could be improved, is by Flexibles not using quantity discounts at all when pricing ARPS. As there exists no positive outcome of quantity discounts since they only drive larger inventory levels, it would be more beneficial to develop a price which is applicable to all sizes and favorable to both parties. With such a price, a minimum order quantity could be agreed on. As Flexibles currently find themselves faced with the same quantitative discounts from their own supplier, they have great incentives to use the same discounts towards ARPS. Realizing that this becomes a problem in the value chain, it is better to redesign and even for Flexibles to renegotiate terms with their own suppliers.

Another example of improved collaboration would be considering smaller batch quantities, where Flexibles could possibly produce and deliver the same material in two cycles per week instead of one. This could for example be beneficial for RM1 where very large batches are ordered every week. It should be in both Flexibles and ARPS best interest to operate as efficiently as possible, since they are in many ways mutually dependent on each other.

6.13. Risk management

6.13.1. Identified value chain risks

All risks should be assessed and depending on their probability and impact, be mitigated accordingly. Figure 6.5 briefly illustrates value creation activities over the supply chain from Flexibles to the distribution of goods from ARPS to their customers with corresponding risks.

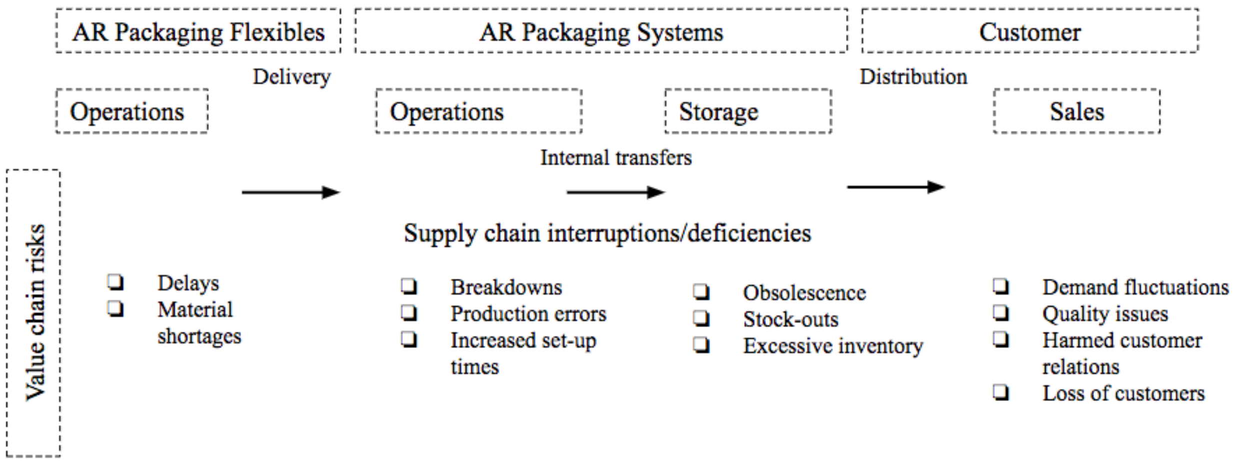

Figure 6.5. Risk elements across the value chain

The move of sheeter from ARPS premises to Flexibles causes greater complexity in controlling materials due to a higher number of articles to consider. The rearrangement causes a need for discussion between ARPS and Flexibles about ownership of the sheeter activity and hence who should be operationally responsible for it. That involves dedicating labor and resources to handle the machinery. It also means that ARPS would lose control over one of their value-adding activities. However, due to the mutual and close business relationship between ARPS and Flexibles, the rearrangement may be beneficial and rather result in a closer collaboration between the two business partners.

Although new circumstances might advance collaboration between the two business partners, it will simultaneously put more pressure on their communication and teamwork. Since this rearrangement will be less capable to guard against fluctuations in volumes due to constraints, it will most certainly be important to keep the flow of goods between ARPS and Flexibles scheduled. As for now, Flexibles are relatively free to deliver articles to ARPS as they produce and have realistic batches to handover. Future-wise, there will be a need to schedule and control the flow of materials better, and there is a risk that the two parties will disagree on elements that must be renounced. For example, keeping materials in house until the ordered batch is complete and ready to be delivered. However, the risk of dispute between Flexibles and ARPS seem less likely since they have a sort of mutual dependency in between.

Previously spoken of are the significant prerequisites that comes with having the sheeting machine and the printing press running at the same pace. This allows for a synchronized production with good opportunities for continuous material flow. That is beneficial in the means of inventory level since Flexibles will leave batches to ARPS that directly can be handled, and thus not drive up inventory due to production bottlenecks. However, the material flow relies on the capacity of these two production machines, which can cause major problems if complications arise and impede on scheduled material. Such complications could for example be production errors, breakdowns and downtimes.

Furthermore, considering the discrepancies between forecasts and actual customer order, there is a big risk of either building up too much stock, or stock-outs. Such discrepancies impede on a frictionless flow of material. Due to the long lead time from Flexibles with the short notice given by customers to ARPS, ARPS are faced with a tough problem; how to forecast and order raw material in a satisfactory way when demand is random and infrequent. However, the suggestion of renegotiating terms with customers would solve this problem to some extent, as ARPS would have better prerequisites to deliver according to agreed terms to all customers. This will also mitigate the risks of both stock-outs and excessive inventory.

The characteristics of this production line, i.e. sheeting machine and printing press, allows for a more responsive way of work for ARPS. However, additional problem-causing elements, typified for production lines, are for example set-up times. It is not to be neglected that the two machineries require certain times of installment and set-ups for different material specifications. The sheeting requires less time for readjustment than the printing press, due to the vast amount of designs the customers can wish for. This could potentially become a production bottleneck but has yet not been one, why it is assumed to not become one either.

Further, a normal problem that manufacturing and industry companies traditionally face is the risk of obsolete products. Obsolescence has bad effects on business since it becomes sort of a waste in invested time, labor and capital. Normally, preventing products to turn obsolete is of high priority, and impacts the direction of selected storage strategy. Obsolescence has thus been discussed, but as for this case, the nature of products makes the risk for it almost neglectable.

As the formulated strategies for inventory control and procurement have not yet been tested or implemented at ARPS, it is recommended to initiate the application of the chosen strategy before the relocation is done. This in order to eliminate any potential operational problems that may arise while implementing changes. All errors that occur after the relocation is completed will be more difficult to handle considering an unfamiliar work environment and space restrictions.

Additional overhead risks fair to address, are potential deficits in product quality and material shortages. Material shortages can be treated as fairly improbable since the products originate from accessible resources and are considered relatively simple to manufacture. On the contrary, one of the most critical aspects for ARPS is to keep extraordinarily good quality on their products that always meet standards. This makes the tolerance for quality mistakes non-existing. For illustrative risk analysis, see Figure 6.6.

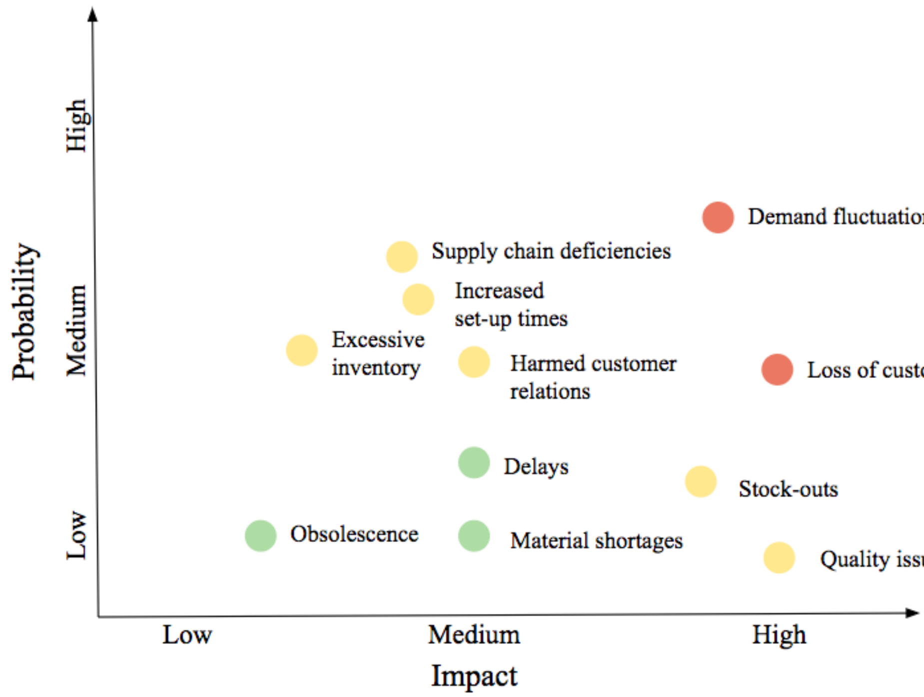

Figure 6.6. Illustration of identified risks ranked according to their probability of occurring and impact if doing so

6.13.2. Proposition 1

Pose that this study would lead to ARPS reformulating their order policy towards their customers, in the means of putting higher requirements on ordering routines to receive more accurate and frequent updates. This would benefit ARPS remarkably, leading to more precise inventory management with less approximates and better communicated information from their customers. However, not to be neglected is the value of great relationships between both parties, which for ARPS is a necessity. Introducing new requirements and policies can thus be sensitive and might worsen the relationship. If ARPS would go for this alternative, one might be prepared to discuss the probability of customers actually looking for other supplier options, and what lock-in effect ARPS solution have for their customers.

6.13.3. Proposition 2

If ARPS instead were to maintain their current policies, namely, to let Customer A to Customer D continue to follow their ordering routines and simultaneously store the amount required for 99% service level, an external storage would be needed. A reasonable solution would thus be to communicate the new premises to their customers, what this means and have them pay for the extra costs accompanied by this solution. Adding an extra fee to compensate for the external storage might be less appreciated out of a customer perspective, which implies it might also harm a currently very reciprocal relationship. In the worst case, this might result in customers seeking alternative suppliers. The impact of losing customers is discussable, being that Customer A accounts for a significant majority of ARPS revenues, restricted to the raw materials covered in this thesis. However, the risk of actually reaching this scenario is considered as relatively small and maybe even none, being that ARPS provides a unique solution difficult to find elsewhere.

Storing articles externally might involve other risks and is a major project if it would be considered. This would potentially lead into discussions of who would be responsible for the storage with everything it might involve, e.g. internal transportation of items, labor required to manage the storage as well as the security of items. This alternative is the one that significantly triggers stock levels and drives them to grow. Alas, escalating inventory levels will lead to a corresponding boom of capital tied up in stock, which one should be carefully aware of.

6.13.4. Proposition 3

Alternative three suggests that treated articles should be classified according to their individual demand pattern. To help with this analysis, indicator coefficient of variance figures as great guidance for how to handle the materials differently. Pose that all articles with a coefficient of variance > 1 are assigned new manufacturing strategies that would be MTO rather than MTS. The lead time towards customers ordering these articles would thus increase remarkably to 12 weeks from the time an order is laid. This alternative puts more pressure on ARPS and Flexibles internal processes, meaning that the margin for sudden and unprepared complications will be close to non-existing. With that said, there is always a risk of delays or sudden complications, e.g. set-up times or else., which might prolong the lead time even further. Moving on the edge of what the customers might be willing to accept in terms of lead time, puts more pressure on not only ARPS and Flexibles, but on all entities downstream the value chain. System breakdowns, delays of deliveries or limited resource accessibility are only suggestions of what could cause problems downstream the supply chain.

For all three alternatives, Customer A will be the least affected by the new premises, which is reasonable since it accounts for the largest volumes. However, the likelihood and impact of risks should be evaluated, nevertheless. Determining and developing mitigative strategies for these risks play a critical role in further assessment processes.

7. Conclusions and recommendation

This chapter will begin with concluding the analysis and its findings, and thereafter move on to make recommendations for future strategies within inventory control at ARPS. The chapter will end with reflections regarding academic contributions and ability of generalization, as well as interesting studies for future work.

7.1. Conclusion

The goal of this master thesis has been to develop and formulate a strategy for cost optimal ordering and inventory control regarding raw materials at ARPS, after relocating to new premises. Based on theoretical findings and empirical data, it is now possible to present a strategy, accompanied by a recommendation, that will serve as guidance for ARPS continuous partnership with targeted customers and supplier Flexibles. The change prospect has not yet been tested nor implemented since the handover is due before the actual relocation. However, to better prepare for unexpectant issues that might arise during change initiatives, it is suggested for ARPS to test the chosen strategy under current basis.

The underlying cause of the formulated problem in this thesis, was found in theoretical and empirical findings, namely that ARPS are, or will be, experiencing a dilemma. They are currently positioned between two counterparts, where high expectations from customers are thwarted against the aim towards a cost-effective partnership with their supplier, Flexibles. Consequently, ARPS have found themselves in a quite impossible situation. While wishing to achieve quantity discounts and simultaneously maintain a remarkable service level, regardless of infrequency in demand, they must now consider a cap on maximum inventory.

Found during this master thesis is the complexity in controlling and handling products with infrequent and random demand. Besides being quite impossible to forecast, such demand contributes with a large standard deviation driving up stocks. There is little use in having stock for products that will not be able to even serve a “normal” customer order size. The inconvenience of storing such articles was emphasized while investigating the cost savings between proceeding with alternative 1 and alternative 3. Keeping the high variable products, namely RM2-RM5 except RM4 1065, in stock would cost ARPS an additional amount of 1.5 MSEK. Worth mentioning is also that these products only account for approximately 6.5% of the sales volume. Consequently, there is a risk that the gains of serving these customers does not offset the cost of doing so.

As new circumstances for ARPS were communicated during the end-phase of this master thesis, this information could not be fully applied due to the delimited timeframe. Further, as the communicated sheet dimensions and unit measures were still preliminary and had yet no decided pallet sizes, it seemed more realistic to continue with the old dimensions. This approach also felt realistic since the new dimensions and unit measures will have the same ratio as old dimensions and unit measures, meaning that the same amount of space will be required for the end units. What may become a problem, however, is that the number of pallets will increase with decreasing sheet dimensions, resulting in more loss of space between these. Nevertheless, this has been neglected in this master thesis.

Valid, reliable and objective studies, in combination with literature and interviews, have figured as the foundation for continuous work and applied proxies in this thesis. These components enabled a profound analysis, where three different suggestions for ARPS were conceptualized based on product classification through coefficient of variance. The analysis presents the alternatives in detail, where ARPS now have the opportunity to renegotiate agreements accordingly. It allows for ARPS to evaluate and also communicate these alternatives to their customers. The idea of proposing three different suggestions is to incentivize and engage all parties involved, motivating a discussion for reaching mutual agreement. By doing so, ARPS creates an inclusive change environment where their customers are given the opportunity to impact the direction of future partnership.

7.2. Benchmark between developed propositions

Considering that the aim of this master thesis has been to develop a cost-optimal strategy for ordering and inventory control for ARPS system customers, it can be concluded that the economic impact of each solution is a driver for what strategy that is finally recommended for ARPS to implement. As quantity discounts is concluded to not give any remarkable economic gains, only tied-up capital and inventory holding costs are taken into consideration when striving towards cost-efficiency.

Further, it has been the authors ambitions to develop a solution for ARPS that is feasible to implement in the means of being as simple as possible as well as not requiring more resources in the future compared to current state. This also means not testing the boundaries of the given inventory space more than necessary, avoiding any potential complications or errors.

7.3. Recommendation

Taking the aspects mentioned in section 7.2, the authors recommendation is for ARPS to proceed with proposition 3 if possible. Namely to not keep any raw material in stock for products with a coefficient of variance that exceeds 1, or where no distinctive production cycle is present. Such a solution would reduce ARPS costs in tied-up capital by ~2.5 MSEK and enable improved production planning for a longer horizon. If ARPS were to complement this suggestion with continuous forecasting, preferably moving average where using a historic time period of 6 weeks, inventory control will require significantly less monitoring and excess work effort. Thus, having the potential of realizing even more benefits.

Besides the cost savings and reduction in complexity this solution could realize, the authors further recommend this solution as it is highly supported by theory. From D'Alessandro and Bavejas case study from 2000 it was described how a company could realize benefits of product classification through coefficient of variance and develop storage strategies upon such classification. Such segmentation was further strengthened by conversations with Jan Olhager, the supervisor of this master thesis. For a company, it may be natural to think that any customer should be served no matter the cost, but it is easy to end up losing on such a deal. Sometimes, customer behavior may need tougher requirements in order to reach agreements where both parties are mutually dependent on one another.

However, it is beneficial for ARPS to be able to offer different solutions for their customers, likely making ARPS seem more agreeable and solution-oriented from a customer point of view. Making the customer feel in charge and included should not be underestimated. So, even though proposition 3 is suggested to proceed with, risk of either customer loss or harmed customer relations are likely to be reduced if ARPS initiates conversations with their customers and engage them in the outlook of future partnership.

It is further recommended for ARPS to strengthen the relation between Flexibles and themselves, making them collaborate more closely than today. There are many benefits to be found for both parties with a closer collaboration, as they are mutually dependent on one another. This could for example be to align production cycles, strive towards operating leaner and thus reduce waste, or unlocking the values of close and regular communication. However, from the empirical findings it has been found highly unlikely that such a collaboration will happen without top-management initiative or incitements to do so.

One further example of deepened collaboration between ARPS and Flexibles would be developing price lists without quantity discounts, and instead settling on a minimum quantity that can be ordered. Since quantity discounts only have the effect of driving up stock and realizes no real benefits considering the situation at hand, developing prices with no quantity discounts would remove this operational challenge. Another benefit that could potentially be realized would be if Flexibles could agree to supply ARPS with smaller batches but more frequent for RM1 1015. Meaning that Flexibles would have to produce RM1 1015 more than once per week. However, this idea was presented for Flexibles during interviews, and was not received very positively due to implicating larger production setup times and costs. Alas, such a change would enable ARPS to keep inventory levels steadier and to avoid the highest peaks of stock, which would benefit the limited storage space considerably.

In order to mitigate and reduce any disruptions that may arise with a new setting of inventory strategy, it is recommended for ARPS to test the chosen strategy before the relocation. This allows for detecting potential challenges under less critical circumstances while still operating under familiar conditions. Operational challenges can potentially be stock-outs, increased inventory, delays, longer lead times and so on. Preparing for potential issues and running the recommended strategy before the move is realized, will advance the prerequisites to start operations seamlessly at the new premises. However, contracts and agreements need to be established with both customers and Flexibles before proceeding with this change initiative.

7.4. Sensitivity analysis

As assumptions have been made throughout this master thesis, some assumptions have greater impact on the result than others. Firstly, the carrying rate *r* of 20%, decided by ARPS is considered. Such a value has proven to have significant influence on the EOQ-modeling and may cause quantity discounts to result in lesser gains than it would if *r* was given a smaller value. However, according to theory it can be concluded that carrying costs is a real cost and should not be ignored. Further, as quantity discounts creates incentives of ordering larger quantities, resulting in larger inventory stock, it is not wished for while considering the space restrictions. This have also been validated by supervisor Jan Olhager.

The ordering cost of 300 SEK, also set by ARPS, can be assumed to be of minimal impact, being that this amount constitutes of a small part of the total costs. Given that the ordering cost would be assigned a larger value, this would result in a larger optimal quantity, but has no real impact for the developed recommendations.

The chosen solution will have to be redesigned according to new sheet dimensions and thus pallet dimensions. More pallets will be needed to satisfy the same amount as earlier, being that sheet dimensions will be smaller and thus less components can be derived from each sheet, except for RM5. Given that more pallets will be required, less efficient space will be available given that space is lost between pallets. This might result in less space available than the assumption of 360 sqm. Given that the real amount of available space could be lower, the solutions would have to be adapted. However, as the authors recommend ARPS to test and implement the chosen strategy before relocation, the company will have sufficient time to explore the exact boundaries of the new inventory.

7.5. Academic contribution

In terms of contribution to the academic field, this master thesis tests the limit of established methods and their applicability. The method of using coefficient of variance on articles that are highly inconsistent in demand and frequency has been tested, but on a larger scale than this case. This case rather treats few articles with large variety. Since no change implementation has taken place, there is still a lack of knowledge regarding its applicability for the specific nature of this study. It is however assumed to render equal results as previous studies have shown and thus contribute to the method’s recognition.

As the limit for classification of products according to coefficient of variance was moved from the recommended 0.52 to 1, this could affect the outcome of inventory control in this study. Previous research has confirmed that classification according to coefficient of variance can bring great benefits during inventory and demand control. However, applying a critical mindset, it is difficult to anticipate how the new limits used in this thesis will impact the result. No similar research has been conducted/acknowledged, but the approach still follows equal principles. Thus, it will be interesting to evaluate if it is possible to adapt the coefficient of variance according to the nature of products and their demand.

According to industry standard, it seems that many companies deal with quantity discounts in order to account for production setup costs. However, as proven in this master thesis, does not always the advantages of accepting larger batches offset the consequences of inventory tied-up capital and carrying costs. As quantitative discounts are a driver for large inventories, it seems that such pricing should be avoided from the conclusions drawn in this case.

Moreover, results from this master thesis acknowledge and confirm theoretical suggestions regarding inventory control. It shows that classification of products and demand pattern control can simplify inventory management in many of its elements. For example, it can help to reduce and set stock levels, schedule ordering or determine a suitable forecasting method for more accurate inventory planning. The vitality of demand pattern control is thus emphasized and confirmed.

7.6. Suggestion of future studies

Considering that a new value was chosen for classification of products, it would be interesting to conduct future studies on how choosing different values for coefficient of variance impacts the end result. It would be interesting to investigate if this measure could be adapted and used differently depending on the nature of products and their demand. Further, interesting complementary studies would involve the best way to implement a theoretically formulated strategy, consequently a study from an operational point of view. Deeper investigation in best practices of change management would further be interesting, and how such changes should be communicated to stakeholders and internally in the company.

Moreover, during this master thesis, it has been highlighted that Flexibles and ARPS have tight bonds and collaboration due to being under the same flagship, AR Packaging. However, considering the companies being sister companies, the information sharing is not as transparent as one could imagine. It would therefore be interesting to further investigate how relations can be improved between companies in the same positions as ARPS and Flexibles, and how they could achieve a deepened relationship which could be beneficial for both.

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Appendix A

A1. Price lists

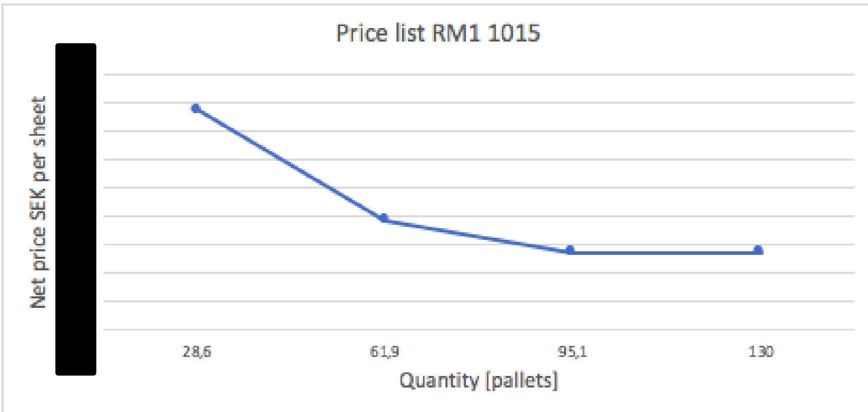

Figure A1.1. Price list for RM1 1015.

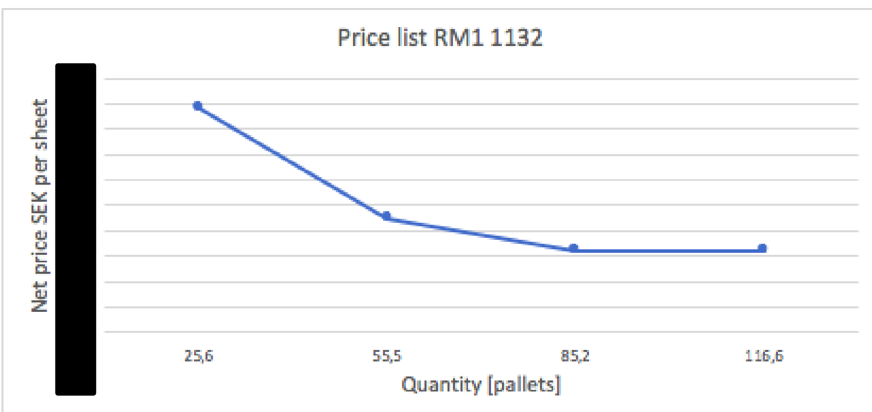

Figure A1.2. Price list for RM1 1132

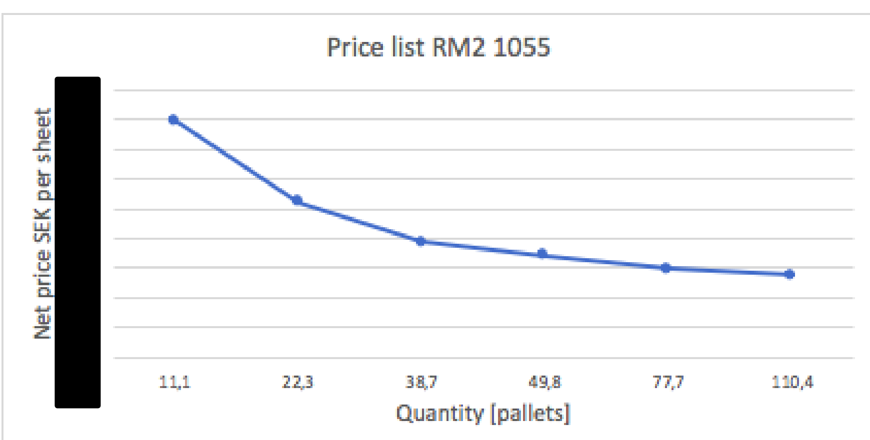

Figure A1.3. Price list for RM2 1055.

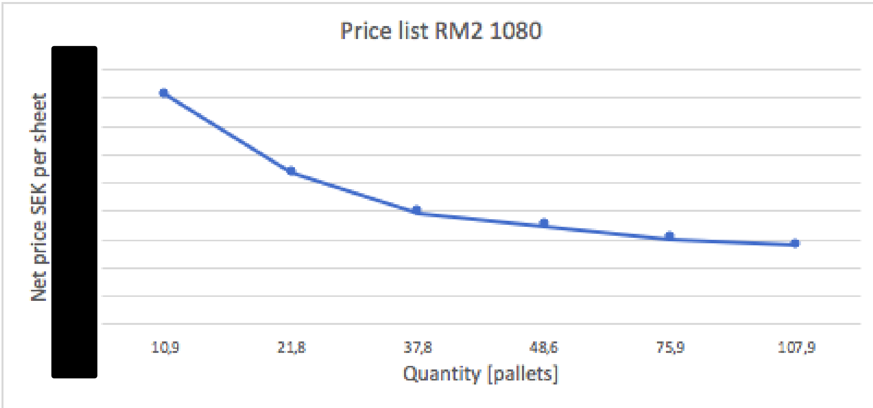

Figure A1.4. Price list for RM2 1080.

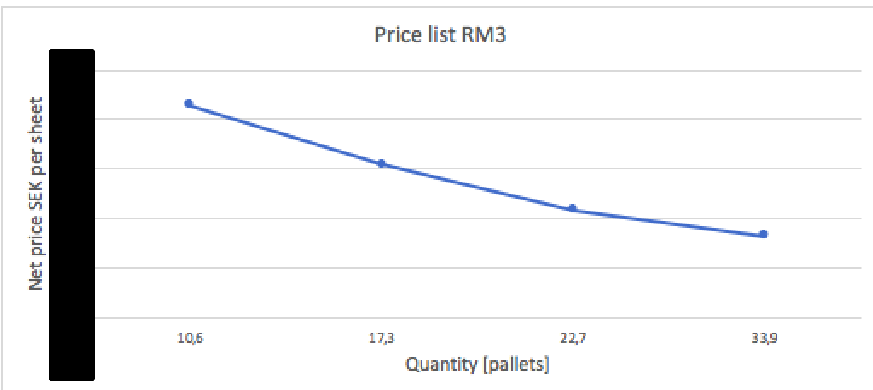

Figure A1.5. Price list for RM3.

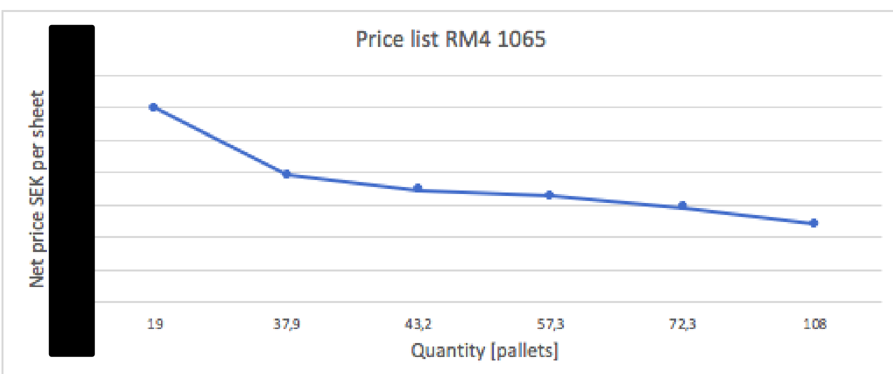

Figure A1.6. Price list for RM4 1065.

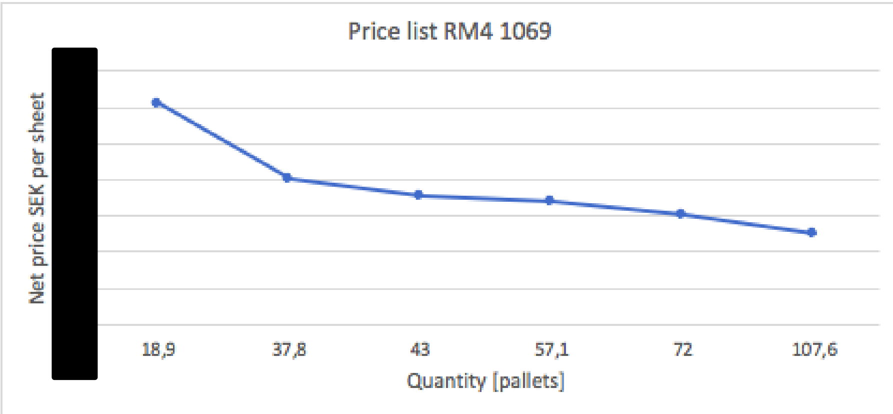

Figure A1.7. Price list for RM4 1069.

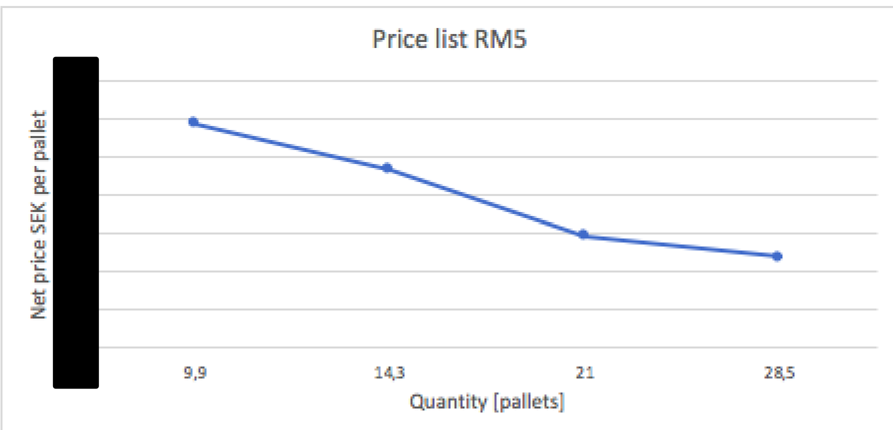

Figure A1.8. Price list for RM5.

A2. Demand data

Table A2.1. Demand data from printing press for RM1.

Date	**RM1 1015** *[sheets]*	**RM1 1015** *[units]*	**RM1 1132** *[sheets]*	**RM1 1132** *[units]*
January-19	1066584	10665840	98423	1771614
February-19	1012759	10127590	96203	1731654
March-19	1275436	12754360	40435	727830
April-19	865502	8655020	31980	575640
May-19	1168079	11680790	66719	1200942
June-19	1024901	10249010	45030	810540
July-19	1409482	14094820	68717	1236906
August-19	1086023	10860230	26591	478638
September-19	1107330	11073300	61906	1114308
October-19	1248563	12485630	67512	1215216
November-19	1307971	13079710	61271	1102878
December-19	836547	8365470	72245	1300410
January-20	971820	9718200	58100	1045800

Table A2.2. Demand data from printing press for RM2.

Date	**RM2 1055** *[sheets]*	**RM2 1055** *[units]*	**RM2 1080** *[sheets]*	**RM2 1080** *[units]*
January-19	24000	288000	11161	111610
February-19	18661	223932	4332	43320
March-19	11248	134976	0	0
April-19	32753	393036	10882	108820
May-19	25790	309480	11000	110000
June-19	35541	426492	10758	107580
July-19	27284	327408	0	0
August-19	52173	626076	28043	280430
September-19	0	0	0	0
October-19	42424	509088	14640	146400
November-19	0	0	0	0
December-19	24000	288000	5100	51000
January-20	31155	373860	0	0

Table A2.3. Demand data from printing press for RM3.

Date	**RM3** *[sheets]*	**RM3** *[units]*
January-19	54406	3917232
February-19	35496	2555712
March-19	34187	2461464
April-19	64	4608
May-19	0	0
June-19	11580	833760
July-19	0	0
August-19	0	0
September-19	30053	2163816
October-19	51900	3736800
November-19	0	0
December-19	47399	3412728
January-20	0	0

Table A2.4. Demand data from printing press for RM4.

Date	**RM4 1065** *[sheets]*	**RM4 1065** *[units]*	**RM4 1069** *[sheets]*	**RM4 1069** *[units]*
January-19	-	-	-	-
February-19	-	-	-	-
March-19	-	-	-	-
April-19	-	-	-	-
May-19	-	-	-	-
June-19	-	-	-	-
July-19	-	-	-	-
August-19	-	-	-	-
September-19	-	-	-	-
October-19	71763	717630	12 600	176 400
November-19	125492	1254920	0	0
December-19	195630	1956300	12 600	176 400
January-20	203584	2035840	0	0

Table A2.5. Demand data from printing press for RM5.

Date	**RM5** *[sheets]*	**RM5** *[units]*
January-19	0	0
February-19	0	0
March-19	101630	3658680
April-19	0	0
May-19	0	0
June-19	79432	2859552
July-19	0	0
August-19	56281	2026116
September-19	0	0
October-19	54000	1944000
November-19	57768	2079648
December-19	37525	1350900
January-20	30000	1080000

A3. Dimensions

Table A3.1. Dimensions for raw materials.

Raw materials	**Roll diameter** *[mm]*	**Roll width** *[mm]*	**Roll size** *[sqm]*	**Cut-off length** *[mm]*	**Sheet size** *[sqm]*	**Pallet size** *[sqm]*
RM1	1900	857	1,63	1015 1132	0,87 0,97	0,89 1,4
RM2	1900	887	1,69	1055 1080	0,94 0,96	1,4 1,4
RM3	1900	1096	2,08	984	1,08	1,4
RM4	1900	814	1,55	1065 1069	0,87 0,87	1,4 1,4
RM5	Ordered on sheets	624	-	743	0,46	0,49

Table A3.2. Sheets and units obtained per one unit of raw material.

Raw material	**Cut-off length** *[mm]*	**Sheets per roll**	**Pallets per roll**	**Units per sheet**	**Units per pallet**	**Units per roll**
R1	1015	3 907	1,95	10	19 890	39 070
R1	1132	3 478	1,74	18	35 546	62 604
R2	1055	3 741	1,87	12	23 755	44 892
R2	1080	3 658	1,83	10	19 816	36 580
R3	984	4 044	2,02	72	143 698	291 168
R4	1065	3 727	1,86	10	19 908	32 270
R4	1069	3 712	1,86	14	27 866	51 968
R5	-	1 998 *(delivered on pallets)*	-	36	71 402	-

A4. Setup waste

Table A4.1. Approximate values for materials through the printing press with waste.

Raw Material	Avg sheets per job order before setup waste	Avg sheets per job order after setup waste	Setup waste - printing and sheeting
RM1 1015	7 294,8	[redacted]	[redacted]
RM1 1132	3 174,2	[redacted]	[redacted]
RM2 1055	3 916	[redacted]	[redacted]
RM2 1080	4 359,8	[redacted]	[redacted]
RM3 984	18 905,8	[redacted]	[redacted]
RM4 1065	8 732	[redacted]	[redacted]
RM4 1069	8 400	[redacted]	[redacted]
RM5 743	48 071	[redacted]	[redacted]

The setup waste is calculated by deriving the average size of one job order for all materials, subtracting [redacted] sheets from that job order and thereafter calculating the percentage this gives. This waste only considers the waste the sheeter and the printing press provides.

A5. Demand pattern

The demand pattern is derived from quantities through printing press each week.

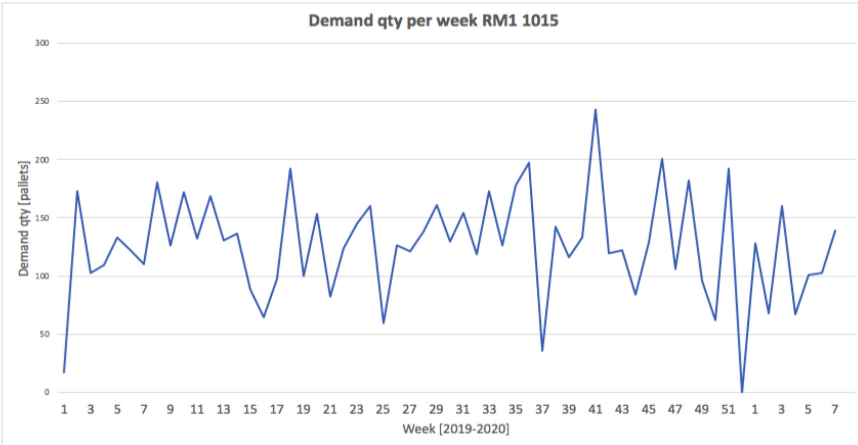

Figure A5.1. Demand quantities per week RM1 1015.

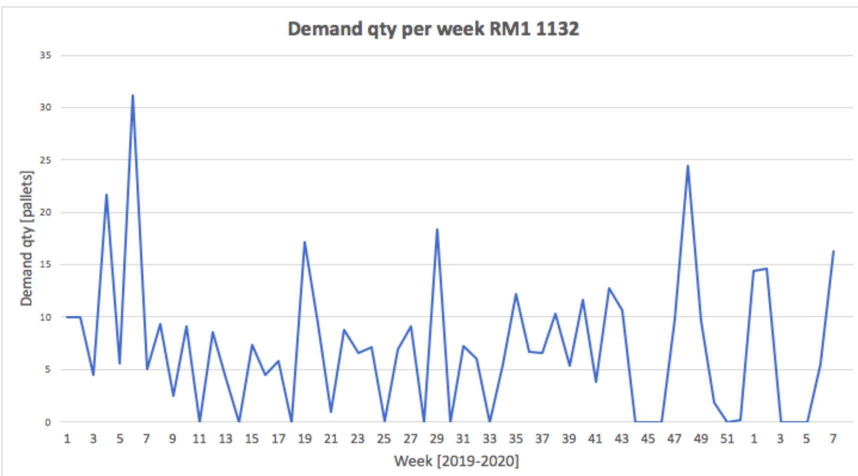

Figure A5.2. Demand quantities per week RM1 1132.

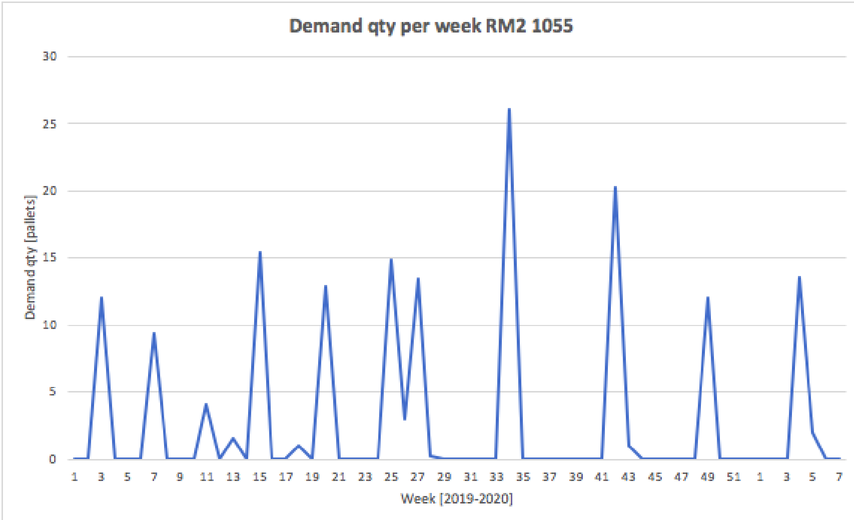

Figure A5.3. Demand quantities per week RM2 1055.

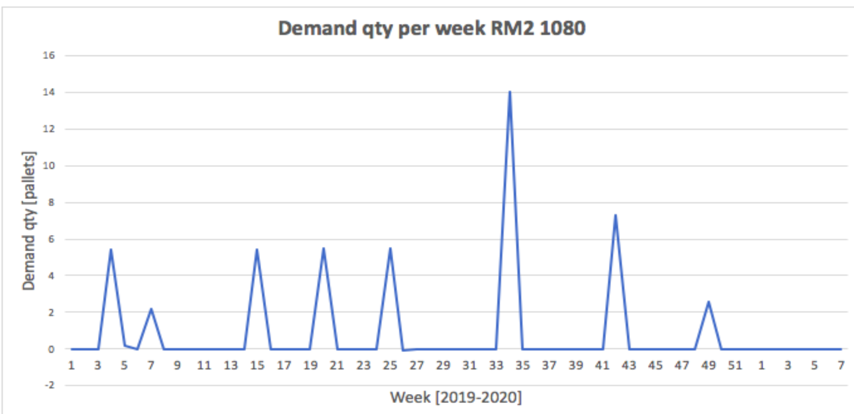

Figure A5.4. Demand quantities per week RM2 1080.

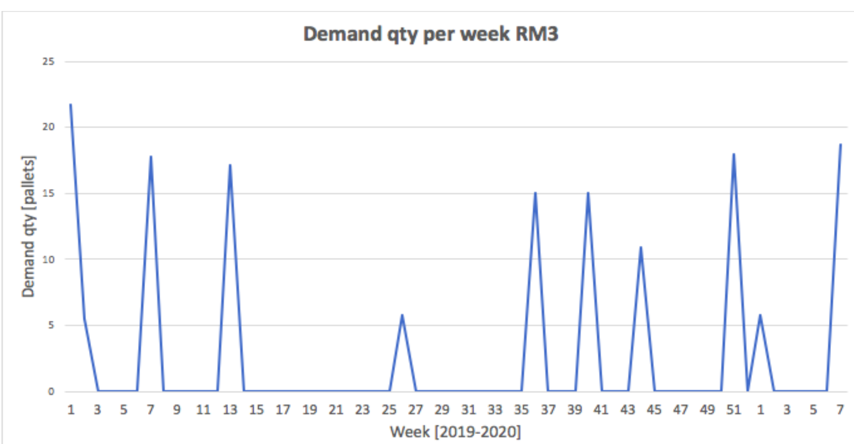

Figure A5.5. Demand quantities per week RM3.

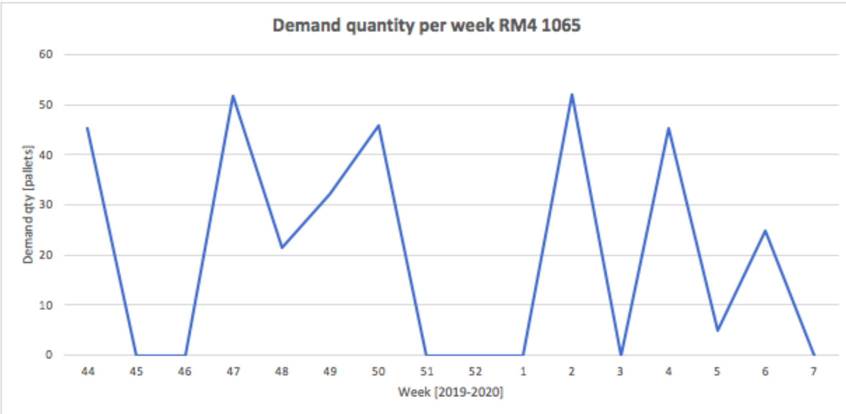

Figure A5.6. Demand quantities per week RM4 1065.

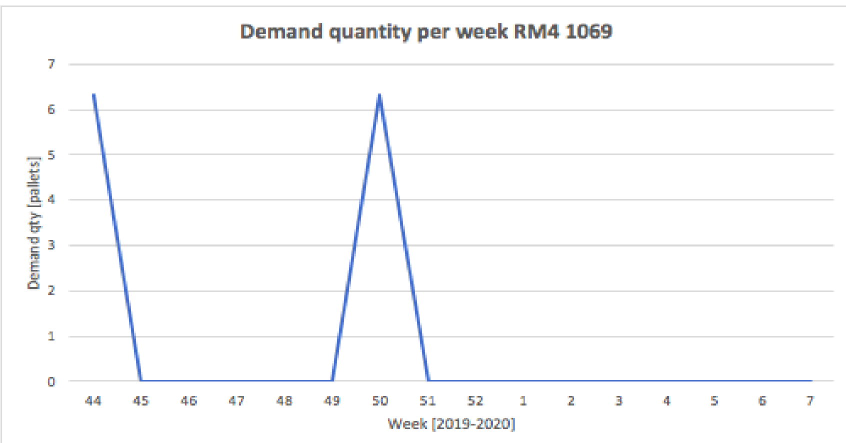

Figure A5.7. Demand quantities per week RM4 1069.

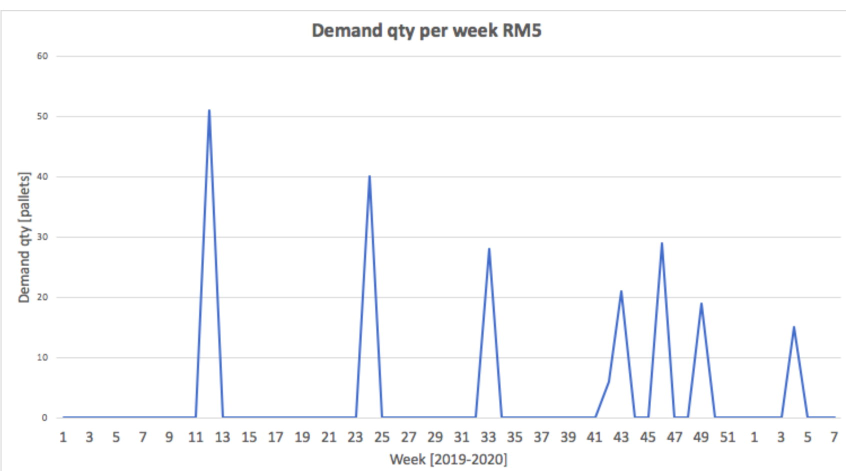

Figure A5.8. Demand quantities per week RM5.

A6. Demand distribution, histograms

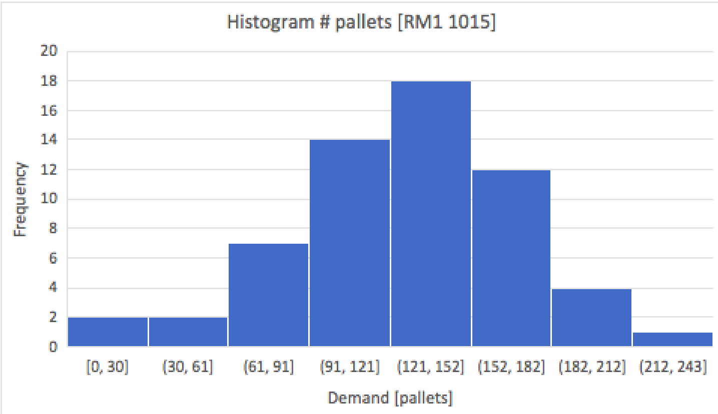

Figure A6.1. Demand distribution for RM1 1015.

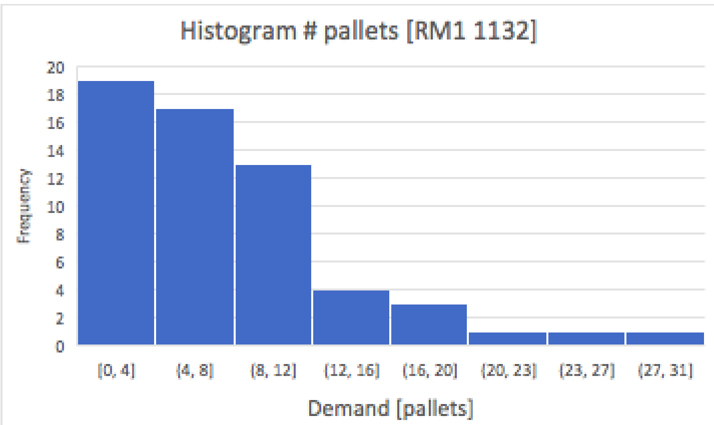

Figure A6.2. Demand distribution for RM1 1132.

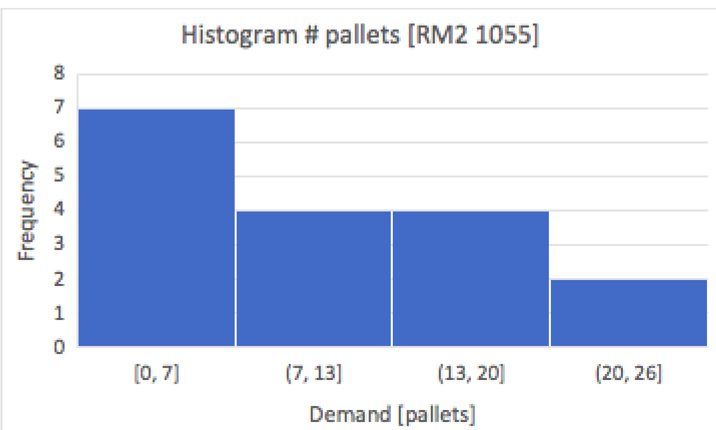

Figure A6.3. Demand distribution for RM2 1055.

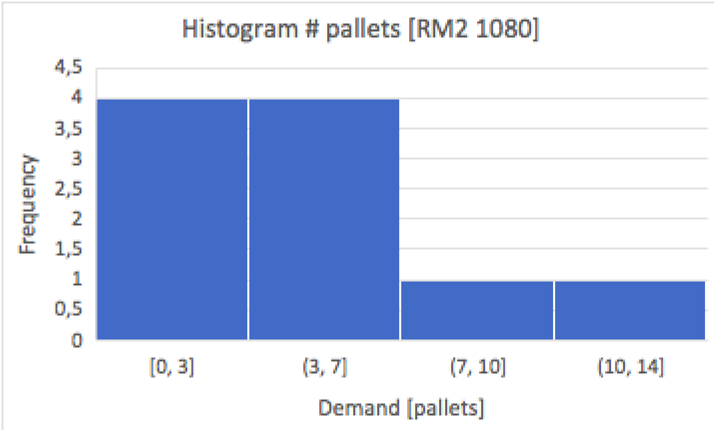

Figure A6.4. Demand distribution for RM2 1080.

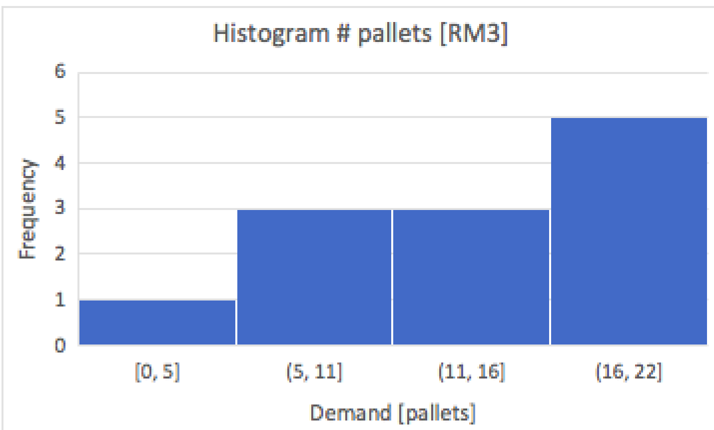

Figure A6.5. Demand distribution for RM3.

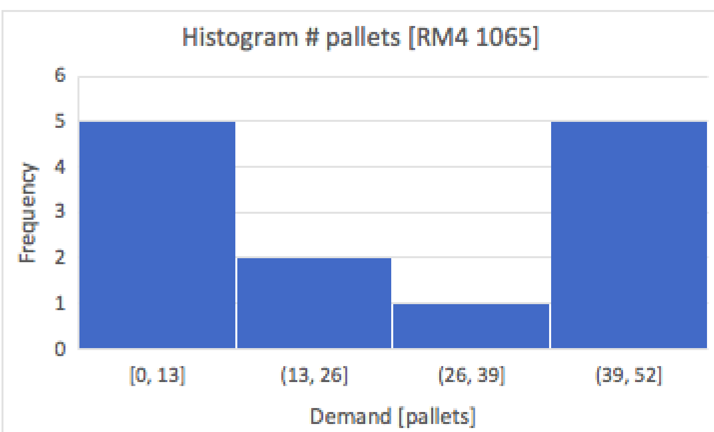

Figure A6.6. Demand distribution for RM4 1065.

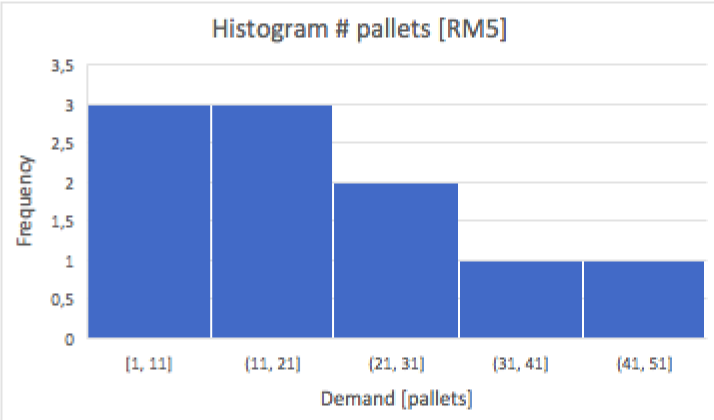

Figure A6.7. Demand distribution for RM5.

Appendix B

B1. Interview guide

Questions - Supply Chain and Inventory Control

1. Who are your customers?
2. What is a system customer and what is the solution that ARPS provided them with?
3. Which raw materials concern which product and customer?
4. What is your strategy for procurement?
5. How is raw materials replenished today?
6. What is the lead time for the raw materials?
7. Do you use forecasting methods? If so, which?
8. How are forecasts monitored?
9. What information is shared from the customers?
10. What service level are you aiming for and what lead times have you promised towards customers?
11. What methods do you use to practice inventory control?
12. Do you find these methods satisfactory?
13. How is the level of safety stock determined?
14. Are any models used to calculate this level?
15. How is inventory kept? On racks, or on the floor?
16. How is the raw material refined before sent to the end customer?
17. What are the dimensions and measured units for the raw materials?
18. What pallet dimensions are used for each of the raw materials?

Questions - Characteristics of production

19. What is the pace of the printing machine?
20. How does the sheeter match the printing press pace wise?
21. How many hours per week does it operate?
22. Are there any larger bottlenecks identified in the production?

Questions - Characteristics of supplement

23. How is the relation between Flexibles and ARPS today?
24. At what pace does Flexibles deliver raw material to ARPS?
25. What has been historical batches?
26. Does Flexibles have any specific production cycles?
27. What is Flexibles possibility to produce less and more frequent?

Questions - Relocation and future premises

28. What will be the layout of the future premises?
29. What will be the capacity of the future premises and storage area?
30. What further changes will the relocation mean?

Questions - Costs

31. How are prices affected by quantity discounts?
32. What is the ordering cost for one order?
33. What is the holding rate?
34. Are there any penalties if ARPS do not meet the agreed service level?
35. What is the self-cost of sheeting?

Questions - Other

36. Are there any other comments you would like to add?