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Production Line Efficiency Management in the Context of Product Portfolio Expansion

Case study

School of Technology and Inno-
vations
Industrial Engineering and
Management
Strategic Project Management

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UNIVERSITY OF VAASA**School of Technology and Innovations**

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| Title of the thesis: | Production Line Efficiency Management in the Context of Product Portfolio Expansion: Case study | | |
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ABSTRACT:

The topic for this thesis is the production line efficiency management in the context of product portfolio expansion. The case company is working in the field of paper industry and the production line is facing challenges regarding the expanding product portfolio. The main aim for the thesis is to find ways to keep the efficiency level of the production line in a level that it has been before the expansion of product portfolio, or possibly improve it.

The project is completed in a four person project team, which consists of project manager, supply chain planner, supervisor and production engineer. The team has been carefully selected in a mindset that there would be as much expertise as possible around the theme of the study. Other people from the organization are being contacted in the project as well for consultancy, and to increase the knowledge of certain project phases.

The research method for the study is quantitative and the solutions for the thesis will be created with the help of constructive method. Sample size for the study is around 200 000 measurements. The data used in the case study has been collected from the case company on a monthly basis to measure the progress of the project. The project has been done with a selected framework of stakeholder management and DMAIC. DMAIC and stakeholder management have been selected as the framework because the project affects multiple stakeholders and Lean Six Sigma is a mindset that the factory works around.

The case study focuses around three different controllable topics: reference cycle, unplanned stock and grade change waste. The topics are measured with eight different key performance indicators that are updated regularly to track the progress of the project. All of the enhancement ideas for the three topics are being evaluated and analyzed before implementing them into the production line and the results of the implementations are being measured monthly to avoid any possible challenges or mistakes that would be caused by the improvements.

The results of the project shows that by enhancing the reference cycle, the production line efficiency increases in almost every key performance indicator. By increasing the volume of the production runs, the waste reduces and the production line becomes more efficient and leaner. One of the outcome from the project was a tolerance amendment to paper grade change and it is a suggestion to the case company to test and implement the idea to the production line as they best see. Other suggestions of the study are targeted to unplanned stock to improve the management and material flow of the stock.

KEYWORDS: Production line, efficiency management, lead time, paper industry, waste

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TIIVISTELMÄ:

Diplomityön aihe on tuotantolinjan tehokkuuden hallitseminen tuoteportfolion kasvaessa. Yritys X toimii paperiteollisuudessa ja yhdellä tuotantolinjalla on haasteita kasvavan tuoteportfolion vaikutuksista tuotannon tehokkuuteen. Diplomityön tarkoituksena on löytää tapoja pitää tuotannon tehokkuus aikaisemmalla tasolla tai jopa parantaa tuotannon tehokkuutta.

Projekti tehdään neljän hengen projektitiimillä, johon kuuluu projektipäällikkö, tuotannonsuunnittelija, tuotannon esimies sekä käyttöinsinööri. Projektitiimi on valittu siten, että projektitiimillä olisi mahdollisimman paljon asiantuntemusta projektiin liittyviin aiheisiin. Organisaation muita henkilöitä konsultoidaan myös projektin aikana, jotta saataisiin mahdollisimman kattavaa tietoa projektin onnistumisen takaamiseksi.

Tutkimusmenetelmänä diplomityössä käytetään kvantitatiivista tutkimusta ja tutkimustulokset analysoidaan konstruktiiivisella menetelmällä. Mittausten määrä tutkimuksella on noin 200 000 tulosta. Diplomityössä käytettyä dataa on kerätty Yritys X:ltä kuukausittain, jotta pystytään seuraamaan projektin kehitystä. Diplomityön raameina käytetään sidosryhmäjohtamista ja DMAIC:ia. DMAIC ja sidosryhmäjohtaminen on valittu raameiksi, koska projekti vaikuttaa moniin sidosryhmiin ja tehdas noudattaa Lean Six Sigman periaatteita.

Diplomityö keskittyy kolmeen hallittavaan aiheeseen: ajosykliin, lattiavarastoon ja lajinvaihtohylkyyn. Aiheita seurataan kahdeksan eri keskeisen suorituskykymittarin avulla, joita päivitetään säännöllisesti projektin seuraamisen mahdollistamiseksi. Kaikki kehitysideoita kolmen hallittavan aiheen parantamiseksi arvioidaan ja analysoidaan ennen niiden implementointia tuotantolinjaan. Implementointien tulokset mitataan ja arvioidaan kuukausittain, jotta vältetään mahdollisilta haasteilta ja ongelmilta, joita implementoinneista voisi syntyä.

Projektin tulokset osoittavat, että parantamalla ajosykliä saadaan lisättyä tuotantolinjan tehokkuutta lähes jokaisen suorituskykymittauksen mukaan. Lisäämällä tuotantoajojen kokoa, hyllyn määrä laskee ja tuotantolinjasta tulee tehokkaampi sekä hukka vähenee. Yksi projektin seurauksista on toleranssien muutos lajinvaihdossa. Tämän kehityksen jatkaminen on jatkosuositus yritykselle ja heidän kannattaisi testata sekä implementoida idea tuotantolinjalle heidän parhaan näkemyksensä pohjalta. Muita suosituksia diplomityössä ovat lattiavaraston hallinnoimisen kehittäminen sekä sen materiaalivirran parantaminen.

KEYWORDS: Production line, efficiency management, lead time, paper industry, waste

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1 Introduction

This chapter will provide the introduction into the thesis topic with the main points being a brief background of the study, research gap, research questions and limitations.

1.1 Background of the study

Field of business for the case company is paper industry. The case company has faced challenges with the production line efficiency since the product portfolio has been expanding over the years. There are new paper grades coming to the product portfolio catalogue annually and this causes various different challenges regarding the production line and the aim for this study it to control the production line efficiency through different actions. This study will be done as a project to the case company and later on, there will be an introduction to the project team and the different actions that there will be taken in the project. The main challenges that will be considered in the study of production line efficiency management will be the reference cycle, unplanned stock and grade change waste. These challenges will be measured and analysed with different reports and calculations.

1.2 Research gap

Production line efficiency is a general topic in the industry and manufacturing. However, there are not many articles and papers regarding production line efficiency in paper industry, and none in the context of product portfolio expansion. The lack of literature in product portfolio affecting efficiency indicates that there is a clear research gap for this study. For example, there is a research done by Braguinsky et al. (2021) about the expansion of product portfolio in Japan's industrialization and how can lead to a business growth and success. There is also literature about production efficiency improvement and management, and as Minh (2023) has concluded, PEF ("Production efficiency

improvement”) management and complimentary tools and techniques can be useful to have as a guideline in production efficiency improvement.

However, there is still not enough relevant literature around production line efficiency management in the context of product portfolio expansion, especially in the paper industry. This study will try to figure out the possibilities to control the efficiency when the product portfolio is expanding and this will be done by researching different sections of the production line to see where the waste can be saved. In short, the study focuses on production reference cycle, unplanned stock and grade change waste.

1.3 Research questions and limitations

There are three research questions in this study that are designed and defined by the case company. The research questions have been created to help in achieving the objective of the thesis, which is to complete a project and provide improvements to control the flow in production line within defined service level without adding cost. Research questions are the following:

1. What are the effects that growing product portfolio and production lead time has to production line efficiency?
2. What are the production line limitations to product portfolio and how can the company overcome these?
3. How to optimize production efficiency and cycle as the product portfolio changes?

The limitations of this study are naturally the lack of generalization. Since, this study will be a case study, the results cannot be generalized to all the production lines in the paper industry and the results will only be indicative and they need to be applied carefully into production. Other limitations are the limitations of the production line and limitations regarding the reference cycle adaptations from sales office point of view.

1.4 Structure of the study

This study will consist of seven main chapters that will include the introduction, literature review, methods, project introduction, results and conclusion. This chapter provides short introduction to the study, including brief background, research gap, research questions and limitation and the structure of the study. Literature review will be about the framework of the study, and the literature review of the production line and systems in paper mill as well as the effects and limitations of the growing product portfolio. Methods will be explaining the research methods, data collection and analysis of the data. Project introduction showcases the project scope, project team and the means and aim for the study. Visualization and the final progress of the project can be seen in the result chapter. Conclusion will summarize the whole thesis together and provide future recommendations to the case company.

2 Literature review

This chapter will provide information about the literature around the project, the production line, and the production control systems that has been chosen to be monitored and managed in this master's thesis work as well as effects and limitations of growing product portfolio. The project will be done by using DMAIC and stakeholder management as the base framework for project optimization and management.

2.1 Stakeholder Management

According to Pedrini & Ferri (2019) the term stakeholder has been conceptualized first in 1963 as "those groups without whose support the organization would cease to exist." After this, the definition has been developed into the concept of stakeholder management which means the relationship between stakeholders and companies. Pedrini & Felli mentions that the recent developments in stakeholder managements have been about how the business can reach their objectives through stakeholders wishes.

Communication is important in stakeholder management and as Pedrini & Ferri noticed in their results "the views of various stakeholders increase the effectiveness of data and information." This is why the project for production line efficiency management has a wide spread of experts in the project team, and the project has support from every stakeholder group in the company if needed. To get effective information, the project manager will tour in the production line and ask help and opinions from the production line operators to ensure that there are many different views and thoughts noted in the thesis and project.

It is also important to evaluate the stakeholders outside the organization, in other words customers, and to think about how the changes would affect them. The production lead time changes might not have a clear effect on the customers since the lead times are defined to a certain level in the system but the changes might affect indirectly. For

example, the changes in reference cycle can affect the availability of certain grades but also improve the amount of delays to the customer and the flow of the production line. The potential effects to the customers will be evaluated in the evaluation phase of the project improvement suggestions, so there would not happen any unexpected results from the improvements.

In the end of the project, there will be an summary of the project that can be read and explained to the key stakeholders that are directly impacted by the project. It will explain the results and improvement recommendations. This is to improve the communication between stakeholders within the company.

2.2 DMAIC

“Six Sigma is an organized and systematic method for strategic process improvement” (Linderman et al., 2003). So, in practice, Six Sigma is a problem-solving methodology that tries to improve and enhance the process or product to be more cost-efficient. DMAIC is a Six Sigma based method that has five different steps for the enhancement process. Every step represents its own alphabet in the name of the method, DMAIC. According to De Mast & Lokkerbol (2012) the five steps for DMAIC are define, measure, analyze, improve and control.

These will be noted in the project followingly: before the project starting, the problems have been defined, which means that there has been identification and selection of challenges that fits this project’s scope. Next, the challenges will be measured with the help of different key performance indicators (KPIs), this way the objectives can be set for the challenges. Analyzing phase will consist of the meetings with the project team where the challenges will be analyzed and evaluated to see if there is any room for improvement within the defined challenges. After that, improvement part of DMAIC will be about the evaluation and implementation of improvements to the challenges. This will also be done together with the project team. The help of the experts in the project team, means

that the practical mistakes can be possibly eliminated and avoided from the implementations and therefore the implementation process can be easier and smoother. Last phase, control, basically means the results and the following of the defined KPIs to see that the improvement proposals have been implemented correctly and the process has not suffered from the improvements.

Lean methodology will be used as a result of the DMAIC methodology. Improvements are meant to reduce the waste in the production line to increase the efficiency. The main focus of Lean methodology and production is to eliminating waste (Grupta & Jain, 2013). Grupta and Jain explain that by eliminating waste, the organization can produce the goods with the best possible quality and the least amount of cost. In this project, the Lean manufacturing and methodology can be seen in all three main topics. Lean manufacturing is seen in the reference cycle improvement as a try to produce goods with the least amount of waste from the process and to shorten the lead time. Lean is seen in unplanned stock because the aim is to control and reduce the unplanned stock. This means that the invested capital, and the amount of unplanned paper, on unplanned stock would be reduced, thus making the unplanned stock more lean. The aim for grade change waste is to reduce the amount of paper that cannot be used to the customer orders, so to eliminate the process waste. This is one of the main principles in Lean manufacturing. Lean methodology has been used also in the recommendation for the company, where the grade changing tolerance process has been analysed, and there has been recognized the opportunity to improve the process and eliminate waste. So, even though the methodology used in this project is DMAIC, the share of Lean manufacturing / methodology cannot be understated. Lean methodology has been applied to this project through the use of DMAIC.

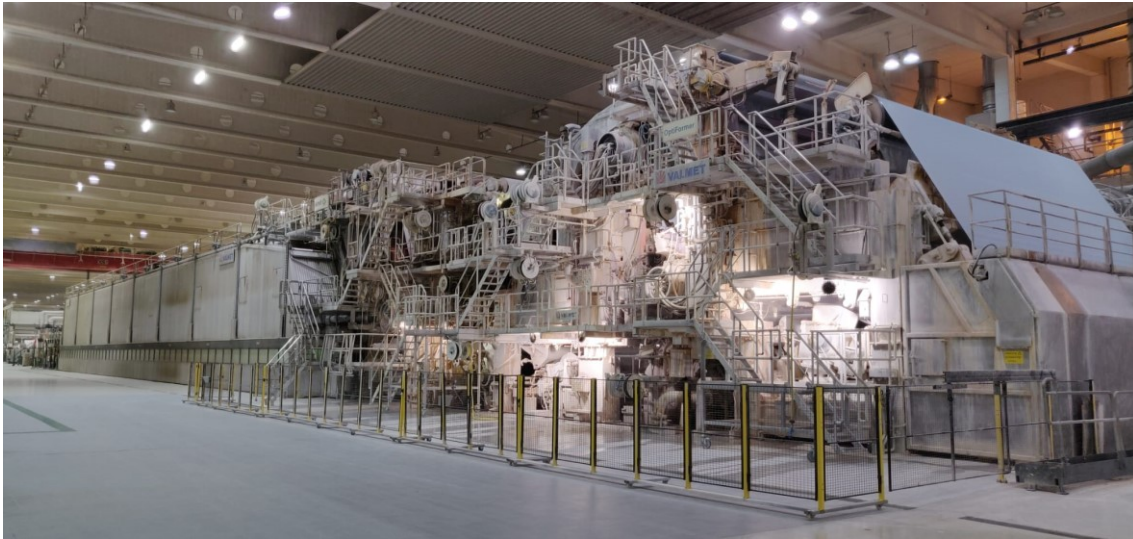
According to Lynch et al. (2003) DMAIC project needs to be scoped effectively to ensure that the project stays within the defined guidelines of the project. If the project has not been scoped at the start of the project, it can lead to challenges in time efficiency, team members losing their interest and ultimately leading to the project falling into failure.

Lynch et al. mentions that it is critical to follow the steps in DMAIC process and to have experience in DMAIC projects, because that reduces the amount of time in choosing different tools and therefore it will save time and resources in the project lifecycle. After all, the effective scoping of the project can help in consistency and duration of the project.

2.3 Production line

The project will be done and implemented to one production line and this subchapter will explain all the phases of the paper production line. The literature about the functions and basics of production line phases is important, since the whole project focuses around the efficiency management of a well-functioning production line. It is important to plan the manufacturing line properly and according to Pérez-Gosende et al. (2021, chapter 1) planning of the production line is important, so the company can accomplish the strategic targets more efficiently. This subchapter has been translated from my bachelor's thesis "Asiakasrullan läpimenoaika" (Strömberg, 2023).

2.3.1 Paper machine



Picture 1. Paper machine (Strömberg, 2023)

The picture above shows the paper machine. According to Paulapuro (2008, chapter 2) paper machine is a technical machine, where the paper quality is being ensured by using advanced gadgets. The paper quality can be measured in real-time with for example measuring frames and hole recognition system. In the research by Saini and Kumar (2019, chapter 1), they state that paper machine consists of wet-end (headbox and wire part), pressing part and dry-end (which means dryer and post-drying operation), after those, the paper is rolled over a moveable spool to form an intermediate product called jumbo reel. Spool is a type of roll that the paper will be temporarily moved to in different parts of the paper making. The purpose of paper machine is to manufacture base paper from paper pulp.

The wet-end on paper machine consists of wire part and headbox (Knowpap 2023). In their research (Saini & Kumar, chapter 2) mentions that there are two types of headboxes: open type or pressurized headbox. The main objective for headbox is to spread out the paper pulp evenly to the wire part through supply piping (Knowpap). This leads to as equal quality of paper as possible. Paulapuro (chapter 5) mentions that the equal quality is extremely important in the work of headbox. In practice, this means that the paper

pulp needs to come at an even speed to the headbox and go through the supply piping simultaneously to ensure the best possible paper quality. Wire part defines the structure of the paper (Knowpap) and the most important objective for wire part is to control the paper square mass / grammage. In practice, the customer orders products by their grammage, and the wire part controls the grammage of the base paper.

The objective for pressing part is to remove the excessive water from the paper (Knowpap). According to Knowpap, there are two types of presses, for open tail threading there is twin-nip press and for closed tail threading, there is shoe press. Both are efficient nowadays because of the long development of them. However, closed tail threading and shoe presses are more popular due to the fewer amount of breaks. The press functioning is important in paper manufacturing, because drying helps the paper forming but also reduces the durability of the paper in the meantime (Paulapuro, chapter 6). Press needs to work correctly, so the quality and characters of the paper will be as good as possible.

In the drying part of the paper machine, the paper will be dried to complete base paper. Drying part is located in the hood which can be recognized from the picture 1 as a big "box" in the left end of the picture. The drying happens with heat, so this is why the hood has doors that keep the hot air inside of the inverted funnel. If break occurs, the doors will open, so the tail threading can be done. According to Chavan et al. (2015, chapter 2) the drying of paper is happening through a hot air that comes from the drying cylinder in the hood. This way, the paper can move forwards in the outer ring of the drying cylinder. In my experience, I know that the drying cylinders create multiple cylinder groups and there is a drying wire going through each of the cylinder groups. The paper goes through the cylinder groups either on the outside of drying wire or in between the drying wire and drying cylinder. According to Karlsson (2010, chapter 1) drying part is the longest and most energy consuming part of the paper machine. Often, there are over 50 cylinders in the drying part. To minimize the energy consumption. It is important to get the paper as dry as possible after the pressing part of the paper machine (Karlsson, chapter 1). After the drying part, there is a cylinder wheelchair, where the

paper will be rewinded over the spool. Complete base paper will be rewinded to the spool and the base paper will be going to the next procedure in the production line after the completion and change of paper jumbo reel. The next procedure in the production line is re-reeler.

2.3.2 Re-reeler



Picture 2. Re-reeler (Strömberg, 2023)

Re-reeler (picture 2) is the second production phase in the production line after paper machine. Jumbo reel goes through the re-reeler before advancing to the coating machine. According to Belgacem & Pizzi (2016, chapter 18) the most important objective for re-reeler is to prepare the jumbo reel to be ready for coating machine and supercalender, because the breaks that happen in those phases of production lengthens the time of the whole process and can cause huge expenses if the machines break. The preparing means that the re-reeler needs to figure out the problems in the jumbo reel, such as fix the possible holes in the base paper (Belgacem & Pizzi, chapter 18). According to Know-pap, the other objective for re-reeler is to cut the edge strips off the paper edges, so the paper goes through the next production phases more smoothly.

2.3.3 Coating machine



Picture 3. Coating machine (Strömberg, 2023)

According to Chang & Weng (2001, chapter 2) there needs to be four parts in the paper machine: unwinding section, coating section, drying section and rewinding section. Unwinding section, which is in the right hand side of the picture, spins the jumbo reel and guides the base paper from the spool into the coating machine. Base paper needs to be intact and good quality so there will not be any problems in the coating machine. As Podgornik (2001, chapter 1) noticed in the research, the core of the paper is the most important factor to a successful coating.

There needs to be a coating section in the coating machine to coat the paper. Multiple coating stations form the coating section, the amount of coating sections can vary but in my experience, I have seen coating machines with two coating stations and four coating stations. The objective for coating station is to coat the paper. There are various of different coating methods, for example SymSizer coating. SymSizer is a method that was invented in the 1990s. The transition to SymSizer coating happened in the 90s because it reduced the paper breakage and added the speed that the coating machine could operate, also the coating was good quality and the stability in quality increased and the service of the machine got easier (Toyota, 1997, chapter 1). However, according to

Situmeang, SymSizer coating damages and reduces the service life of the applicator rod that locates in the coating station.

Drying part of the coating machine is partly the same as in paper machine. The paper is dried using air-float web-driers which blow hot air to the paper. As Sugarman & Vitale (1992, chapter 5) noticed in their research, the paper drying depends mostly about the structure of the paper, for example the thickness of the paper. This is why different paper products/grades are dried using different amount of drying power. In my own experience, the drying power is mostly controlled by the use of air-float web-driers by shutting down some of them or reducing the power of them. Air-float web-driers are air drier machines that dries the paper from its both sides. There are also one-sided air driers but according to Paltakari (2009, chapter 5) two-sided air-float web-driers are more common because they can be used to more paper products / grades. The company which production line is under investigation in this thesis uses two-sided air-float web-driers because of their versatility. There is also second function for air-float web-driers according to Paltakari (chapter 5) which is to guide the paper into the next destination in the coating machine. There are drying wire groups in the coating machine as well. They are quite similar to paper machine, but the difference is that the coating machine does not have a big hood (coating machine might still have a small hood). The function of drying wire in coating machine is the same as in paper machine, so the paper goes through the cylinder groups either on the outside of drying wire or in between the drying wire and drying cylinder. The drying power of drying wire groups are commonly worse than in paper machine because the paper has already gone through the air-float web-driers and is already quite dry before the drying wire groups as the research by Paltakari (chapter 5) states.

The cylinder wheelchair and rewinder works in a similar way that they work in paper machine. So the paper will rewind over the spool and during the spool change, the old jumbo reel will discharge from the cylinder wheelchair and new spool will be replacing the old jumbo reel.

2.3.4 Calenders



Picture 4. Supercalender (Strömberg, 2023)



Picture 5. Mattcalender (Strömberg, 2023)

In the pictures 4 and 5 (beneath), there are two kinds of calenders, supercalender and mattcalender. The basic mechanism behind the calenders are similar but these two calenders are used for different paper grades. Mattcalender is being used for matt grades and supercalender is being used for gloss grades. As visible in the pictures 4 & 5, the

supercalender is vertical and mattcalender is horizontal. As can be reasoned, calenders can be either horizontal or vertical.

Rautiainen (2010, chapter 1) states that the basic principle of supercalender is to squeeze the paper through a nip that appears between two different cylinders. Nip means the small gap between cylinders, and the paper goes through it. In my own experience, I know that the nips are dangerous in paper manufacturing and it is essential to be careful around them to ensure the safety at work. Vernehs et al. (2010, chapter 1) claim that the objective of calendering is to add the paper quality and enhance the ability to print the paper. As noticed in the bachelor's thesis "Asiakasrullan läpimenoaika", calendering is slower than other parts of the production line phases, which leads to bottlenecks. Paper mills often use multiple calenders in the production line to avoid the bottlenecks in this part of the production phase.

Vernehs et al. (chapter 4) state that the calendering reduces the variances in the surface of the paper and therefore reduces the amount of quality claims and mistakes. Rautiainen (chapter 1) writes that the calendering can be adjusted by changing the amount of pressure and heat in the nips. In their study, Ozcan & Tutak (2021, chapter 3) compared the paper quality before and after calenders. The results of their study was that the biggest change in the quality of the paper was the significant improvement of the softness of the paper after calendering.

There are three basic parts in the calender: unwinder, cylinder part and rewinder. Unwinder and rewinder works exactly the same as in the coating machine, except for the jumbo reel exchange. The jumbo reel change happens in slow speed with the use of automation. Cylinder part consists of multiple cylinders that have nips in between them. This way the paper can be prepared into the next process phase, which is winder.

2.3.5 Winder



Picture 6. Winder (Strömberg, 2023)

Winder is the place where the jumbo reel will be cut to the ordered length and width, so called customer reels. According to Zwart & Lindgren (2012, chapter 1) the main objective for winder is to cut the customer reels to a set trim that the production planner has trimmed beforehand. Trim is defined by width, length and diameter. The speed of the winder is fast in the beginning of the ongoing drop, but slows down towards the end of the drop since the diameter of the jumbo reel reduces (Zwart & Lindgren, chapter 1). Drop means a certain length of the jumbo reel.

The important control targets for winder are the control of the paper web, high quality cutting, keeping the distance between cut paper reels and ensuring the hardness and tension to keep the customer reel undamaged during the rewinding, transporting and unwinding later on in the product lifecycle (Knowpap, 2023). According to Knowpap, on top of that, it is important to make sure that the paper quality is within the defined framework. This is because there will not be any changes to the customer reel after winder, so the customer reel must meet the standards that has been set by the customer. The quality is being ensured for example by random quality checks and samples.

2.3.6 Wrapping machine



Picture 7. Wrapping Machine (Strömberg, 2023)

Wrapping machine is the last phase of the production line. The objective for wrapping machine is to pack the customer reels that comes from the winder into a transportable form. This means that the customer reels are tightly packed into cardboard, so the customer reels will not damage during the transportation process. Wrapping machine is the fastest phase of the production line.

According to Pires et al. (2001, chapter 2) wrapping machine consists of four phases: identification of the customer reel, packing, external packing and naming of the customer reel. Identification of the customer reel means that the customer reel will be measured according to its size and weight. After this, the customer reel will be packaged to the cardboards. External packing means the finishing of the packing, so the official wrapping of the customer reel will be made in this phase of the wrapping machine. In the last phase of the wrapping machine, there will be the naming of the customer reel. This means that the customer reel will get its label (which consists of name, identification number, reel number etc.), so the customer reel can be recognized in the warehouse and be sent to the customer. After this phase, the reel is ready to be transferred to the

warehouse and eventually to the customer, so this is the point where the lead time calculation for customer reel ends.

2.4 Production management

This chapter explains the production control systems that are being used in the case company and also describes and defines the terms jumbo reel and customer reel, which are often used in this thesis. This chapter is based on the bachelor thesis “Asiakasrullan läpimenoaika” (Strömberg).

2.4.1 Production Control System

The case study company uses two different production control systems. One is a well-known ERP-system (Enterprise Resource Planning), SAP (System Application and Product), and the other one is MICS, that is mostly used in the production line.

MICS enables the tracking of jumbo reel, customer reel and winder information (Know-pap). MICS is the most important production control system in the case study company for the production line. One of the most important tools, throughput calculation tool has been created directly from the data that is available in MICS. In my own experience, MICS is being used in every phase in the production line and every change to the jumbo reel will be made according to MICS. MICS is also the direct connection between the production planning and the production line workers. Next up is the tool for sales and production planners, SAP.

Lubis et al. (2021, chapter 1) states that SAP-system is one of the best ERP-systems in the world, and it is used in many of the well-known businesses in the world. SAP-system is meant to combine all of the company's functions in the same whole. According to Dave et al. (2023, chapter 7) it is important for the business to have a proper functioning ERP

system from customer point of view because this means that the customer can enhance their order creation by making the order easier or independently. This reduces the time and cost for the business and possibly even improves the deals. In the case company, SAP connects to the production line in a way that the customer sales representatives book the order into the SAP-system and the production planners plan the orders to fit the production. In short, the orders will be automatically exported from SAP to MICS, where the production planner will trim the orders into the production runs. After trimming, the order can be seen from the MICS and the production line workers can produce the goods.

2.4.2 Jumbo reel



Picture 8. Jumbo reel (Strömberg, 2023)

Jumbo reel is the object that is being handled in every phase of the production line, except for the wrapping machine. According to Faïree et al. (2020, chapter 1) customer reels will be produced out of the jumbo reel once the jumbo reel is finished. So, the jumbo reel is the intermediate product that the customer reels will be made of, and sent to customers afterwards. Jumbo reel forms of the paper that has been rewinded over

the axel. There are multiple axels in the production line and the paper goes through many different axels throughout the production process.

2.4.3 Customer reel



Picture 9. Customer reel (Strömberg, 2023)

Customer reel is a white roll as seen in the picture 9. The size of the customer reel varies depending on the desired width and diameter by the customer. According to Chauhan et al. (2008, chapter 1), customer reel is the end product in some factories, such as in the case study company, and the customer reels are being sold forwards as they are, rather than doing any modifications. In their research (Chauhan et al., 2008, chapter 1) the researchers find out that the cost of making customer reels in winder is high since the trimming of the reels cause waste that cannot be used. This is why it is important to trim as efficient as possible, so the cost of waste will not raise.

2.5 Product portfolio expansion and limitations

This subchapter reviews and explains the effects that the growing product portfolio has to the efficiency of production line and what limitations the product portfolio expansion may mean to the production line. These topics are research questions in this thesis and they need to be assessed in the literature review before jumping into the methodology and the practical side of this thesis.

2.5.1 Effects of growing product portfolio

Product portfolio expansion effects sales, production line, and the supply chain in terms of product availability, supply chain lead time, and production line limitations and lead time. In terms of sales, the expansion of product portfolio is good because they have a wider catalogue of products to offer to customers. However, this thesis focuses on the effects on the production line, so the aim is to figure out them.

Growing product portfolio increases the complexity for production line, since the different paper products need different amount of raw materials to produce them. This means that the grade change waste increases as there are more products available and therefore, it increases the cost of producing the goods. The availability of different paper products also changes the reference cycle of paper grades, which means that there are more paper grades to be produced in the same time period than there was previously. This leads to the fact that paper production runs will be smaller and there are more grade changes in the production line. The trimming of the production runs also becomes more difficult since there are not the same amount of volumes in the production runs and the trimming of the production run will therefore cause more waste.

According to Koskinen & Hilmola (2009) the amount of production lots also increases the lead time by a big margin. Koskinen & Hilmola state that by increasing the number of production lots by one, "the production time increases by 2,5 to 4,2 days." However,

Koskinen & Hilmola fail to take the trimming of the production runs into consideration. In real-life, it is better to produce the goods in a way that the waste percentage is relatively low, which means that the production of the goods can be happening on multiple production lots. By minimizing the waste, the factory can be more efficient. In these cases, it is extremely important to consider warehouse spacing. Regarding this project, the warehouse spacing is not a problem since that was measured pre-project with the experts. The aim for reference cycle modification is to reduce the amount of production runs to decrease the waste from grade changes and trimming by increasing the volume in production runs. According to Koskinen & Hilmola, the number of produced reels and the number of production lots effect four to six percent of the total supply chain lead time, so the aim for reference cycle is to target that part of lead time in the total supply chain.

2.5.2 Production line limitations

Production line has some limitations in terms of reference cycle and the availability of the products. There are some paper grades and grammages that cannot be produced straight after certain paper product and that causes limitations to the reference cycle. Some grammages cannot be produced directly after each other because that would increase the paper grade waste substantially. Also, some paper grades cannot be produced in a row because of the raw materials and their compatibility. This is why the reference cycle needs to be modified with the help of paper quality management and production line engineers.

Other limitation that is existing is the limitation of how long a certain paper grade can be produced in a row. This is because too long production runs of a certain products can cause problems in the throughput in production line. There is also a limitation in terms of the shortness of production run, and there needs to be at least a certain amount of tonnage (meaning orders) that needs to be produced in a single production run for it to be efficient and beneficial for the company.

It is important to be aware of the limitations of the production line before taking any actions and implementations in this project, so the mistakes can be avoided in the paper manufacturing in terms of limitations that are already known in the production line. This is one of the reasons that the project team consists of experts from the production line to avoid the practical challenges in the implementation process.

3 Methodology

This chapter introduces the methodology that will be used in this thesis. This includes the research methods, data collection and data analysis.

3.1 Research methods

The research will be quantitative, since the reports and key performance indicators (KPIs) are based on quantitative data. Sample size for the data is around 200 000 measurements. The possible actions to improve the challenges will be evaluated before implementing these actions, and the improvements are being monitored with the help of the KPIs. Actions will be made together with the project team and the quantitative data, so there will be experts working on every aspect of this project to ensure the quality of the possible solutions. These procedures are done to every improvement idea to follow the methodology of the thesis, DMAIC (which comes from five phases: define, measure, analyze, improve and control).

3.2 Data collection

The data will be collected from the systems of the company with the help of reporting tools. There will be eight different key performance indicators that will be followed within certain time period, and the status of the key performance indicators will be uploaded monthly to an excel file to measure the progress of the project. The data can be measured accurately from the system, and the data collection tools and reports have been made to accurately measure the chosen KPI's to ensure the success of the project. The data has chosen to be collected in quantitative data, because it can be visualized and the progress of the study is easily measurable.

3.3 Data analysis

As mentioned in Mertens et al. (2017) research, first thing to do in the data analysis is to structure and clean the data, before continuing to explore with the data. In this project, the structuring and cleaning of the data will be done after collecting the data from the systems. The data will be placed into individual reports and those will be modified to match the need for the certain key performance indicator to be visualized in one picture. After structuring and cleaning the data, the exploring will have the data formatted to one, simple chart that can be transferred to the excel file that has the progress charts of every key performance indicator. The data analysis will be then used as a tool to find solutions to the challenges that there are in the project.

The solutions for the challenges will be created by using the constructive method. According to Smelser & Baltes (2001) constructive method means the open-ended thinking of a new solution based on combining different details until the solution is created to fit the challenge. So, in this thesis, the solutions will be slowly created based on previous knowledge of the challenge and combining them with the quantitative data and expertise that the project team experts have.

3.4 Validity and reliability

According to Heale & Twycross (2015) validity and reliability in quantitative research can be existent if the study is accurately measured and the study can be replicated. Validity, accurate measurement, is existent in the study if the results have connection to the core of the study, in other words, research questions. The reliability is existent in the study if the results can be replicated in similar conditions with the same measurements.

In this study, the project has been scoped as accurately as possible to be able to provide answers to the research questions and therefore, increase the validity of the research. The reliability of the study can be seen from the quantitative data, the project is planned

to last six months. This is enough time to ensure the reliability of the data, and to see the possible enhancements of the project from the data sample as the project progresses. To ensure the reliability, the measurements, reports and data must be modified to a similar format that will be used in this project.

4 Project Management

This chapter introduces project scope and project team. After that, there will be introduction to the possible improvements and enhancements that are being considered to be implemented into the production line to fulfil the objective of production line efficiency management and optimization project. The project follows DMAIC methodology, so all the project topics will be analysed with the help of DMAIC phases. This will involve the introduction of the topic, improvements to the topic, the evaluation of the topic, and the implementation of the topic (define, measure, analyze, improve). The results and analysis of the implemented actions will be presented in the result chapter of this thesis (control). There will also be an introduction to the key performance indicators that are invented to track the project progress and help in the analysis phase of the project.

4.1 Project scope

As mentioned earlier in chapter 2.2, the most important thing for DMAIC project is to scope the project correctly in order to successfully complete the project. The scope for the project is that the project will be done to one production line in the paper factory and the production lead time and efficiency analysis will be directed in between the start of the paper machine and end of the packing machine. This means that the warehouse will not be considered in this project, and the analysis and evaluation about the possible impacts to the warehouse has been done as independent research before starting this project.

The data for this study will be collected from the company's database within a certain time period and the data will be analysed by comparing the pre-project data to the post-project data. The data will be transferred from the company's database to excel files that have been specifically created for this project to make the data analysis part of the study simpler and more presentable. The project consists of three different target objectives that are related to the reference cycle, unplanned stock and grade change waste. The

aim for these objectives is to improve them individually, and also to optimize the management of lead time and efficiency for the whole production line.

4.2 Project team

According to Oh & Choi (2020, chapter 5) by defining the competence of the team members, it will be the “foundation for project success and sustainable competitive advantage”. Based on that, the project team consists of four people and the people have been selected based on their work position. This is to ensure that there would be an expert in every challenge that will be researched in this thesis. On top of the project team, there are three people that can be contacted during any time in this project and the three people will offer guidance to the project manager. Project manager will be me, the author of this thesis and the main objective for the project manager will be to lead the project through and being on schedule. The challenges of this project has been figured out before the start of the project, so project manager will arrange monthly/weekly meetings with the project team to find solutions and possible enhancements to the challenges.

Project team has three more people on top of project manager, the work positions for the remaining three people are supply chain planner, production engineer and supervisor. Supply chain planner does the trimming of the production runs, so she is in the team to help solve problems regarding the production planning and waste side. Production engineer and supervisor works with the production line workers so they are in the team to help figuring out the solution to challenges that regards the unplanned stock and waste in grade changing. The three people that will help in guidance in the project are all managers in mill, production line or supply chain.

4.3 Reference cycle

Reference cycle is the scheduled cycle for the paper products within a certain time. The paper products need to be produced in a certain order to maximize the efficiency regarding the paper mass and waste. King et al. (2023) explains that typical project of improving scheduling (in this context, reference cycle) improves the manufacturing efficiency by even 30 %, and releases more time for production planners to do other work. King et al. also argument that a structured and regularly repeated cycle have many advantages to production, and to customer delivery.

One reference cycle in the case company's production line lasts for one month, in where some of the paper products are produced weekly, some are produced bi-weekly and some products are produced monthly. The aim in this project is to reduce the amount of time losses and waste because of the reference cycle. Reducing grade change waste will be own chapter 4.5. Time losses regarding the reference cycle occurs when the production runs are too small and the line productivity decreases. This leads to a situation where there are not enough spools for the paper machine, and the production has to be stopped for a certain time period to wait for the production line clearance to get enough spools again. Time losses also occur when the trimming of production runs is bad, and the spools cannot be emptied in the reel cutting machine, leading to the lack of spools in the paper machine. To reach the objective of reducing time losses, the reference cycle needs to be adjusted, so the production runs would be bigger, and the trimming of the runs would be more efficient.

4.3.1 Enhancing the reference cycle

One paper product consists of two different diameters from which the customer can choose from, this means that there are two different production runs for each of the paper products. It is also common that there will be excessive paper produced per every single production run. This means that there will be tied-up capital on the excessive

paper that has been produced but cannot be allocated to any order yet. This is not the main objective in enhancing the reference cycle, but it might come as a side effect in the project. The main aim for reference cycle enhancement is to cut down the amount of production runs in the reference cycle period.

The first option is to reduce the diameters to only one option for all, or some of the products. This would cut down the production runs in the monthly cycle and solve the problem easily. The downside of this solution is that it would be a limitation for customers, since it they would be able to order only one diameter of the paper product they want and their machines might not be a fit for that diameter.

Other option for enhancing the reference cycle is to calculate the annual volumes of every paper product to see if it is efficient to offer so many different products weekly and bi-weekly or would it be possible to reduce the amount of times that the certain paper products are being produced within the month.

After the consideration of the other option, the calculation of annual volumes was needed. That was done by calculating all the orders that were ordered and produced during year of 2024 and sorting them out by their product. According to the data from 2024, there was a possibility to reduce the production runs in a month by a bit over 12 %. This would be possible if some of the bi-weekly products would be reduced to monthly produced products, so the availability of the chosen products would reduce by 50 %.

4.3.2 Evaluating the enhancement ideas

After the two options were figured out, they need to be evaluated and accepted together with the sales office and production team. Option one, limiting diameters to reduce the production runs was not possible according to the sales office because it would have limited the customers too much and the company would face a risk of losing a lot of

orders. So, the first option was declined in the evaluation phase of the reference cycle enhancement process.

Second option was the reduction of some products to a monthly basis from bi-weekly status. This was more pleasing to the sales, and they accepted some of the change proposals. However, all of the products were not accepted to be reduced to monthly basis because sales did not want to drop the availability of certain strategically important products. Regardless of that, the percentage that the sales accepted for production run reducing was almost 8,5 %. Next step was to ask production team if this change in production runs was okay to them. The production team accepted the idea because this production run change means that theoretically the amount of waste will be lower due to less product grade change waste and bigger production runs. This can also lower the production line lead time because theoretically the possibility for lack of spools will be less than it used to be.

4.3.3 Implementation of the enhanced reference cycle

After the evaluation and acceptance of new reference cycle, the next step is to implement it into production line. The desired week for new reference cycle implementation was chosen to be week 20. The needed changes to the previous reference cycle were done couple weeks in advance so the implementation of the new reference cycle would go as smoothly as possible. The previous reference cycle was replaced by the new cycle from week 20 onwards and the already existing orders were moved to correct production runs, so there would not be any delays because of the new reference cycle. Only problem was the latest date of revision status for the already existing orders. Latest date or revision means the last day for the order to be released so the order can be produced, so basically if order still has a latest date of revision status, it is just a reservation order and not a confirmed order. Some of the orders have been booked in advance and the LDR (latest date of revision) was too late for the new production run date, because some of the previous runs were removed from the reference cycle. This problem was solved

by letting the sales know of the new dates for the production run, so the orders could be released from the LDR status in time for the updated production run. After the implementation of the new reference cycle, the enhancements have to be followed to see the true effect that the new reference cycle has to the production line. Results and analysis will be shown in the result section of the thesis.

4.4 Unplanned stock

Unplanned stock means the stock of all the extra and unplanned paper produced that can be allocated to a new order. Unplanned stock has positive and negative side for a company. Positive sides are that some of the orders can be filled straight from the unplanned stock which reduces the lead time for the orders. This is because the order does not need to be produced again and it can be just packed or cut, and then packed straight to a customer reel and shipped to the customer. Negative sides of unplanned stock are when the stock is too high and the cycle of the overproduced paper is too slow. It is not efficient unplanned stock when the cycle of the overproduced paper is slow, for example some of the reels can be laying in the unplanned stock for a year and they can be forgotten to there. Also, when the stock is too high, there is a risk that the warehouse cannot hold everything and the warehouse becomes ineffective. Ineffective warehouse can lead to delays in deliveries and the possibility that the reels can go missing. Too high unplanned stock also creates safety risks to the personnel.

4.4.1 Brainstorming for the enhancement of unplanned stock

The project manager organized couple of meetings with the project team to figure out ideas for improvements to the unplanned stock. First, the ideas were collected and thought through before final evaluation of the ideas. The ideas were the following: to have the same principles and framework for every production worker so the efficiency in work can be secured, the better use of information in the production line so everyone

can be up to date in the important decisions, the wider spreading of information to keep the excessive paper production into minimum to ensure that the lead time can be optimized, the proper use of the stock by eliminating the slow cycle of the stock, packing the reels as soon as possible from the production line, eliminating the reels from the stock that cannot be used in the future, having a meeting every week about the unplanned stock, collecting replenishment orders to get rid of the excessive paper in unplanned stock, and to have a recommended size for the reels that will be cut to the unplanned stock so they can be easily allocated to the orders in the future. All of the ideas have to be evaluated after the brainstorming and the evaluation process needs some help from people that are not part of the project team. The project manager needs to organize meetings for the needed people in order to evaluate the improvement ideas for them to be viable to be implemented.

4.4.2 Evaluation and possible implementations of the ideas

Evaluation of the ideas needs to be done separately and one idea at a time. First idea was that everyone would have the same framework regarding work instructions, this is difficult to implement since the workers have variation between their methods in work and the instructions have variation depending on the instructor. The recommendation to overcome this challenge is that there should be one clear instruction to each job position and everyone should be instructed according to that in order to eliminate the variation between methods in work. Other idea, enhancement of information accessibility can be increased by guiding the shift supervisors to be more open regarding the information that they have and that the supervisors would share the information to every phase of the production line rather than just one phase. The concern for excessive paper was evaluated within the team, and the challenge is that the excessive paper is produced because of the decisions in the production line. To solve the problem, the team came up with the idea that there should be a guide for the supervisors. The aim for the guide is to control the amount of excessive paper, especially for the paper grades that are not

produced often, because the paper is harder to allocate to orders that are not commonly ordered.

The challenge of eliminating the slow cycle of stock was analyzed by the project team and the idea was found followingly: change stock types, so that certain paper will be transferred to another stock type which will be eliminated every three months from the production date, if the paper has not been used. This improves and speeds up the cycle of the stock and therefore reduces the amount of tied-up capital in the stock. However, when the project manager contacted other people outside the project team that can help with the change for stock types, it came up that the change for this is already on the way. With the help of project team and the worker in charge of this change, the solution was pushed towards IT to make it happen. The risks were assessed and the proposal included a “backdoor” that can be used to revert the changes if they do not work as hoped.

To control the amount of tons in the unplanned stock, the idea was to pack the reels as soon as possible to customer reels. The solution for this was that the fine planner should send a excel file to the operators so they can see which reels can be packed from the stock. Eliminating the unnecessary reels from stock was the next challenge that was assessed. Solution for this was to send out a list to paper quality management every once in a while so they can go through the reels and let the operators / fine planner know about the reels that can be eliminated, so the stock can be optimized. Final challenge that was assessed in the meeting was the need for replenishment orders. Replenishment orders can be asked from the officers that are working with replenishment stocks and replenishment is just a stock order to different warehouses around the Europe that are made according to the reports. Fine planner can ask for replenishment orders if they see that there is a lot of paper that is certain width and the replenishment officers can make an order for the quantity of the paper grade. The team did not find a better solution for this but the solution for this already exists and the fine planners got a reminder of it.

4.5 Grade change waste

Grade change waste comes from changing the paper grades to different grammage or optical attribute. The paper needs to be within certain tolerances and all the paper that is not within the tolerances is considered as a waste. One objective for lead time optimization is to reduce the amount of grade change waste because, naturally, the more excessive paper each production run produces, it will increase the production lead time in average. Paper grade change waste reduction also happens with the optimization of reference cycle, because the variation of the paper grades produced monthly drops by almost 8,5 % and therefore the paper grade change reduces by the same amount. This leads to savings in paper grade change waste.

Other improvement for paper grade change waste can be calculated from the tolerances to see if it would be viable to change the tolerances to save production lead time and resources without affecting the paper quality and avoiding the complaints from the customer. However, this can only be calculated in theory since this thesis will not plan a trial run for the tolerance change, and therefore it is only going to be an improvement recommendation for the case company. There will not be a chapter about the calculations of the tolerance change, since it is classified information. However, calculations indicated that there is a huge opportunity for the tolerance change, and with one paper grade change, the potential savings for paper grade change waste were 14,32 %. This can be applied to other paper grades and grammages, which would reduce the percentage savings, but would increase the total savings and efficiency for the production line. This can lead to huge annual savings from paper grade waste if the improvement proposal is evaluated and implemented correctly.

4.6 Key performance indicators

This subchapter will introduce the key performance indicators (KPIs) that are used in this project to analyse the data and track the results of the improvements. Each of the KPI will be introduced and the usage and importance of them to be included in this project will be explained.

4.6.1 Lead time

KPI for lead time calculation is very obvious one, because one of the main reasons for the project is to manage the lead times of the production line even though the product portfolio is expanding. The lead time calculations are based on a excel tool that I have created in my bachelor's thesis for the company, so the data for this analysis covers all the product lead times starting from year 2023. However, the sample size will be taken from the project duration, meaning a six month period in 2025 (from April to September). The lead time calculations have time for the jumbo reel throughput time, which means the lead time from paper machine to cutting machine, and also the throughput time for customer reel, which consists of the time needed in between paper machine and packing machine. The data will be anonymized but there will be a graph that shows the development of lead times during the project. Analysis of the lead time will also consider other variables outside from the project that have affected the lead time.

4.6.2 Trim waste

Trim waste measures the efficiency in trimming the orders from the jumbo reel. The orders will be cut to customer reels from the jumbo reel and the aim is to do that with the least amount of trim waste as possible. This is one of the most important objective for fine planning in the production planning, so the amount of waste will not raise, and the profitability of paper manufacturing can be as high as possible. Trim waste has been selected as one of the key performance indicators because the change in reference cycle

will hopefully have a positive effect on the trim waste percentage and this KPI is measuring it. Of course, other variables need to be considered also when thinking about the changes in trim waste, such as the amount of produced tons and the amount of orders and the width (trimming) of the orders.

4.6.3 Side run

Side run is paper that cannot be allocated to any order from the jumbo reel, so it goes to waste. Side run is considered as a waste reel which will be produced from the winders and then it will be placed into pulper afterwards. Side run has been selected as one of the KPIs because the enhancement of the reference cycle should theoretically reduce the amount of side run needed, thus making trimming of the orders more effective and profitable for the company.

4.6.4 Grade change waste

Grade change waste has already been a topic in subchapter 4.5, but in conclusion, grade change waste comes from changing grades because the paper is not within the defined parameters of the next grade, and therefore, creates waste. Grade change waste is an important KPI because there are parts of the project that target the grade change waste, and this is why it is important to follow and investigate grade change waste through reports.

4.6.5 Breaks (lack of spools)

One of the bottlenecks in the production line is the situation when all the spools are tied in some phase of the production line, and there is not enough spools for the paper machine. This leads to a situation where the production on the paper machine needs to be stopped

completely for a number of hours needed to clear enough spools in order to continue the paper production. This situation happens usually because some, or one of the production line phases have a problem and creates a bottleneck. This leads to the jumbo reels stacking up before that production phase and the spools cannot be cleared out of the paper, because the jumbo reels cannot be produced through that production line phase. This problem is being considered in the reference cycle adjustments and therefore this KPI is a good to have in the project. However, this problem cannot be tackled completely because sometimes the breaking of paper production machines just happen and there is no way to predict that.

4.6.6 Unplanned stock

As mentioned in the subchapter 4.4 “Unplanned stock means the stock of all the extra and unplanned paper produced that can be allocated to a new order.” Unplanned stock is important key performance indicator because it is one of the main topics in the thesis. Unplanned stock has influence in the production line efficiency and the production flow and therefore it is important to include it in the key performance indicators. The KPI measures the level of unplanned stock daily, so the monthly average can be calculated and compared to other monthly averages of unplanned stock. Of course, there needs to be noted the influence of production line problems or trial runs into the level of unplanned stock, but the main aim is to enhance the control of the unplanned stock by following this KPI.

4.6.7 Sets per day

This KPI is another measure for the efficiency of trimming. The aim for efficient trimming is to keep the trim waste as low as possible, and also to keep the number of sets per day as low as possible. The set change slows down the production line efficiency in winders and that is why it is important to have as few sets as possible in the trim. This KPI is used

as a tool to see the effects of the enhanced reference cycle change into the winders operation.

4.6.8 Tons per day

Tons per day is a KPI because it is important to know the amount of tons produced daily to have a clear comparison with other key performance indicators. When comparing the key performance indicators, it is important to consider the amount of tons per day to have a fair comparison. For example, naturally there is less sets per day if there is noticeably less tons in a day produced, because that means that the winders have not been in use for the whole time in the month. In the end, we can compare the results and months by comparing months that have similar monthly tonnage volumes. The aim is to find two months that have similar tons per day before and after the project, to see if there has been any improvements in the project.

5 Results

This chapter will present and analyze the results from every KPI from the duration of the project. The duration was 6 months, and every KPI has been analyzed in the end of the month, so there are six measure points in each of the key performance indicator. When it comes to the timetable, all the enhancements and implementations were done by mid-June – July.

5.1 Lead time

The first KPI that will be presented and analyzed is lead time. Lead time KPI has been measured with an excel -sheet that has every throughput time for every reel produced from the whole 6 month time period. All the data has been filtered to correct months and the measurement point is the average time for jumbo reel and customer reel from the whole month production. The amount of reels produced per month is related to the volume of production, so the average throughput time will be influenced by the ordered volumes and the possible challenges in production line.

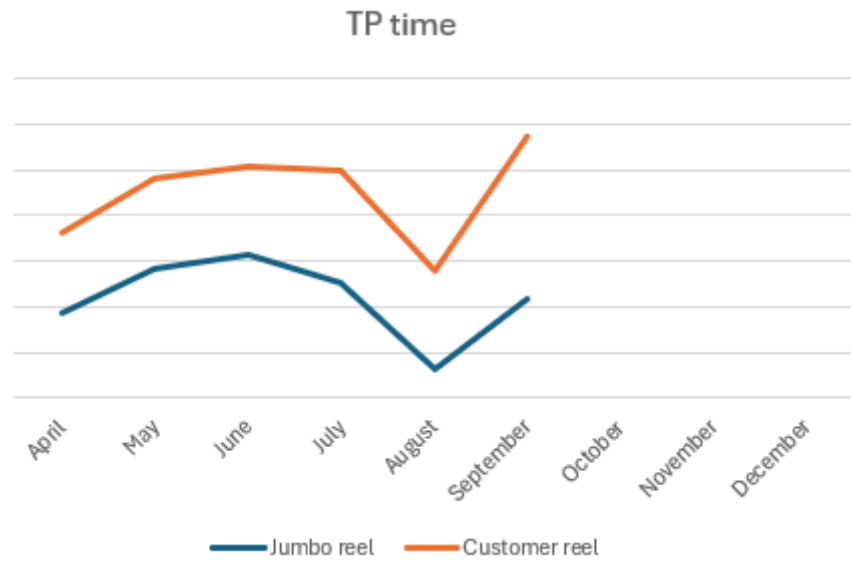


Figure 1. Throughput time

As seen from the figure above, the trend for throughput time has been decreasing in time after the implementations of the project, with record low on August. However, there is a huge bump towards longer throughput times in September, especially for customer reels. Jumbo reel throughput time is still lower than in the previous months apart from August (and on a similar level compared to April). The following will be noticed later on, but September was a challenging month for the production line in terms of other key performance indicators as well. The results from September cannot be excluded from the results of course, but in general, we can see the trend of quicker lead times in the production. It can be concluded that the enhancement procedures did not cause problems in the production line, and also they probably are one of the reasons for the downwards trend of throughput times.

The trend for quicker lead times should have happened mainly because of the changes in reference cycle, at least in theory. The changes in reference cycle means that the production runs should have been longer, causing less grade change waste and trim waste, and therefore enhancing the lead times. There did not come any feedback from the production line about any challenges and problems from the change of the reference cycle.

So based on the throughput time averages and lack of negative feedback, we can assume that the reference cycle change was an improvement.

5.2 Trim waste

Trim waste, which consists of waste that comes from cutting the jumbo reels to customer reels, and the waste that comes from every production phase because the edges of the paper track needs to be straightened, is the next key performance indicator. The aim by the enhancement of reference cycle was to get bigger production runs which would lead to better trim efficiency.

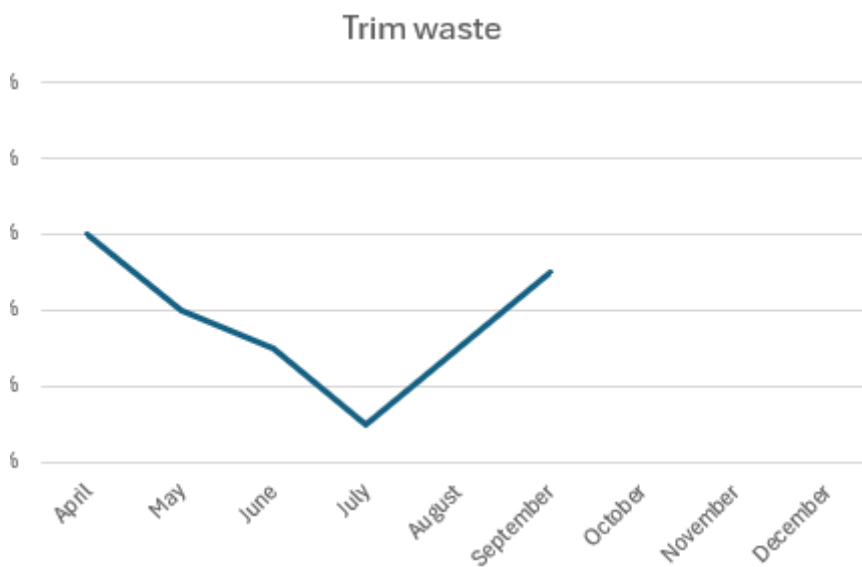


Figure 2. Trim waste

The change in trim efficiency has been getting better from the start point (the lower, the better), however there has been a small increase in trim waste percentage in August and September. What needs to be noticed from the figure is that the differences between the highest and lowest trim waste percentage is only 0.5 %. This means that while there is visibly an enhancement in trim waste efficiency, the improvement has been quite small

percentage wise. But in a long run, it is still an improvement that develops the production line towards lean thinking mindset. Every decimal point counts in efficiency.

5.3 Side run

Side run is the excessive paper that cannot be allocated to a customer order. The decrease in side run was expected to happen due to the change in reference cycle, because the main thought behind the reference cycle enhancement was to get bigger production runs. This leads to more efficient trimming and therefore, less side run.

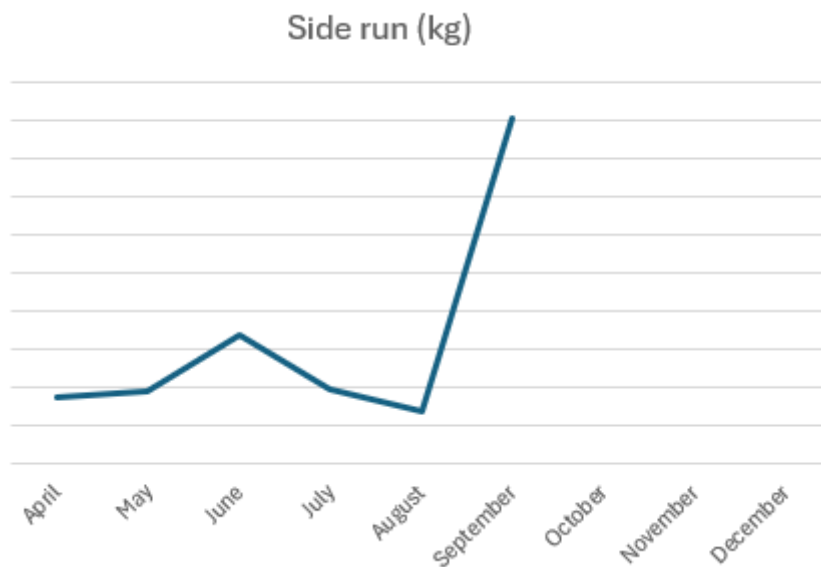


Figure 3. Side run

As seen from the figure, the amount of side run has been slightly decreasing from June, even dropping below the numbers in April, until September. September was a challenging month in many key performance indicator, but this spike in the chart was due to challenging order quantity and width, and lack of other orders from the same grade. This led to the result of side run quantity spiking into the highest level in the whole six month period. However, apart from the one bad month in the project, the side run volumes have been dropping since all the implications had been completed. So, there was no

problems and challenges after implications in the side run, and it can be stated that the implementations of the project were successful from side run point of view.

5.4 Grade change waste

Reducing the grade change waste was one of the main targets in reference cycle enhancement. The idea is that theoretically, the grade change waste should be reducing because certain grades are not in the production runs as often anymore. This leads to less paper grade changes and should reduce the amount of waste that the grade changes cause.

Other idea to save grade change waste was the idea of changing the paper grade production tolerances. This idea was only planned theoretically and the implementation of this will be passed forward to the production team when presenting the results. The theoretical annual savings from the tolerance change are significant if the idea will be evaluated and applied into every production grade successfully. As mentioned in chapter 4.5, “the potential savings for paper grade change waste were 14,32 %”, and this was for only one paper grade change.

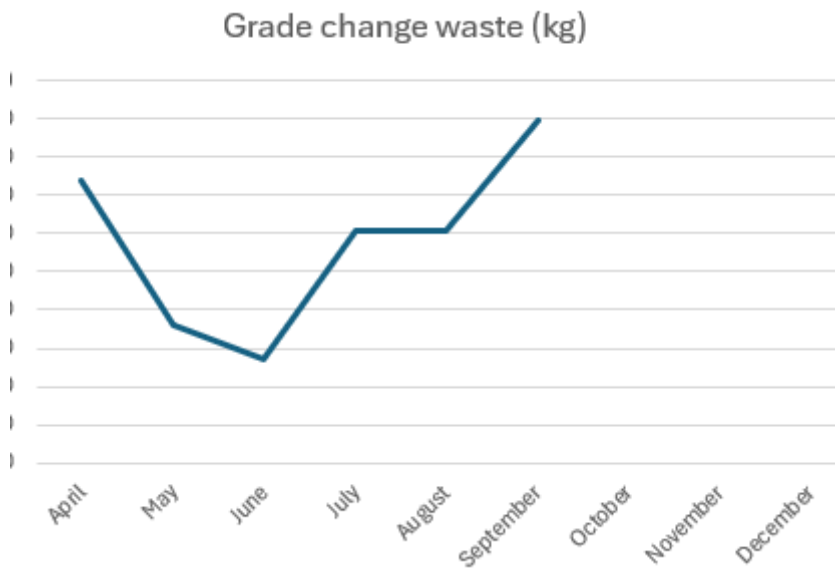


Figure 4. Grade change waste

As seen from the figure, the grade change waste has dropped significantly after the starting period of the project. Unfortunately, there was a huge bump into higher level of grade change waste from June to July. However, July was still better month in terms of paper grade change waste than the pre-project month (April). Of course, on top of that, the bad month in September can be seen from this key performance indicator as well. However, with excluding the bad month in September, it can be seen that the reference cycle improvement has been successfully implemented. Other things that affect the grade change waste are the produced tons per day. If there are no production someday, there will not be any grade change waste. This will have to be taken into consideration and there will be a comparison for every KPI when comparing all the data in two separate comparable months later on in this chapter.

The theoretical improvements to the tolerances of production visualized that the possible grade change waste reduction can be even lower and more significant than the reference cycle improvement. It can be stated that the implementation and trials with new tolerances is highly recommended for the paper quality management when they want to make further improvements based on this project.

5.5 Breaks (lack of spools)

Breaks can happen for multiple reasons, for example: the production line has lack of spools from reasons that are related to the reference cycle and limitations of the production line, there might be lack of malfunction in some production phase which causes too many spools to be tied in certain production phase and production has to be stopped, or there is some problem in the systems and it cannot be worked before production has to be stopped. This indicator counts all the breaks that have been marked as a cause from lack of spools in production, or the malfunction in the production runnability.

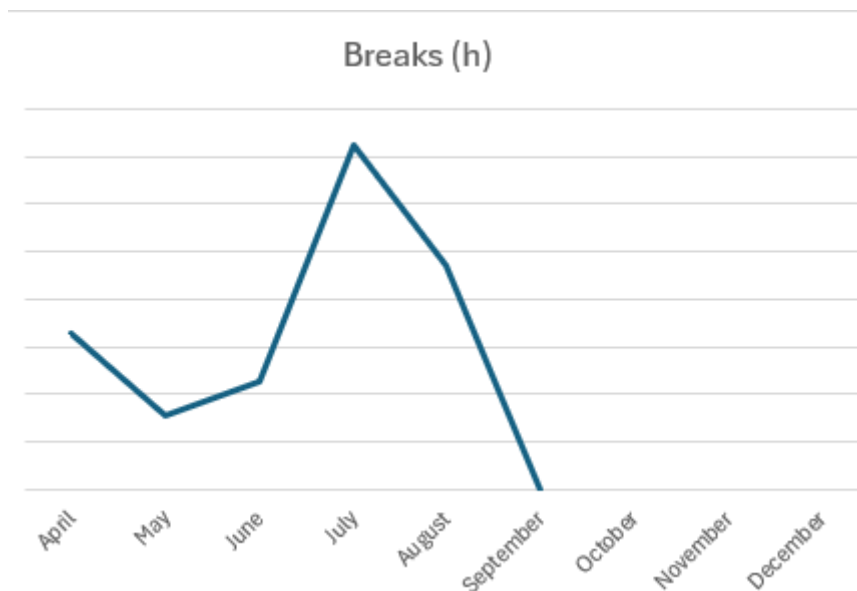


Figure 5. Breaks

As seen from the figure, the break time has a huge variation between different months. This is because production faces different types of problems each month and it is also hugely related to production tonnages. Surprisingly, September had no downtime due to breaks that were caused by reasons that were mentioned earlier, even though September has been the worst month in every other key performance indicator thus far. I contacted production line about this and they confirmed that the data was correct. This proves that the production has huge variety day-to-day and from the graph, it is not possible to certainly say that the implementations in this project has been successful or

unsuccessful. If the company wants to improve on reducing the break time that is caused by runnability or lack of spools, this statistic needs to be examined more carefully in production line with the operators that have hands-on experience in this matter.

5.6 Unplanned stock

Unplanned stock is the reels that have been produced but cannot be allocated to any order in the current time. The level of unplanned stock is directly connected to the production of paper and this is why the levels of unplanned stock varies a lot every day. For example, the stock increases in volume often after different trials or when there is a lot of orders that need side runs, and in the contrary, the volume reduces when the production is stable and the production runs are bigger.

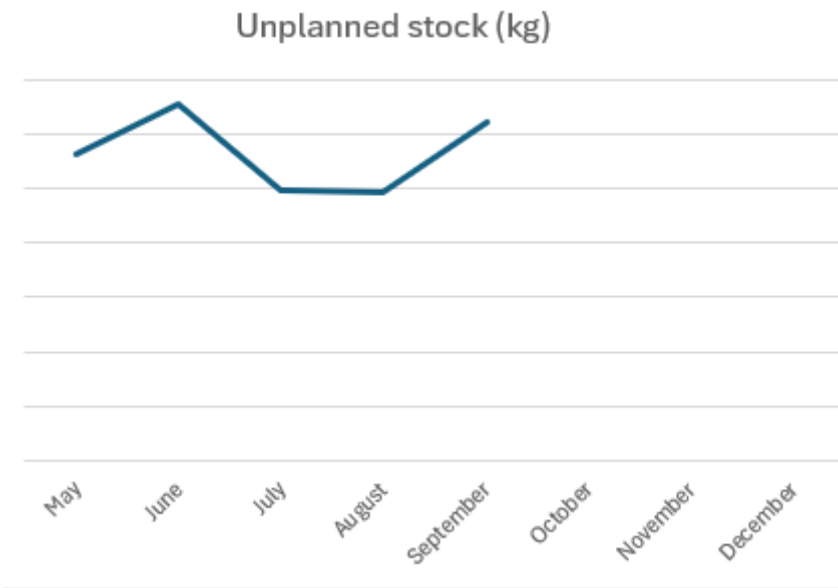


Figure 6. Unplanned stock

The figure shows a reduce in unplanned stock after all of the implementations, except in September. The increase in unplanned stock in September can be mainly explained by the huge increase in side run. Otherwise, the graph shows a downwards trend in unplanned stock and therefore it can be assumed that the unplanned stock has been in

control after the project implementations. The change in sorting AM and S9 stock can only be seen in longer term levels for unplanned stock. This is because the S9 stock type means that the paper has a three month cycle in unplanned stock before it can be pulpered. Pulpering means eliminating the paper from the stock. The change in sorting stock types will be implemented after the project closing so the change in unplanned stock related of the change cannot be seen in the project closing statistics. The trust for the AM and S9 stock change to help in unplanned stock is high and all of the project members have a positive forecast that the change will improve the control of the unplanned stock.

5.7 Sets per day

The winders need to change sets multiple times a day, because of the different trimming widths. Every set change causes extra work and therefore it is important to keep the amount of sets per day as low as possible. Sets are also affected by the production volumes, so the more volume produced, the more sets are needed. The reference cycle is meaning to eliminate the unneeded trimming width changes by ensuring bigger production runs.

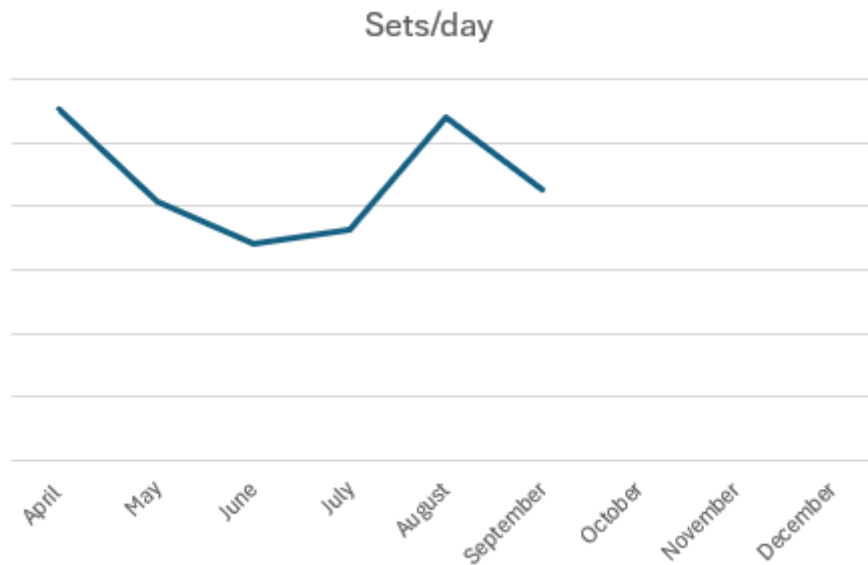


Figure 7. Sets per day

Sets per day have been lower than the starting month every time, so it can be stated that the improvements that have been made were successful. In general, the amount of sets per day has been in moderate level, so this improvement in sets per day is good from operator point of view, because it helps to free time for the operators to concentrate on other things.

5.8 Tons per day

Tons per day visualizes the production rate and efficiency of the production line. If the level of tons per day has been lower than in the previous month, it means that there has been more breaks, stops, or maintenance, or in the contrary, less orders to be produced. Tons per day is a key performance indicator that directly or indirectly has an effect to every other key performance indicator as well.

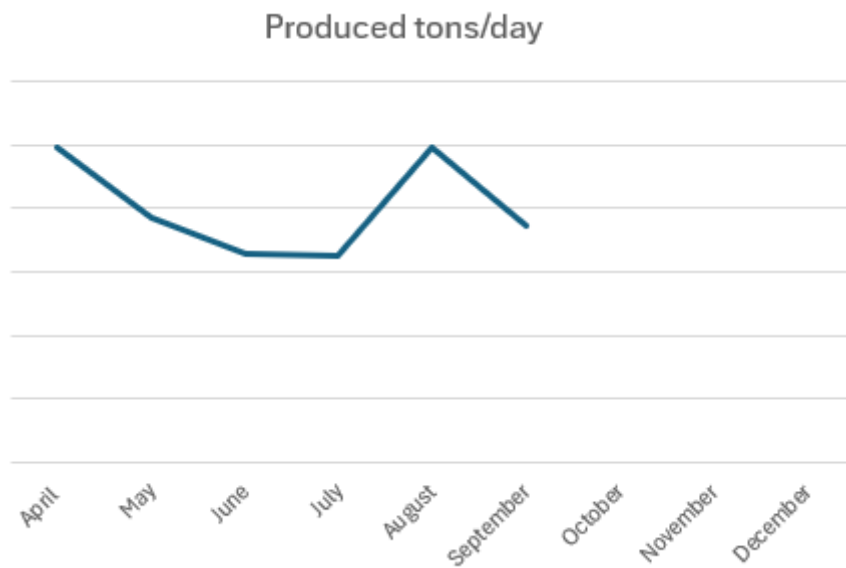


Figure 8. Tons per day

From the figure on top, it can be seen that the produced tons per day has been similar to the pre-project month only once in the six month period. This is why it is important to compare the differences between those two months, to see if there has been an impact to the results from the project implementations. Of course the production has had an impact from some other factors that have not been considered in this project, but the project key performance indicators were selected to be as efficient as possible in measuring the changes.

5.9 Comparison between months pre- and post-project

This chapter compares two similar months before the project and after the project. The months have been selected because of similar tonnage levels, and as stated previously, the tonnage levels influence all of the other key performance indicators directly or indirectly. The graphs have two separate points, red point and green point, which have been marked as the pre-project point (red point) and post-project point (green point). This is because the scaling of the graphs would have changed if other months would have been

deleted from the graph. The two months will be compared by the graphs and by percentage change, because of the anonymization of the data.

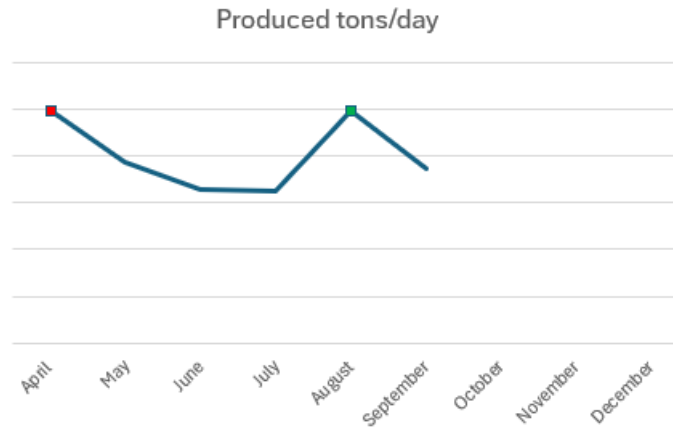


Figure 9. Tons per day difference

As seen from the figure on top, the two most comparable months were April and August. The tons per month were 0,26 % higher in April than in August, so the difference is almost non-existence when comparing the results of other months. The similar level of tons per day is ideal for the project closing, because the results of the project can be easily interpreted from the different key performance indicators without any scaling of the results.

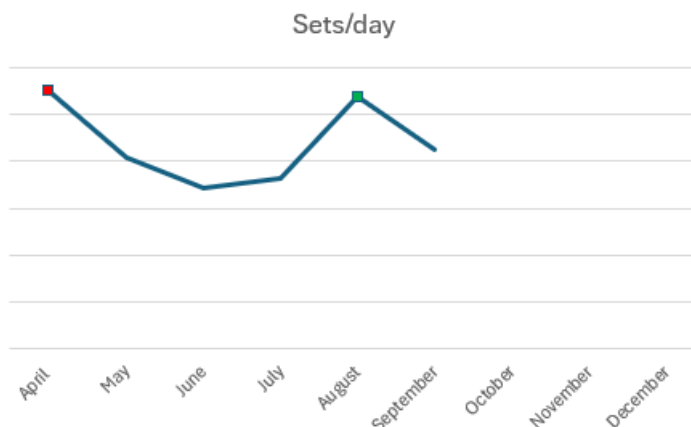


Figure 10. Sets per day difference

Sets per day was 2,17 % lower in August compared to April. The difference percentage is quite low, so while there has been improvement in reducing the sets per day, it is not enough to say that the implementations of the project were successful enough for this KPI. Of course, 2,17 % enhancement is an improvement, and everything counts in the lean thinking process. If the sets per day difference can be kept at 2,17 % in the future also, it is a bigger difference for a whole year of production, and on an annual level, 2,17 % is a big time saving for production line operators. So while the implementations of the project did not manage to enhance the sets per day statistically enough per day, it is a huge increase on annual level.

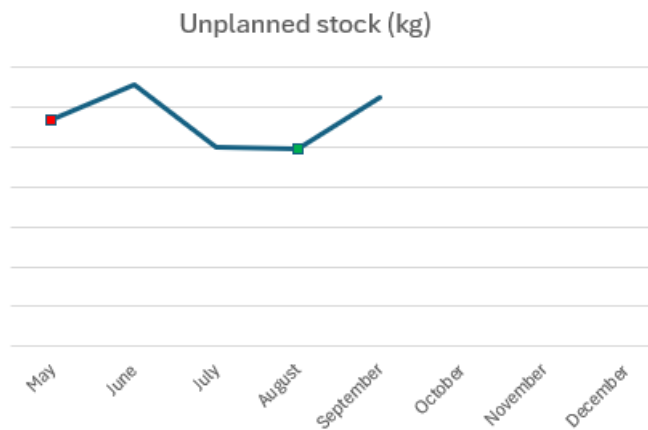


Figure 11. Unplanned stock difference

As seen from the figure, there has been a bigger improvement in unplanned stock when comparing the selected months. However, this KPI is influenced by different trial runs and possible problems in production, so we cannot rule out the possibilities of external factors that have had an influence on this KPI. The percentage change is 12,8 % which is extremely good, so from the statistical side, the improvements to unplanned stock were successful.

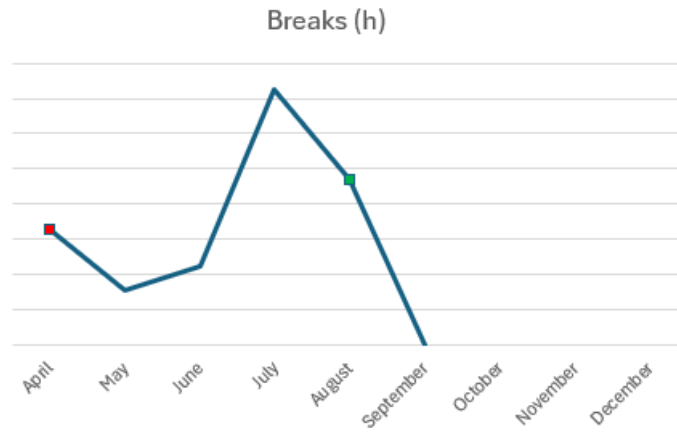


Figure 12. Breaks difference

We can see from the breaks in production graph that August is noticeably higher than in April. There has been more problems in production in August compared to April. However, there has not been any evidence from production side that the problems were caused by the implementations of the project. According to the reports, the problem was withing one production line phase and its malfunctioning, so it can be stated that the differences in this KPI has been caused by external factors. The percentage difference is 43,79 % so the increase in breaks were huge between these two months. From this KPI point of view, the project was not successful.

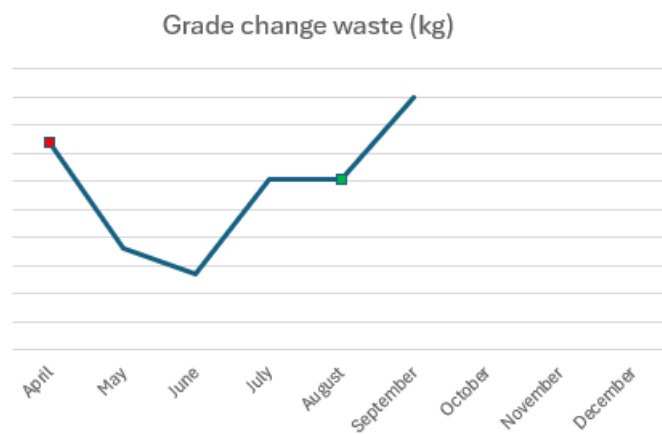


Figure 13. Grade change waste difference

Grade change waste is extremely important KPI in the project, since this was one of the main targets to be reduced. There was a reduction of almost 8,5 % in production runs in month (mentioned in chapter 4.5), so there should be a drop in grade change waste. As seen from the graph on top of this paragraph, the grade change waste volumes have been dropped compared to the start of the project. The percentage difference between pre- and post-project is that August had 17,94 % less grade change waste than April. The implementations for this key performance indicator were completed successfully and the enhancement of reference cycle was implemented correctly.

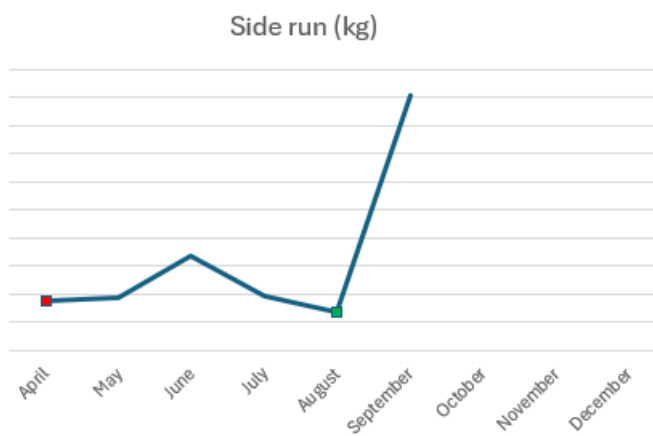


Figure 14. Side run difference

Side run KPI also influences unplanned stock and trim waste. As can be seen from the side run graph, the level of side run is lower in August than in April, same as it was for unplanned stock. The percentage drop for August compared to April is 21,59 % lower. This is due to the changes in reference cycle, and the aim for better trimming efficiency which leads to the drop in side run as well. Therefore, the project successfully decreased the amount of side run.

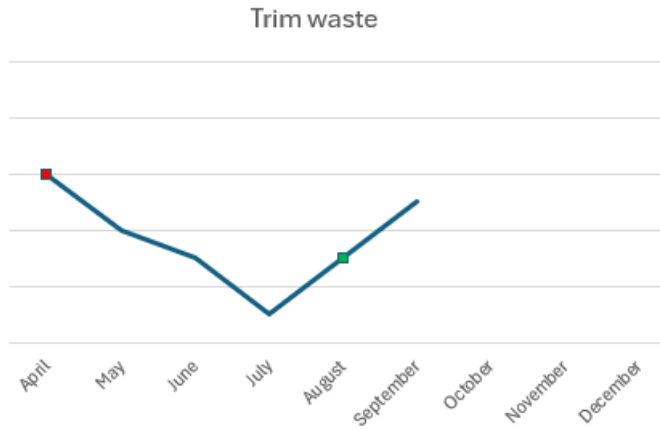


Figure 15. Trim waste difference

As already mentioned in the previous paragraph, the enhancement of reference cycle is expected to reduce the trim waste also, due to better trim options from bigger production runs. This improvement can be seen from the trim waste graph, and the percentage difference is an improvement of 6,5 % in trim efficiency for August compared to April. This KPI was successfully enhanced in the project.

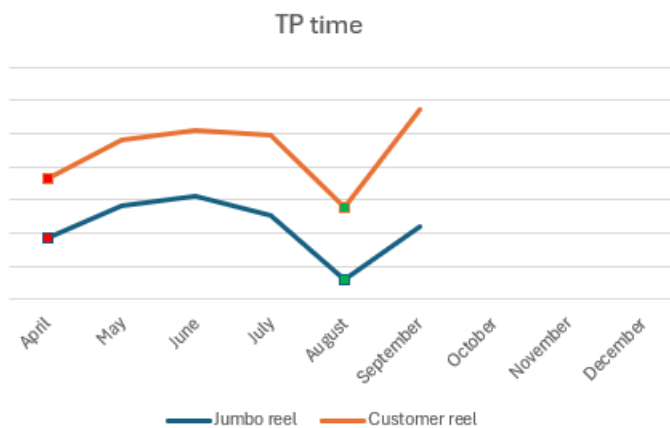


Figure 16. Throughput time difference

Last KPI, and maybe the most important for this project. The aim for the whole project was to manage the efficiency and trying to enhance KPIs. However, lead time in production line is a performance indicator that can easily indicate the efficiency in the factory for all people that are not familiar with paper production and the functionality of the

factory. There are two different measurements inside the key performance indicator, jumbo reel and customer reel. The throughput time for jumbo reel dropped, from August compared to April, by 6,25 % and for customer reel, 3,91 %. So, according to the measurements, the lead time efficiency has been enhanced relatively well throughout this project and the implementations can be seen as successful.

Altogether, the key performance indicators were successfully reduced post-project compared to pre-project, excluding the breaks key performance indicator. In the project closing phase, the project can be seen as a successfully managed and completed, since the overall outcome in the project was positive. The main aim after the project for the production line is to maintain the achieved efficiency and enhance the efficiency of the production line in the future with the help of continuous improvement.

6 Conclusion and recommendations

As already stated in the results chapter of the thesis, this project was implemented and completed successfully according to the data. There was one KPI that did not succeed compared to the level before the project, otherwise every single key performance indicator outperformed the original pre-project data. The risks were evaluated correctly since there were not any indications that the implementations were incorrectly done, and there was not any unexplainable reasons for some of the raises of the key performance indicators. The project was completed in time and the company was happy with the project results. The mission for future is to continue on the same path, and keep the efficiency level on the same level as in August.

The research questions in the case study were about the effects of growing product portfolio and production lead time, production line limitations and the optimization of the production efficiency. This thesis explains that the growing product portfolio increases the complexity of production line, which ultimately leads to added costs of manufacturing the goods. Production line limitations in the production line includes that the production run needs to be at least certain amount of volume and some of the paper grades cannot be produced directly after each other. Optimization of the production efficiency was the main topic of the study and the whole study focuses around the procedures that were evaluated, analyzed and implemented in the project to optimize the production efficiency. As the results concluded, the efficiency was optimized, and improved, successfully.

Recommendations for the company involves the increase in routine for the operators, increase the information availability, to be more initiative, and to continue working on the paper grade change waste tolerance project. The increase in routine for the operators, especially in the last phases of the production line will increase the efficiency for the production line, and also increase the communication with the production planners, since the production planners would get to know the operators better. While interviewing the operators in the production line, there were couple of mentions about the lack

of communication between different production line phases. This can be increased by enhancing the information availability and by being more initiative from the production line management side, meaning supervisors. The initiative should increase for unplanned stock management as well, for example the sorting of trial reels after all the trial production runs, so the unplanned stock level does not rise from unnecessary and unusable reels that can be pulpered from the stock. The last recommendation is to continue working on the tolerance change for paper grade change, which can lead to future savings in production line efficiency. This would be especially important if the product portfolio increases during the next years.

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