TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

AKI PÖNNIÖ

IMPLEMENTING CONTINUOUS FLOW TO REDUCE LEAD TIMES IN PLASTIC FILM PRODUCTION

Master of Science Thesis

Examiner: Associate Professor Minna Lanz
Examiner and topic approved by the Council of the Faculty of Engineering Sciences on 6th April 2016

ABSTRACT

AKI PÖNNIÖ: Implementing continuous flow to reduce lead times in plastic film production
Tampere University of Technology
Master of Science Thesis, 66 pages, 6 Appendix pages
April 2016
Master's Degree Programme in Materials Science
Major: Product Development
Examiner: Associate Professor Minna Lanz

Keywords: lead time, Lean, QRM, efficiency paradox, flow efficiency, resource efficiency, continuous flow, FIFO, implementation, change management

This thesis focused on implementing more efficient continuous flow in plastic film production. The target of the project was to shorten the lead times in production while reducing the amount of unnecessary work. Reduced unnecessary work enables to confirm customer orders more often as customer requests. The theory was based on Lean methods which were compared with QRM (Quick Response Manufacturing) methods. The old resource efficient mindset was replaced with flow efficient mindset where the focus is on increasing the relative value-added time compared with non-value-added time.

The experimental study consisted of implementing FIFO lanes and standard routes for material families. The requirements of both production steps were considered when production schedules were planned so that it was possible to use exactly the same production plan on both steps. For that reason, it was no longer needed to plan the production separately through the production steps. In the production, the goal after the implementation was to minimize the level of work in progress.

As supportive actions for the continuous flow, the workforce was balanced between shifts and the amount of both teamwork and cross-training were increased. This thesis also included a short literature review about the theory of change management which was later exploited in managing the change. The most important actions of change management were creating dissatisfaction with the current state, obtaining the appropriate levels of participation in planning the change, and forming a clear understanding about the opportunities behind the change.

The results after the implementation were monitored during a two-month monitoring period. The average queuing times between the two production steps decreased by 76.2 – 96.2 % and the flow efficiencies increased significantly. At the same time, the level of the semi-finished goods inventory decreased more than 40 % compared with the average level in 2015. Moreover, confirming the orders as customer had requested increased 35 %. Because of the good results, the plant continued using the implemented continuous flow.

TIIVISTELMÄ

AKI PÖNNIÖ: Jatkuvan virtauksen implementointi muovikalvotuotannossa läpimenoaikojen lyhentämiseksi
Tampereen teknillinen yliopisto
Diplomityö, 66 sivua, 6 liitesivua
Huhtikuu 2016
Materiaalitekniikan diplomi-insinöörin tutkinto-ohjelma
Pääaine: Tuotekehitys
Tarkastaja: Associate Professor Minna Lanz

Avainsanat: läpimenoaika, Lean, QRM, tehokkuusparadoksi, virtaustehokkuus, resurssitehokkuus, jatkuva virtaus, FIFO, implementointi, muutosjohtaminen

Tämän työn aiheena oli implementoida jatkuvan virtauksen periaatteita muovikalvotuotannossa. Jatkuvan virtauksen tavoitteena oli lyhentää tuotannon läpimenoaikoja vähentäen samalla tarpeettoman työn määrää, jotta asiakastilauksia voitaisiin toimittaa paremmin asiakkaiden pyyntöjen mukaan. Työn teoria pohjautuu Lean menetelmiin ja sen tukena sekä vertailukohtana käytetään QRM (Quick Response Manufacturing) teoriaa. Vanha resurssitehokas ajattelutapa korvattiin virtaustehokkaalla ajattelutavalla, jonka tavoite on parantaa virtausyksikön vastaanottamaa arvoa tuottavaa aikaa suhteessa arvoa tuottamattomaan aikaan.

Implementointivaiheessa otettiin käyttöön FIFO –linjat ja vakioreitit materiaaliperheille. Tuotannon ajojärjestykset suunniteltiin siten, että niissä otettiin huomioon molemmat tuotantovaiheet. Tämän seurauksena tuotannonohjauksessa ajojärjestyksiä ei enää suunnitella erikseen eri tuotantovaiheille, vaan ensimmäisen tuotantovaiheen ohjelma voidaan kopioida sellaisenaan toiseen tuotantovaiheeseen. Tuotannon tavoitteeksi asetettiin keskeneräisen tuotannon tason pitäminen mahdollisimman alhaalla.

Jatkuvaa virtausta tukevina toimina työvuorot tasapainotettiin sekä lisättiin tiimityöskentelyä ja ristiinkouluttautumista. Työssä tehtiin lisäksi lyhyt kirjallisuustutkimus muutosjohtamisen teoriasta ja hyödynnettiin sitä muutoksen jalkauttamisessa. Muutosjohtamisen tärkeimpiä toimenpiteitä työn kannalta olivat työntekijöiden osallistuminen muutoksen suunnitteluun ja edeltävän toimintatavan puutteellisuuden sekä muutoksen tarpeellisuuden osoittaminen.

Implementoinnin tuloksia seurattiin kahden kuukauden seuranta-aikana. Keskimääräiset jonotusajat kahden tuotantovaiheen välillä lyhenivät 76,2 – 96,2 % ja prosessin virtaustehokkuus nousi erinomaiselle tasolle. Samaan aikaan välivaraston taso laski yli 40 % suhteessa edellisen vuoden keskiarvoon ja tilauksia voitiin vahvistaa asiakkaan toivomalle päivälle lähes 35 % useammin. Saavutettujen tuloksien vuoksi implementoitu jatkuva virtaus ja uusi tapa suunnitella tuotantoa päätettiin ottaa pysyvästi käyttöön.

FOREWORD

This Master of Science Thesis was conducted for a plastic film production plant that strives to become Lean. This thesis was also performed as a requirement of Master of Science degree in Materials Science at Tampere University of Technology. Making this thesis has been an extremely valuable experience for me, and it has helped me to find my professional interests.

I would like to take this opportunity to thank my examiner Associate Professor Minna Lanz for great guidance especially at the last stages of the work. I would also like to thank everyone who helped making the results in this work possible. Finally, I would like to express the most special gratitude to my family and loving girlfriend for the endless support.

In Tampere, Finland, on 17 April 2016

Aki Pönniö

TABLE OF CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

Customer reel	Slit reel from the last step of production
ERP	Enterprise Resource Planning
FIFO	First In First Out
FTMS	Focused Target Market Segment
JIT	Just In Time
MCT	Manufacturing Critical-path Time (QRM definition)
Mother reel	Big reels that are produced in the film production lines
MTO	Make To Order
PCE	Process Cycle Efficiency
QRM	Quick Response Manufacturing
TPM	Total Productive Maintenance
TPS	Toyota Production System
VSM	Value Stream Map
WIP	Work In Progress

1. INTRODUCTION

Since Toyota first started its Toyota Production System (TPS), quicker response and shorter lead times have been targets that many companies have relentlessly tried to reach. Nowadays this operation strategy is often named as Lean manufacturing. Due to the cost savings and competitive advantage Lean companies have achieved, every company should evaluate the possible advantages Lean methods could bring. The evaluation of Lean methods was also the main reason for this project to start.

1.1 Research problems and targets

Long lead times and inefficient flow in a plastic film production plant are the research problems of this thesis. The average lead time from confirming the order to the last step of production is 4.38 weeks. This count does not include orders that are requested to be ready in more than eight weeks (17 % of the orders). This is not quick enough for the customers, because only 38 % of orders were confirmed as customers had requested in 2015 (from January to September). The rest of the orders were confirmed later than customers had requested. That verifies that long lead times are a true problem which reduces the ability to serve the customers well.

The value-added time for the order is few hours when the scope is limited to concern only production. However, the lead time in the same scope is several days. It means that the proportion of non-value-added time is often more than 95 %. Hence, the inefficient flow is clearly one of the reasons why the lead times are long. That is why the most important question in this work is how to improve the flow and how to make the flow efficient.

The main target of this work is to reduce the long lead times in the production by implementing continuous flow, which is at the heart of Lean methods. There are only two subsequent production steps at the target plant: film production and slitting. Both production steps consist of four machines. Because of the rather simple production and the fact that the plant has only eight machines, continuous flow is implemented simultaneously on each route.

The targeted lead time reduction is one week on two traditional film production lines. Another target is to minimize the lead time also on third line that uses slightly different technology. Because of this difference in technology, the reels produced on the third line require shrinking time.

At the same time, the target is to either reduce or keep the inventory levels, wastes and other costs at the same level as before. Another target for the inventory level is that the level is not higher at the end of the monitoring period than at the beginning. This target requires using the old stock from the semi-finished goods inventory as well as successful implementation of the continuous flow. Other ways to reduce lead times will also be examined and suggested as possible future actions.

1.2 Research methods and materials

The research approach in this thesis is deductive. The validity of assumptions in literature is tested in an implementation project. Mainly two different research methods are used in this work: a literature review and an experimental method.

The research method in the first section of this work is the literature review. The first section is in Chapter 2. The material in the literature review consists of literature about Lean manufacturing, Quick Response Manufacturing (QRM) and change management. Lean manufacturing and QRM are two of the most well-known theories about reducing lead times. Lean manufacturing is by far more well-known than QRM but it is reasonable to compare strategies for knowing the possibilities a plant has in reducing lead times.

The experimental part consists of the analysis on how the methods found in the literature review can be put into practice, the implementation of the best methods, and results and analysis on how the implementation affected the performance of the plant. The independent variable in the experiment is the new flow together with supportive actions. The other variables are practically identical to the situation before the experiment. Thereby, the effects of the new flow can be tested.

The research methods in the data analysis are mainly quantitative, but qualitative methods are also often used. The data for quantitative analysis is gathered from SAP enterprise resource planning (ERP) system, mainly from business objects application. Part of the data is gathered calculating mean and median values manually from measured single values when the data is not otherwise available.

Qualitative methods consist of interviewing stakeholders for the opinions and qualitative review of statistics. Operators' opinions about for example production sequences and the difficulties of setups are more important than quantitative calculations in this work, because operators get to decide the things that affect their work. It increases the employee involvement which helps to commit to the change. The qualitative review of statistics is mainly done in the background of the work, and it is needed because the data may not always be correct in the business objects application of ERP.

1.3 Structure of the work

This work can be divided into two main sections: theoretical section and practical section. Theoretical section starts with the definition of Lean manufacturing and the introduction of some Lean methods which are often used when reducing lead times. Next, QRM strategy is reviewed and compared with Lean manufacturing. The last part of the theoretical section focuses on the theory of change management which is needed in order to succeed in the implementation.

The practical study starts with the analysis of the current state at the target plant. The methods that are implemented in this work are presented at the end of the analysis. The analysis is followed by the implementation that was done three months after the beginning of this project. The change management actions done in this work are reviewed in the beginning of the implementation chapter. The events during the monitoring period are documented after that. At the end of the implementation chapter, the lessons learned are concluded.

Next, the results of the monitoring period are analyzed. These results consist of queuing times between the two production steps, the corresponding flow efficiencies, orders confirmed to customer request, lead times from firm to last step of production, and inventory levels. The savings achieved in this project are estimated at the end of the results chapter.

The evaluation of this development project is after the results chapter. Evaluation consists of the validity and reliability of the results, as well as the impact and effectiveness of the project. The evaluation is followed by suggestions for the next steps after this project. Finally, this paper ends with the conclusions.

2. THEORETHICAL BACKGROUND

This chapter is divided into three sections. In the first section, Lean manufacturing is defined and Lean methods are introduced. In second section, QRM strategy is introduced and compared with Lean manufacturing. The chapter ends with a brief literature review of change management.

2.1 Lean

Lean manufacturing is a management philosophy that involves never ending efforts to reduce waste. According to Womack et al. (1990), Lean producers set their sights on perfection: continually declining costs, zero inventories, zero defects and endless product variety. A review of Lean literature (McLachlin 1997) that consisted of 16 sources revealed that there are dozens of practices that are commonly associated with Lean manufacturing. However, some of these practices are included in the studies more frequently than others. According to McLachlin (1997), just-in-time/continuous flow production and quick changeover methods were included most frequently in the literature. Pull system, cross-functional workforce and continuous improvement were other very common practices. Thus, these practices often form the backbone for Lean manufacturing.

The most important methods of Lean manufacturing are introduced in this chapter to help reduce the lead times of the plant. It is important to notice that Lean is a constant state where continuous improvements are at the heart of the strategy, rather than one project where Lean or some Lean methods are implemented. According to Modig & Åhlström (2013), Lean practices are not compulsory methods that every Lean company should use but ways of how some advanced Lean companies have reached their targets. Every company has a chance to use these methods or create their own methods that support their processes and targets.

2.1.1 Efficiency paradox

Modig & Åhlström (2013) define the traditionally operating companies as companies that try to achieve resource efficiency. In a resource efficient company, the utilization of resources is held as a primary target. Resource efficiency for a specific resource is calculated as follows.

$$Resource\ efficiency = \frac{Hours\ the\ resource\ is\ utilized}{Labour\ hours} \times 100\ \% \qquad (1)$$

In this formula, the hours the resource is utilized includes the time the resource is doing something related to work. Hence, it also includes the work caused by secondary needs. Secondary needs are needs that do not add value for a customer, but which need to be fulfilled in order to get products through the production. Because of the secondary needs, the calculated resource efficiency is much higher than actual resource efficiency where only value-added work is taken into account (Modig & Åhlström 2013).

Mass-production is a good example of resource efficiency. According to Womack et al. (1990), mass-producers use narrowly skilled professionals to make standardized products in very high volume. The goals in mass-production are to constantly have all the resources fully utilized and to have no free capacity left. In a manufacturing environment, it means that all the workers and machines should be in use all the time. The company seems to be very efficient when everyone is working the whole time and there is a long queue in front of each operation. One of the key elements in mass-production (and in resource efficiency) is the aim to get advantages from the economies of scale (Womack et al. 1990). The economies of scale can be achieved by producing as similar products as possible, one after another in large quantities. However, the primary focus on resource efficiency is followed by several disadvantages that can **reduce** efficiency. The most important reasons for this efficiency paradox are introduced next.

Because resource efficient company tries to keep each resource working all the time, queues are needed in front of the resources. At the same time, non-value-added time increases for the products in the queues, which has a negative effect on the lead time. According to Modig & Åhlström (2013), long lead times are one of the three main sources of inefficiency in a resource efficient company. Long lead times create secondary needs at many levels of the organization. One of these needs is the handling of requests to make products earlier. The handling of these requests requires communication between a customer, customer service and production planning. Therefore, the fulfillment of this secondary need takes a significant amount of time from the productive working hours.

According to Modig & Åhlström (2013), the handling of many flow units is the second main source of inefficiency in a resource efficient company. A flow unit in a factory environment is a unit that goes through the production. In a resource efficient company, the company has many flow units in the system at the same, because the amount of flow units is greater if the queues and lead time are longer. When the lead time doubles, also the number of flow units doubles, given that the capacity and throughput stay the same. Modig & Åhlström (2013) argue that the handling of the great number of flow units also creates secondary needs.

Warehousing is one of the secondary needs that long lead times and many flow units create. Warehousing in itself leads to additional costs and ties capital. According to Speh (2009), there are four categories of warehouse costs: handling costs, storage costs, operational administration costs, and general administration costs. According to Modig & Åhlström (2013), the secondary needs behind the inventory costs are for example:

- Shifts to the warehouse and from the warehouse to the next operation
- Searching in the WIP inventory (Work-In-Progress)
- The control of the WIP inventory
- The need to check if semi-finished goods exist before production decision
- The increased need for stock-taking

The shifts to the warehouse and from the warehouse to the next operation require two shifts, while a shift straight from previous operation to the next would only require one shift. The time spent searching in the WIP inventory could be spent doing value-added work. The control of the WIP inventory and the need to check if semi-finished goods exist before production decision are also time-consuming. In addition, the errors in the inventory information can, at its worst, consume a lot of time in production as well as in production planning and customer service. Below is an example of such error in the target company, which has happened many times according to production planners.

The inventory information indicates that there are enough semi-finished goods in the warehouse for a new order. A production planner releases this order into the production queue in order to have the last production step ready in a few days. Then the order is confirmed to be at the customer in two week. At the time of production, however, the semi-finished goods are not found in the inventory. The production line worker searches through the inventory a few times to make sure the material is not there. After that, production planner has to schedule the order again from the beginning, which causes the order to be late. Then, customer service assistant has to inform the customer about the late order and negotiate about the compensatory product or quick part delivery of the order with both the customer and the production planner. The production line worker, production planner and customer service assistant seem to be working efficiently, but according to Modig & Åhlström (2013), the work is inefficient because the needs that are being fulfilled are secondary needs.

Another secondary need that many flow units causes is a need for increased control and remembering. If there are occasional deviant issues to control and a long queue of flow units, one must control and remember many things at the same time. In this case, notes are needed and the notes and e-mails need to be organized in a way that they are all found and will stay in memory. It also requires resources to fulfill secondary needs. (Modig & Åhlström 2013)

According to Modig & Åhlström (2013), the need to start many times is the third main source of inefficiency in a resource efficient company. When the subsequent operations that a flow unit has to go through are separated into disconnected entities, there is a need to start working with one unit many times. It usually takes some mental setup time as well as familiarization, classification, searching and organizing for a person to start working with a completely new work. Moreover, if there is a long time between two subsequent operations, useful information can easily be lost between them. There is also a risk for local optimization: Worker only tries to do his or her part of the process well without the responsibility for the rest of the production steps. That is one of the reasons why there are usually a lot of secondary needs between the production steps.

The need to start many times also exists when one person needs to start working with the same work many times (Modig & Åhlström 2013). The earlier mentioned requests to make products earlier are good examples of that. Production planning and scheduling for an individual order has to be started again every time a new suggestion for an alternative product or production time is made and when the customer answers to the suggestion. Also, the customer service assistant has to start working with the order every time a suggestion or an answer is given. Mental setup time and familiarization with the order are always needed, especially when there is a long time between suggestions and answers.

All these secondary needs handled in this chapter and extra work caused by these needs explain the efficiency paradox. Significant amount of work in a resource efficient company is actually inefficient fulfilling of secondary needs rather than working on operations that add value for the customer. But how is it possible to increase efficiency if being extremely busy and working all the time is not efficient?

2.1.2 Lean strategy as an answer to inefficiency

Focusing on resource efficiency is questioned In Lean manufacturing. The Toyota Production System was based around the desire to produce in a continuous flow rather than relying on long production runs to be efficient (Melton 2005). Therefore, Lean operation strategy suggests continuous flow as a solution for the efficiency paradox. The efficiency of the continuous flow can be calculated by comparing total value-added time with the lead time (Modig & Åhlström 2013).

$$Flow\ efficiency = \frac{Total\ value\text{-}added\ time}{Lead\ time} \times 100\ \% \qquad (2)$$

In Lean literature, PCE (Process Cycle Efficiency) is often used as a synonym for Flow efficiency (George et al. 2005; Burton & Boeder 2003). It can be seen from the formula that flow efficiency can only be improved by increasing the sum of value-added time or by decreasing lead time. If the sum of value-added time is stable and the operations are well standardized, the only way to improve the flow efficiency is to reduce lead time. Lead times can be calculated directly by measuring actual lead times from the process.

The factory can get rid of the secondary needs that resource efficiency causes by focusing on flow efficiency. The goal is to reduce lead time, the need to start many times, and the number of flow units that are in the system at the same time in order to reduce the amount of extra work. (Modig & Åhlström 2013) The differences of the resource efficient and flow efficient approaches are visualized in Figure 1.

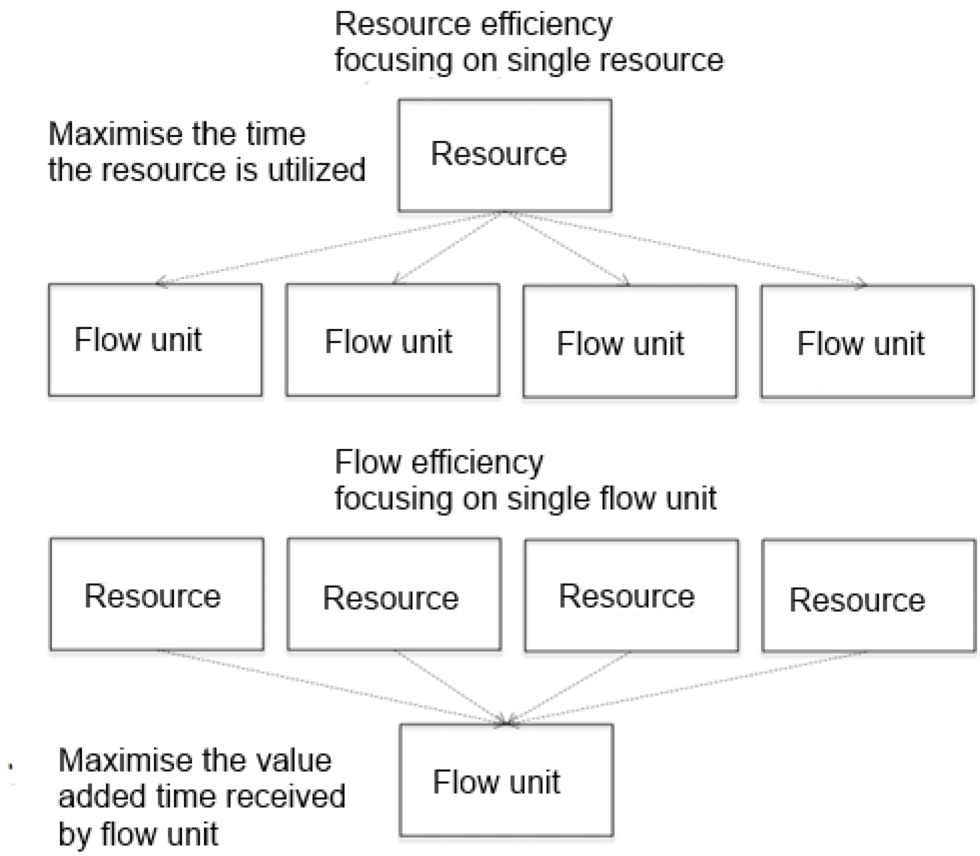

Figure 1. *Differences between resource- and flow efficiency (Modig & Åhlström 2013)*

Ideally, the flow unit moves forward continuously straight from previous step to the next without inventory, reducing the lead time significantly. This means that the value-added time received by the flow unit is maximized. Everyone is aware of what is being produced in each step and the information between the steps shifts from step to step. Many of the secondary needs disappear at the same time: shifts to inventory, shifts from inventory, searching for the material in inventory, the control of the WIP inventory, the control of many flow units at the same time, excessive remembering, the handling of the requests to make some orders earlier, and the need to start many times.

Increased floor space is one of the advantages of maximized flow efficiency because of the decreased need for inventory that uses the floor space. Consequently, it also reduces the capital tied into the inventory. According to Liker (2004), true flexibility increases even though the orders need to be produced seemingly inflexibly in certain order from the start of the production until the end. True flexibility for a customer is a quick order confirmation and short time from order to delivery.

One study (Liker 2004, Lean transformation in Wiremold) even suggest that Lean transformation improves the morale of the employees. Liker (2004) states that people do much more value-added work and the results of the work are clearly visible immediately. This gives the workers a sense of accomplishment that leads to job satisfaction. By contrast, in a resource efficient company people might only see the result of a single step in the production.

2.1.3 Challenges of flow efficiency

It is very important to understand that creating continuous and efficient flow and lowering the level of WIP inventory will make things harder in the beginning. It may also cause big challenges and inefficiency problems. According to Liker (2004), a Lean expression for this phenomenon is that lowering the ”water level” of the inventory brings problems to the surface. The company then has to solve the problems and continuously improve the process or it will sink. This is at the heart of Lean thinking and transformation into a Lean company. Figure 2 demonstrates this idea.

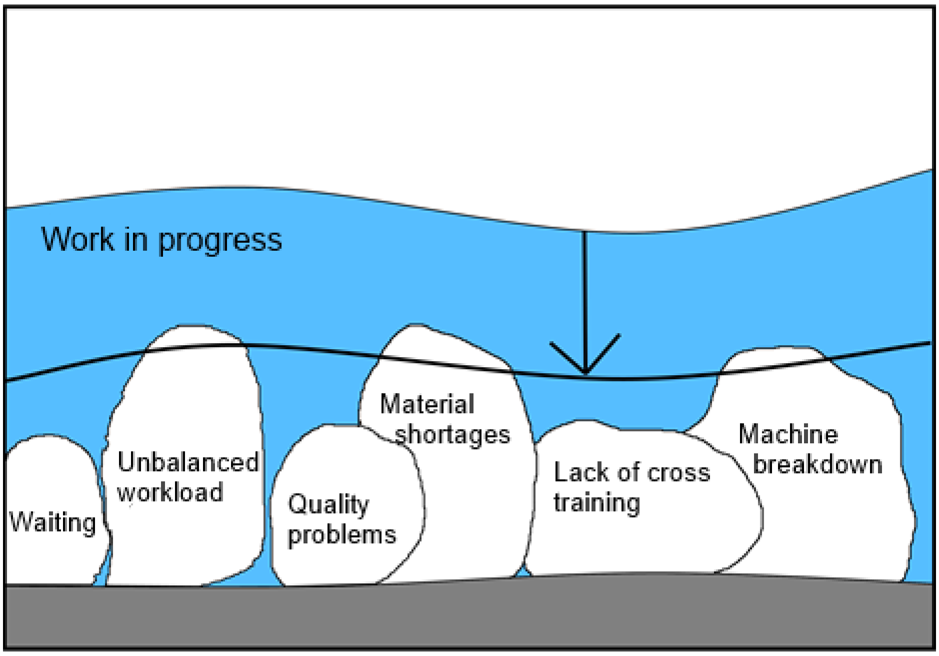

Figure 2. *Problems hidden by the high inventory.*

Creating continuous flow lowers the water level and exposes problems like rocks under the water. Some of these problems need to be solved immediately or the process stops and inefficiency increases. For example, if there is a quality problem in the first step of production that is noticed in the second step and the time between the steps is long, it is not possible to notice the problem until many days after the production. In the worst case scenario, the first step has been producing low quality products all this time without no-one noticing. On the contrary, if the flow is efficient and the second step is right after the first step, the problem can be spotted soon after the mistake has been made and it must be fixed immediately.

2.1.4 Eliminating waste

The essential principle of a Lean mindset is the ongoing and continuous elimination of waste (Womack & Jones 1996; Carreira 2005). To understand the advantages of continuous flow and shorter lead times it is necessary to introduce the seven sources of waste that do not add value for a company. These wastes are defined by Toyota in their Toyota Production System (TPS) which is the basis for the entire Lean philosophy. According to Liker (2004), traditional resource efficient company usually tries to achieve cost savings by trying to increase the performance of value-adding operations, whereas Lean focuses on value stream to eliminate the wastes. The seven sources of waste are listed below (Liker 2004).

1. *Overproduction.* Producing items without orders. This generates more wastes such as overstaffing and excessive storage.
2. *Waiting.* Standing by the automated machine waiting it to produce ready items, waiting for the previous step, or waiting for maintenance to fix a machine.
3. *Unnecessary transport.* Transportation of WIP or ready items long distances into or out of storage.
4. *Over processing or incorrect processing.* Creating better quality than a customer needs and taking unnecessary steps to produce an item.
5. *Excess inventory*. Unnecessary raw material, WIP, or finished goods in an inventory. Causes longer lead times, transportation, storage costs, delays, obsolescence and damaged goods. It also hides various problems.
6. *Unnecessary movement.* All the unnecessary movements the workers have to do, such as searching for, reaching for, or stacking material, parts or tools. Walking is also waste.
7. *Defects.* Production of parts with defects that causes rework, repair, replacement production and inspection.

These wastes have many similarities with the inefficiencies that were handled before (in Chapter 2.1.1). Modig & Åhlström (2013) have just further combined the wastes under the three main sources of inefficiency, but fundamentally the wastes are the same. All in all, by eliminating these wastes it is possible to shorten the lead time from order to delivery.

2.1.5 Pull system

Using a pull system together with a closely related concept of JIT (Just In Time) production is one way to eliminate waste and to improve efficiency. In a pull system, the focus is on producing exactly what the customer wants, exactly when the customer wants it and exactly the amount the customer wants (Liker 2004). According to Stevenson (2014), it also means that each workstation pulls the output from the previous workstation when it is needed. This is the opposite to a push system: After the work is finished on a workstation, the output is pushed to the next station or to the final inventory in the case of a final operation (Stevenson 2014).

In a pull system, each workstation has to communicate its need for more work to the previous workstation to make sure work moves just in time for the next operation and excessive inventory is avoided. Hence, a workstation has to wait until it receives a request from the following workstation, and production takes place only in response to the usage of the following station. (Stevenson 2014)

Pull systems are used to eliminate primarily two types of waste: overproduction and excess inventory. When the production is based on real customer orders and the right amount is produced for the specific order, there will not be overproduction or excessive inventory waiting for a possible order.

As a compromise between an ideal pull system and push system, there is a Lean method called “kanban”. Kanban is Japanese and the meaning of it is “a card” or “a visible record” (Schonberger 1982). In a kanban system, a small buffer inventory of critical parts or material is held between operations to prevent stockouts that will completely stop the flow. Kanban has to be a visual signal, such as a card, an empty bin or cart which tells when to refill the buffer inventory. The kanban signal is sent upstream in the production to inform which components or material is needed more. (Liker 2004) A basic kanban system using empty bins as signals is presented in Figure 3.

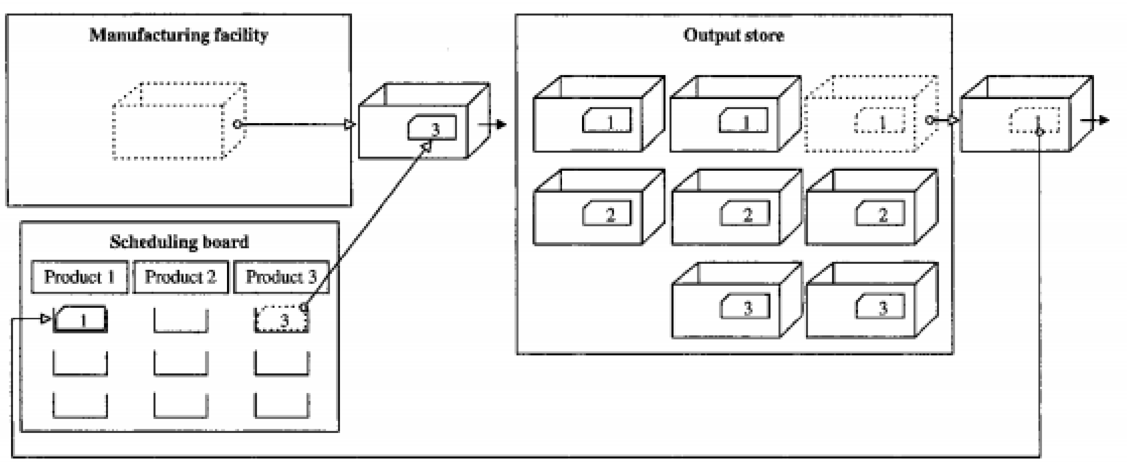

Figure 3. *A basic kanban system with three different products. (Krieg 2005)*

According to Liker (2004), it is important to understand that kanban should only be used when it is not possible to survive without a buffer inventory or when the inventory, unlike usually, improves the flow. Kanban system and the buffer inventory, like any other inventory, are waste according to Lean philosophy. Consequently, they should be eliminated (Liker 2004).

2.1.6 FIFO lanes and Supermarkets

FIFO (First In – First Out) lanes and Supermarkets are methods of handling the flow in a pull system. In a FIFO lane, the first item that goes into the inventory is also the first item that is taken out of the inventory. According to Rother & Shook (1999), there has to be a limit to the maximum number of items on a FIFO lane when this method is implemented. If that maximum number is reached, the preceding process must be stopped, while an empty FIFO lane stops the succeeding process.

One of the advantages of FIFO lanes is that only the first process needs a production plan and the succeeding processes simply continue the same plan (Roser & Nakano 2015). Hence, there is no need to make many production plans and sequences for different processes. It is also possible to have any kind of product mix or lot sizes in a FIFO lane and still have it working well. However, the material flow should be identical to all items on the same route when implementing FIFO lanes (Roser & Nakano 2015). This can be done by creating standard routes for materials.

Supermarkets, on the other hand, can be seen as many FIFO lanes in parallel. According to Carreira (2004), Supermarkets should be used together with a kanban system. In a Supermarket, there is one line for every item type. When an item is removed from one line, information about that has to go to the beginning of the process. Then, replenishment for this particular item type has to be made. (Fernandes & Silva 2006; Liker & Morgan 2006) The output store in Figure 3 is an example of a Supermarket.

According to Roser & Nakano (2015), Supermarkets are more complex to operate than FIFO lanes because the material and information flows split. There should be only identical items on one Supermarket line so that the use and replacement of those items are possible. If the number of item variants was vast, the number of the lines would be vast as well, and therefore it would not be practical to use the Supermarket. (Roser & Nakano 2015)

2.1.7 Value Stream Mapping

According to Nash (2008), a value stream is the process flow from point of requested need to the closure of all activity after the product has been provided. Nash (2008) argues that on manufacturing floor, the focus is on the actions from the point when raw material arrives to the point when finished product is shipped. Value Stream Map (VSM), on the other hand, is a representation of the value stream that includes the flow of materials as well as the flow of information (Locher 2008).

Value stream mapping is a visual technique that enables all stakeholders to understand and improve a process. Value Stream Maps are used to document both the current state and the future state of the process (Nash 2008). Locher (2008) divided the value stream mapping process into four steps that are shown in Figure 4.

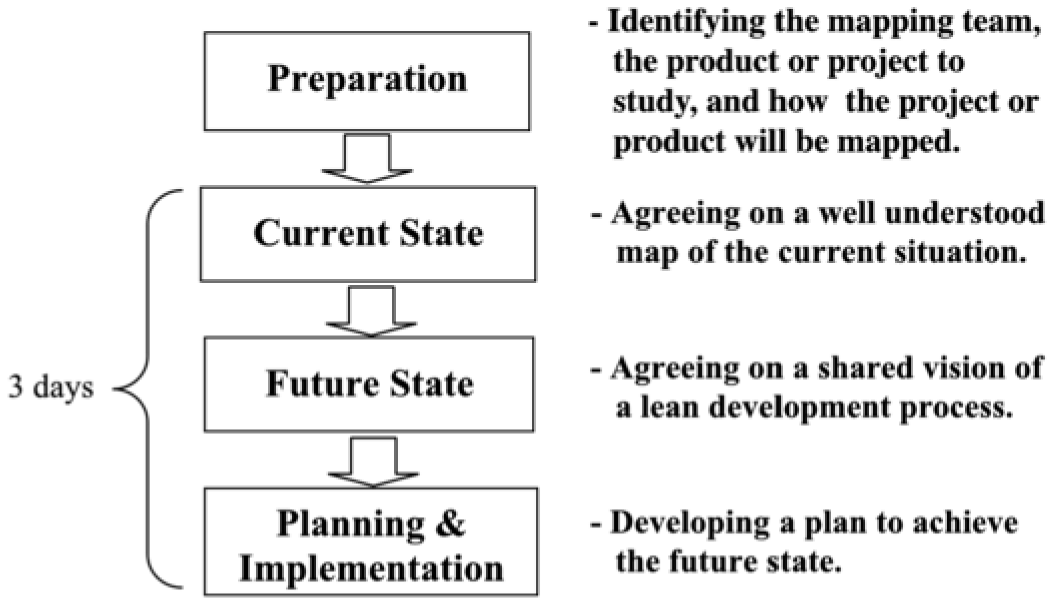

Figure 4. *The value stream mapping process. (Locher 2008)*

According to Locher (2008), the first step before the mapping event should be preparation. During the preparation step, the mapping team and the project are being identified. Next, the current state and future state maps will be developed. The mapping event is followed by the planning and implementation step. The typical duration of the mapping is three days, but the implementation may take from one to twelve months. (Locher 2008)

2.1.8 Balanced workload

Answering an uneven demand is one of the main problems continuous flow and short lead times usually cause in the beginning (Liker 2004). Perfect flow combined with short lead times requires that there is always right amount of workforce available so that the factory is able to react to the demand. If the workload is minimal and make-to-stock production is prohibited, there will soon be workers who have nothing to do. Accordingly, when the demand is much higher and there is no free capacity left, it is nearly impossible to answer the demand. In such case, lead times and work in progress inventories will increase significantly.

Balancing the workload is the most practical Lean method to solve this problem. According to Liker (2004), this method is based on the assumption that on a long time span the demand is rather constant even though there is sometimes great fluctuation in the demand rate. Therefore, rough planning can be based on the average demand in the past as well as in the future, and the volume of orders in a period is then leveled.

The balancing of the workload starts with gathering needed data to aggregate customer demand. Also net operating time available and net resource capacity by process steps have to be calculated. Net operating time means that breaks and lunch etc. are subtracted from gross operating time. Net resource capacity is the same as average output over time. (George et al. 2005)

If the net resource capacity is smaller than the customer demand over the same period of time, the resource will become a capacity constraint (George et al. 2005). In that case, the queue before the resource builds up lengthening the lead time. Extra capacity will be needed to answer the demand or the capacity constraint has to increase its output. Accordingly, the resource will soon have no more work in the queue if the net resource capacity is greater than the customer demand rate over the same period of time. Workload balancing can be done by comparing average customer demand takt-time and production takt-time. Customer demand takt-time is calculated as follows:

$$Customer\ demand\ takt - time = \frac{Net\ operating\ time\ available}{Customer\ demand}. \tag{3}$$

Production takt-time is calculated correspondingly:

$$Production\ takt - time = \frac{Net\ operating\ time\ available}{Number\ of\ units\ possible\ to\ produce}. \tag{4}$$

If the customer demand takt-time is smaller than production takt-time, production takt-time has to be decreased so that lead time does not increase. (George et al. 2005)

When balancing the workload, each resource must be compared with the demand. The goal is to have takt-times as close to each other as possible (George et al. 2005). This means that takt-times of subsequent production steps have to be close to identical. This requirement also supports the goals to implement continuous flow and to minimize work in progress.

2.1.9 5S

5S is one of the most important Lean methods. It is usually the first step when a company strives to become Lean. In this work, 5S is reviewed only very briefly because the target plant has already implemented this method. However, if continuous flow is implemented on other plants, it is important to implement 5S before continuous flow. For these reasons, it is reasonable to briefly introduce this method in this work.

5S comes from five Japanese terms beginning with the letter “S” (Seiri, Seiton, Seiso, Seiketsu, Shikutse). The English translations for these five terms are: Sort, Set in order, Shine, Standardize and Sustain. (Hirano 1996) The core idea of the method is to create and maintain an organized, clean and safe workplace where it is possible to distinguish between normal and abnormal conditions at a glance. It is also a systematic way to improve processes, products and the whole workplace through production line employee involvement. (George et al. 2005)

2.1.10 Quick changeover

Lead time can also be reduced by implementing quick changeover –method. In this method, the changeovers between production runs are as quick as possible (Burton & Boeder 2003). According to George et al. (2005), quick changeover is used to decrease production takt-time, and it may help in balancing the workload.

According to Burton & Boeder (2003), quick changeover is a critical method for companies that try to eliminate waste and improve flow. The method can be used to eliminate great amount of waste with only small investments. The importance of quick changeovers increases when a plant is producing MTO (Make To Order) products. In MTO production, the batch sizes decrease. Consequently, the number of changes in a time period increases. Hence, it is possible to significantly improve the flow with the quick changeover method in MTO production sites.

Quick changeover projects are currently being organized at the same plant, but they are separate from this thesis. Therefore, these projects are not documented in this paper. However, quick changeover method will not be implemented during this work, and hence it will not yet have a positive effect that it could later offer.

2.2 QRM - Quick Response Manufacturing

Quick Response Manufacturing (QRM) is an operation strategy that is in many ways very similar to Lean manufacturing. It is the only rather well known operation strategy along with Lean that has an emphasis on reducing lead times. QRM was developed in the late 1980s by Rajan Suri, professor of Industrial and Systems Engineering at the University of Wisconsin-Madison. QRM suggests that minimizing total time from raw materials to finished products will result in huge cost savings and improved customer service. This operation strategy is reviewed in this chapter to get a wider perspective to lead time reduction. In QRM, the definition for lead time is Manufacturing Critical-path Time (MCT), but lead time will be used in this work to prevent confusion.

2.2.1 The differences and similarities between QRM and Lean manufacturing

QRM and Lean manufacturing have many similarities. According to Suri (2010), they are both strategies that can result in shorter lead times, but QRM has set lead time reduction as its primary goal. Lean manufacturing, however, has an emphasis on eliminating waste and creating flow and these methods will lead to lower costs and shorter lead times (Womack et al. 1990; Liker 2004). Another difference is that in QRM, the takt-times are not calculated at all. QRM is planned to be used in high variety production where the takt-times would be significantly different for each product and that makes it unnecessary or impossible to calculate them (Suri 2010).

Suri (2010) states that QRM can be built on Lean manufacturing strategies and that they enhance one another. Lean manufacturing has origins in the car industry which has high volumes and repetitive production. Lean strategy has proven that it works in such environments. According to Suri (2010), QRM tries to offer the right strategy for low volume and high variety products. Even if these strategies have slightly different emphasis, they have many very similar methods that can be used to reduce lead times.

The similar methods include the cross-training of the workforce, creating manufacturing cells, team ownership, reducing variability and having the focus on lead time reduction (Womack 1990 et al.; Liker 2004; Suri 2010). These methods are introduced later in this chapter.

2.2.2 Benefits of QRM

According to Suri (2010), the application of QRM to reduce lead times results in lower costs, improved quality and a quicker response to the customer. Companies have a whole set of procedures to manage the job flow during their long lead times. If the lead time was much shorter, the company could eliminate many of those activities and resources needed for long lead times (Suri 2010). These principles are in many ways similar to the targets of eliminating waste and focusing on flow efficiency, which were introduced earlier (Chapter 2.1.1 and 2.1.4). In Lean, however, lead time reduction is seen as a consequence of eliminating waste, whereas in QRM, it is the main target.

The arguments supporting lead time reduction are also similar in QRM and Lean. According to Suri (2010), one of the biggest problems that long lead times create is the need to get hot jobs or late orders through the factory quickly. The plant must add some loose time for confirmed orders in order to expedite hot jobs for important customers when they arrive. It results in even longer lead times for all the orders, except hot jobs. That requires a system to manage and execute the changes and even time from top management to negotiate priorities between hot jobs. It also takes time from sales personnel to expedite and explain delays to the customers. Suri (2010) states that it is possible to minimize these wastes by implementing QRM. In Lean literature, the needs created by this problem are included in the secondary needs or wastes that long lead time create (Liker 2004; Carreira 2005; Modig & Åhlström 2013). As mentioned earlier, these secondary needs can be eliminated by focusing on flow efficiency that leads to lead time reduction.

According to Suri (2010), one advantage of shorter lead times is that it makes it possible to have smaller WIP and finished goods inventories. The same advantage is widely recognized in Lean literature and it was handled in Chapter 2.1.1.

Suri (2010) argues that there is also a great opportunity to gain market share by offering shorter lead times, and shorter lead times prevent order cancellations and loss of sales to competition. In addition, the time used to adjust quantity, specification, and delivery date changes is reduced. Quality improvements will also follow because shorter lead time will help to notice the defects much earlier than before. (Suri 2010)

All the wastes mentioned in this chapter also require time spent by planning, sales, scheduling and purchasing. This often results in either excessive workforce or overtime costs. According to Suri (2010), these are wastes that are not typically seen to be caused by long lead times and the opportunity to save costs remarkably in these areas is not well understood by the management. However, in Lean literature these wastes are often understood, and similar methods are used in order to eliminate them. (Womack et al. 1990; Liker 2004; Carreira 2005) All in all, the advantages of QRM and Lean are very similar, and the final targets are close to identical.

2.2.3 Obstacles of QRM

The first obstacle that can end the transition before it even begins is that accounting system might be indicating direct labor costs to increase when total lead time is reduced. This happens because QRM analysis recommends cross-training and smaller batch sizes which will lead to more setups. (Suri 2010) Even if the accounting system indicates increased costs, typically big reductions in lead time will, on the contrary, significantly reduce costs. The reasons for this were presented in Chapter 2.2.2.

According to Suri (2010), the reason why accounting systems may alert is that the systems miss the connection that calculates how shorter non-value-added time reduces the costs of the end products. The cost of the non-value-added time goes into the general overhead pool where it is mixed with other costs and disconnected from its root causes (Suri 2010). As a result, the allocated overhead stays the same after lead time reduction, even if it should decrease. Understanding this issue and the challenges of flow efficiency (presented in Chapter 2.1.3) may help during the planning period if problems like these occur.

The emphasis on on-time delivery can also be an obstacle. According to Suri (2010), if a department is measured by on-time delivery, they tend to lengthen their planned and quoted lead times for on-time deliveries to look good. For example, a department that has usually a 2-day lead time still maintains a 2-week lead time for an operation, so that in case of an equipment failure, a defect or absent employees, they would still have good on-time delivery results. In this case, most of the orders would be finished well in time and the measures would look great but it would also increase costs because the non-value-added time would be much longer than needed.

2.2.4 Four structural changes for quick response

There are four structural changes that are needed for quick response in QRM (Suri 2010). These changes are reviewed in this chapter and compared to Lean practices.

According to Suri (2010), organizing processes into QRM Cells is the first, the biggest and the most expensive part of the structural changes. QRM Cells have to be designed around a Focused Target Market Segment (FTMS). It means that different types of jobs belong to different FTMSs, and therefore they belong to different QRM Cells. Thereby, QRM Cell is a set of dedicated, collocated and multifunctional resources selected to complete a sequence of operations for all jobs that belong to a specific FTMS. A dedicated resource means that the resource can only be used for orders that belong to that particular FTMS. Collocation means that all the resources that form a QRM Cell are located in close proximity to each other in a clear cell area. Multifunctional QRM Cell means that the resources in the cell must cover different functions. These can be, for example, all the subsequent manufacturing steps needed to produce a finished product from raw materials. (Suri 2010)

Manufacturing cells are also an integral part of Lean manufacturing (Wilson 2010; Santos 2015). According to Wilson (2010), manufacturing cells are used for a family of products and they have equipment that is right-sized and very specific for this cell. What is more, cross-trained people are needed for flexibility, and the manufacturing machines have to be close to each other (Wilson 2010; Santos 2015). To sum up, cellular structure is important in both strategies, and it is seen as an essential way to improve process flow.

In QRM, the second structural change is to move from narrowly focused workers to a cross-trained workforce (Suri 2010). The same change is required in Lean transformation (Liker 2004; Wilson 2010; Santos 2015). According to Suri (2010), the most important target for cross-training is to create a flexible workforce that can move to allocate capacity wherever the bottlenecks are at a given moment. Another advantage is that the process will keep on going as planned even if one person is absent. Moreover, worker’s job becomes more varied and more interesting when cross-training is started (Suri 2010; Liker 2004; Santos 2015). Cross-training also results in continuous improvement, because when workers move from a machine to a subsequent machine and vice versa, they are able to notice possible improvements that can help everyone in their work (Suri 2010). According to Santos (2015), task rotation is a good strategy to maintain multifunctionality of the workforce.

Third structural change is to move from top-down control towards a situation where teams have the complete ownership of the processes within their cells (Suri 2010). The teams are given jobs and expectations of when each one needs to be ready. The order in which the jobs are done and all the other decisions in their cells are entirely up to the team. According to Suri (2010), when people have both accountability and authority over their decisions, they usually perform much better than when they only have accountability.

Team ownership is also one of the important principles in Lean manufacturing (Womack et al. 1990). The teams coordinate the work, suggest innovative ideas and even control the work through peer pressure (Liker 2004). Liker (2004) states that team members are at the top of the hierarchy in TPS, and team leaders and group leaders are below them. Again, both strategies support the concept of bottom-up management and employee empowerment.

Changing mindset from efficiency and utilization goals to lead time reduction is the fourth structural change (Suri 2010). In QRM, this principle has more weight than in Lean manufacturing, where eliminating waste, creating continuous flow and JIT production are often cited as the most important methods (McLachlin 1997; Womack et al. 1990; Liker 2004). These methods will lead to shorter lead times, but that is not necessarily the main target. According to Suri (2010), if a company focuses on lead time reduction, the costs will go down even if the cost-based goals are not the main target like before. The same thing will happen to delivery performance. Even if on-time delivery is no longer the primary target, it will still get better. The mindset can be changed by emphasizing shorter lead times, effectively measuring the lead time reduction and keeping the workforce informed about the measures (Suri 2010).

2.2.5 Add spare capacity and reduce variability

Required lead time reduction is not possible when the utilization of resources is always close to 100 %. When a company tries to push utilization higher, the queuing times will increase exponentially. (Suri 2010) This idea is presented in Figure 5.

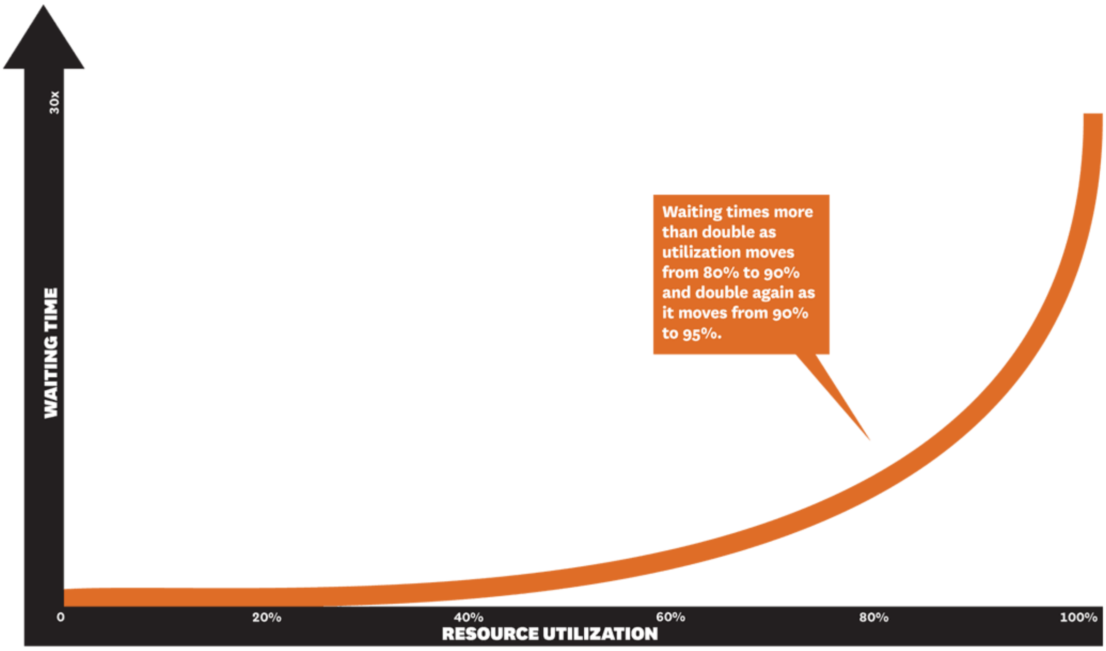

Figure 5. *Magnifying effect of utilization. (Thomke & Reinertsen 2012)*

The curve in Figure 5 is calculated using Queuing theory which is based on the mathematical studies of waiting times (Thomke & Reinertsen 2012). This shows that some spare capacity helps to reduce lead times significantly.

2.3 Change management

No implementation project can be done right without proper change management. There is almost always some change resistance when changes are implemented. Therefore, the right way to manage a change is emphasized in this chapter.

Many studies have indicated that fewer than half of the changes are successful and the main reason for failure is change resistance (Schienmann 1992; Hammer & Champy 1992; Day 2000; Wolfsmith et al. 2000). Vukotich (2011) argues that the root reason for change resistance is often the lack of understanding what change is needed and why. The risk of change is seen as greater than not changing anything, and the unknown that change brings is scarier than current situation when people know what to expect when they come to a workplace (Vukotich 2011).

To overcome change resistance, it is necessary to understand why change happens and to form a clear understanding of the issues and opportunities behind the change. The need for change has to be explained to all the stakeholders. If individuals understand the purpose and potential impacts of the change, they may be open and even willing to help to make the change. (Vukotich 2011)

Modeling or communicating the future state is often considered as the most important action of change leadership (Anderson & Anderson 2002; Sims 2002; Vukotich 2011). There must be a clear set of goals and the change leader has to communicate the end goals and how to achieve them. According to Vukotich (2011), it must not be avoided to share the information on what is the best that can happen, the most likely to happen and the worst that can happen. Nadler & Tushman (1997) argue that the clear image of the future state has to be provided to all the stakeholders to reduce ambiguity. Communication is in an important role and must be done repeatedly through multiple channels to sell the idea thoroughly. Feedback and evaluation must also be obtained through the transition process so that the change leader is able to react to the problems. (Nadler & Tushman 1997)

It is also important to motivate constructive behavior. Nadler and Tushman (1997) suggest using four key actions to motivate people before and during the change:

- create dissatisfaction with the current state
- obtain the appropriate levels of participation in planning/implementing change
- reward desired behavior in transition to future state
- provide time and opportunity to disengage from the current state

According to Nadler & Tushman (1997), the purpose of creating dissatisfaction with the current state is to motivate people to move away from the present situation. It can be done by presenting information on economic impact and goal discrepancies and by telling how the change affects people positively. It is also useful to help people understand the negative effects on business if changes are not made.

Obtaining the appropriate levels of participation improves motivation, helps making better decisions and increases communication. It also tends to capture people's excitement. Hence, implementation planning and evaluation should be done together with the people affected by the change. (Nadler & Tushman 1997) According to Anderson & Anderson (2002), this leadership style is defined as facilitating leadership. Anderson & Anderson (2002) argue that facilitating leadership style is the best style for transformations, unless the company has consciously started to use self-organizing leadership style. On the other hand, high participation has some costs: It takes time and may increase ambiguity and create conflict (Nadler & Tushman 1997). Therefore, it is important to choose how much to build in participation and possibly decrease participation if negative effects occur.

The third action area is to reward desired behavior because people tend to do something they experience they will be rewarded for doing. Reward is often suggested as an important change management action in change management literature (Anderson & Anderson 2002; Sims 2002; Nadler & Tushman 1997). Reward can be informal recognition, feedback, assignments as well as formal measures and a pay. (Nadler & Tushman 1997)

The fourth action area ("provide time and opportunity to disengage from current state") mainly applies when big changes are made and people are dismissed. Then it would be important to allow people enough time to recover from the changes.

It is also necessary to know what may cause the change to fail. Vukotich (2011) has gathered some often cited reasons that make change initiatives fail and therefore must be avoided. These are listed below.

- lacking leadership that visibly supports the initiative
- communicating an unclear vision of the future
- allowing individuals to believe change is an option, not a requirement
- focusing on accomplishing tasks rather than achieving goals
- lacking a process to hear the concerns of those needed to initiate change
- failing to celebrate/reward early successes
- lacking clearly defined roles and responsibilities.

Many of these reasons are clear counterparts to the actions recommended earlier in this chapter. Nevertheless, it is important to keep these in mind so that failure is prevented and change is successful.

3. CURRENT STATE OF PRODUCTION PLANNING

In this chapter, the focus is on the current state of the production planning and material flow in the plant. Production planning uses a combination of push and pull -systems and the most important indicator of success is on-time delivery from order to a finished product. However, the current method does not emphasize short lead times and hence there are no lead time goals.

3.1 Current flow

There are four film production lines at the factory. This is the first step of the production and its outputs are big mother reels. These mother reels can then be sent straight to customers or pushed to the inventory to wait to be slit at the slitting machines. The flow of the flow units when they are not sent straight to the customer is shown in Figure 6.

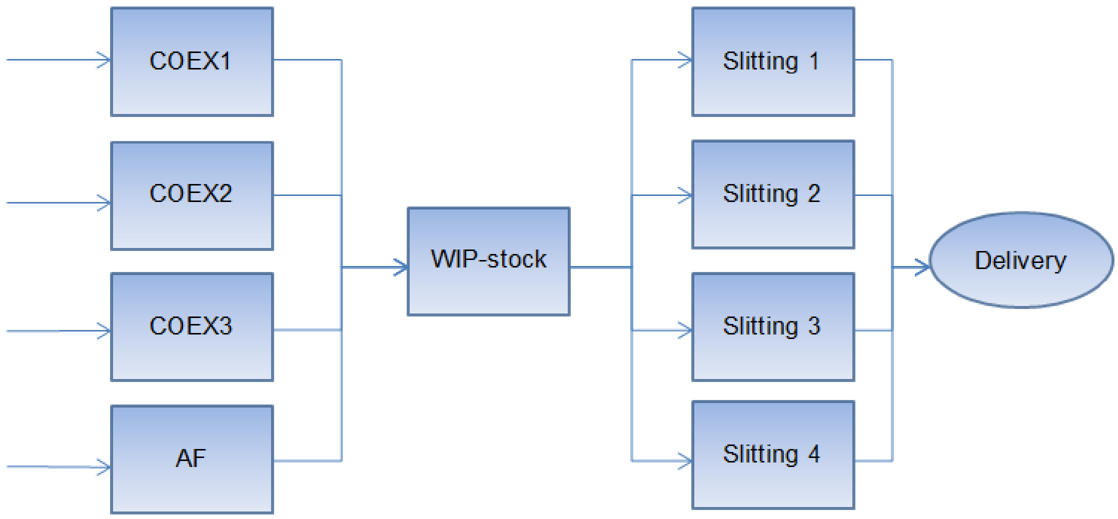

Figure 6. *Chart of the material flow inside the factory.*

In this chart lines COEX1-3 and AF are film production lines and slitting 1-4 are slitting machines. One operator is always needed for each machine that is in use. The arrows before the film production lines represent the queues before the lines, which are typically from one to four weeks. The mother reels wait in the inventory typically from 2 to 14 days after the first step before they are slit. The mother reels from COEX1-3 can be slit right after production, but it must be taken into account that the mother reels from AF have to mature in the inventory at least 24 hours before they can be slit, since they shrink after the production. A production planner can later schedule a mother reel to be slit in whichever slitting machine regardless of the film production line where it was produced. However, the slitting machines have some restrictions that limit the machines that can be used. These restrictions will be discussed in Chapter 3.3.

It must also be taken into account that slitting 2 has been inoperative for around six months before this work. It is not sure what the main problem is, but at least one important part is out of order and it would be very expensive to fix. Moreover, fixing this part may not necessarily fix the machine and for that reason the plant tries to survive without it.

All four film production lines have seldom been in use at the same time during the last few years. COEX1 is in very infrequent use but other lines are in constant use. This might be the case even when there are long queues before each film production line and it would be possible to start a new line. The reasons for this are rather high costs of starting and stopping the lines and the challenges to increase the flow through the slitting machines correspondingly.

The avoidance of the costs (that starting and stopping the line causes) results from not knowing how long the peak in demand will last. If the peak in demand is short, then the need for an extra production line is only temporary. The costs for the material produced on a line increase drastically if the line is in use for only less than one week for example.

Increasing the flow through the slitting machines is also very challenging when all of the film production lines are in use. The availability of the workforce is limited and it is not enough for short lead times when all the lines are in use. The film production lines are prioritized because film production is a continuous process, and therefore one operator is always needed for one production line. If one film production line operator is absent, one operator is taken from the slitting machines to replace him.

In a normal situation only from one to three slitting machines are being used in a shift but there is a need to run from three to four slitting machines when all the film production lines are in use. It is very challenging to slit everything that is produced at the film production lines especially when someone is absent. For that reason, the inventory increases every time four lines are producing film at the same time. As a result, lead times might stay the same even if one more production line is started to reduce the lead times, because slitting machines will end up being bottlenecks.

One characteristic feature of the flow today is that it is uneven. There have been quite a lot of changes in the workforce recently resulting in different amount of workers in different shifts. The allocated number of operators in a shift is from five to seven. Consequently, the combined output of the slitting machines sometimes varies enormously between shifts and production planning has no other way than to add extra time for slitting when confirming orders. The flow through the film production lines, on the other hand, is rather stable because of the prioritizing.

3.2 Resource efficiency and push-pull system

The production at the factory is characterized by a huge number of product variants. A specific product in certain width and length typically goes to one customer only. Therefore, there are different end products for almost every customer. This creates the need for a demand pull system where products are only made to orders. However, the part between film production lines and slitting machines is based on a push system where mother reels are pushed into the inventory (i) and to the second step to wait to be slit. Hence, the system is a combination of push and pull -systems. This push-pull system is visualized in Figure 7.

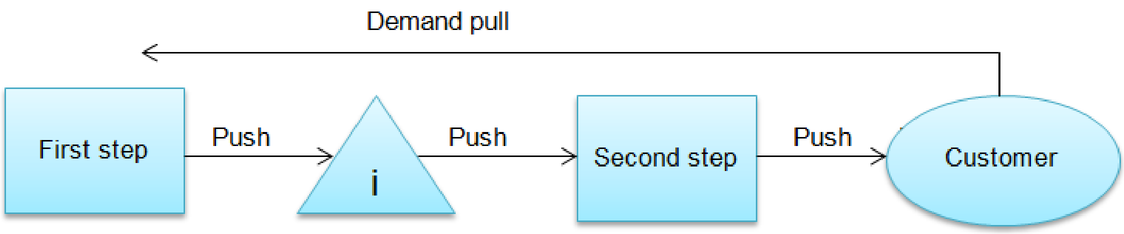

Figure 7. *Current push-pull system.*

The plant has three full time production planners. Their responsibilities are divided functionally. One production planner has the traditional film production lines (COEX 1-3) as an area of responsibility. Another planner plans the production through all the slitting machines and the third production planner is responsible for planning the production through the newest film production line (AF). Third planner also plans the production through another film production line as well as slitting machine at another production plant. The areas of responsibilities are shown in Figure 8.

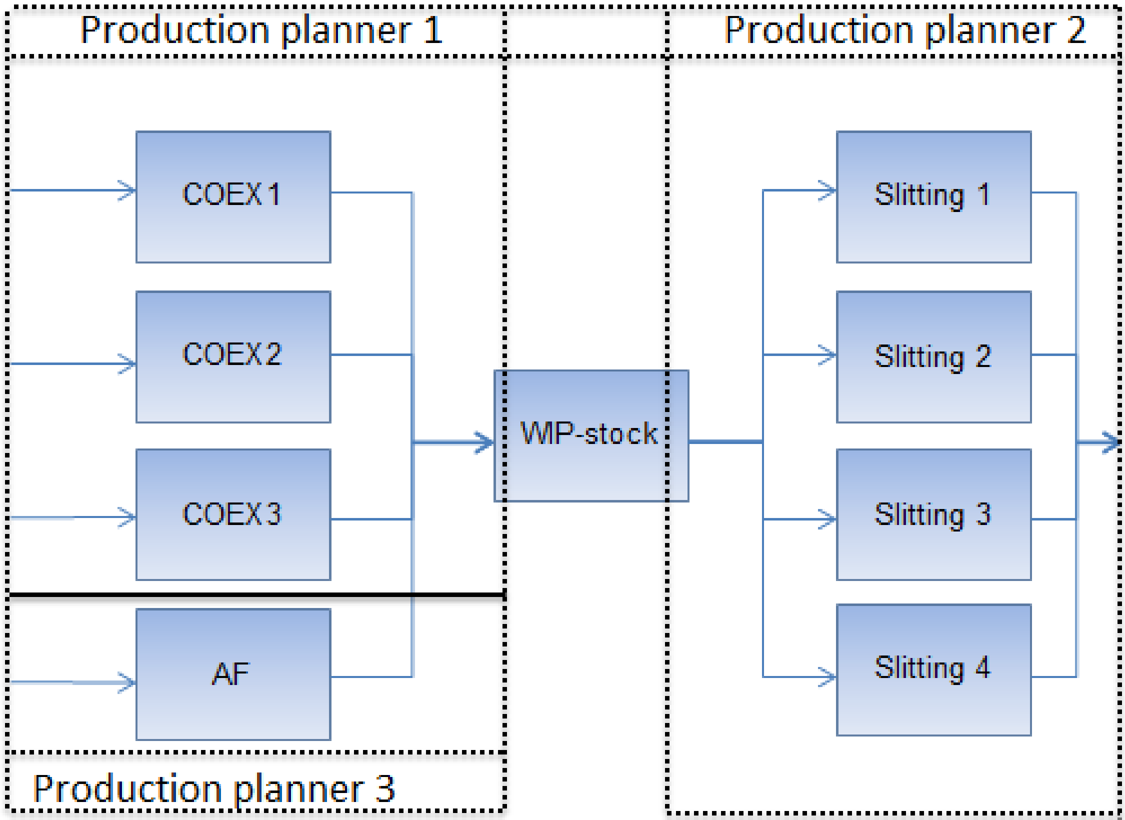

Figure 8. *The areas of responsibilities in production planning.*

Production planning starts working with a new order after it is entered into the ERP system by a sales assistant. Production planner first schedules the film production fairly close to the actual day it will be produced. The scheduled time is often at the same time as the last planned cycle for the material family in question. After scheduling, the production planner confirms an ex-work date. The order is usually confirmed to be ready at least one week after the film production in order to have enough time to slit the reels. Moreover, the confirmed ex-work date is typically Friday so that there is enough time to get the order ready if something unexpected happens. If the material is ordered well in advance, the requested date is confirmed. There is often some loose time in the scheduling of the first step as well. This loose time is added so that the plant is able to do "hot jobs" for key customers and is prepared for surprising events such as machine breakdowns.

The scheduling of slitting is usually made just before the film production starts so that the timing is precisely known. Slitting queues are planned to have as similar production runs one after another as possible. For example, a production planner tries to schedule long periods of production runs where mother reels are slit into three adjacent customer reels. After that, production planner schedules a long queue of production runs where mother reels are slit into two or four adjacent customer reels, and so on. The objective for this is to shorten the changeover time between production runs. Thus, it is typical and recommended for the production planners to focus on resource efficiency and to try to get advantages from the economies of scale.

The on-time delivery rate from order to a finished product (ex-works) is the primary measurement that defines the success of production planning. Hence, production planners add loose times into the schedules to make sure that at least 95 % of the orders are ready as promised. As a result, the orders are often ready sooner than confirmed but they cannot be sent to the customers because ERP –system prevents sending goods to the customers before the confirmed date. Still the measurements look good and it seems that production planning is working very efficiently. The problem is that the lead times get longer at the same time. Production planners need to inform the current ex-works date to the sales each week but there is no target lead time and no emphasis on keeping the lead times as short as possible.

3.3 The challenges of creating continuous flow and pull system

One of the reasons why continuous flow and pull system are not implemented so far is that no-one has really had the time or authorization to examine the possibility to change the system. Nevertheless, there are also a few clear reasons that disturb the flow in the factory. The main reasons are that the machines are all different and have different restrictions, which make it hard to use standard routes for products. Standard routes are necessary in FIFO lanes and in continuous flow. The restrictions of the film production lines are in Appendix B.

Creating standard routes for products to achieve an efficient flow is hard because the output varies greatly between the film production lines. One operator at a slitting machine has enough capacity to slit the output of one traditional line (COEX) but the output of AF needs more capacity.

The restrictions of the slitting machines are in Appendix C.

Another problem is that operators at the slitting machines have great variation in their output. The average output is close to 3000 kg in 12 hours but it ranges from 1000 kg to 7000 kg. The outputs of operators are presented in Figure 9.

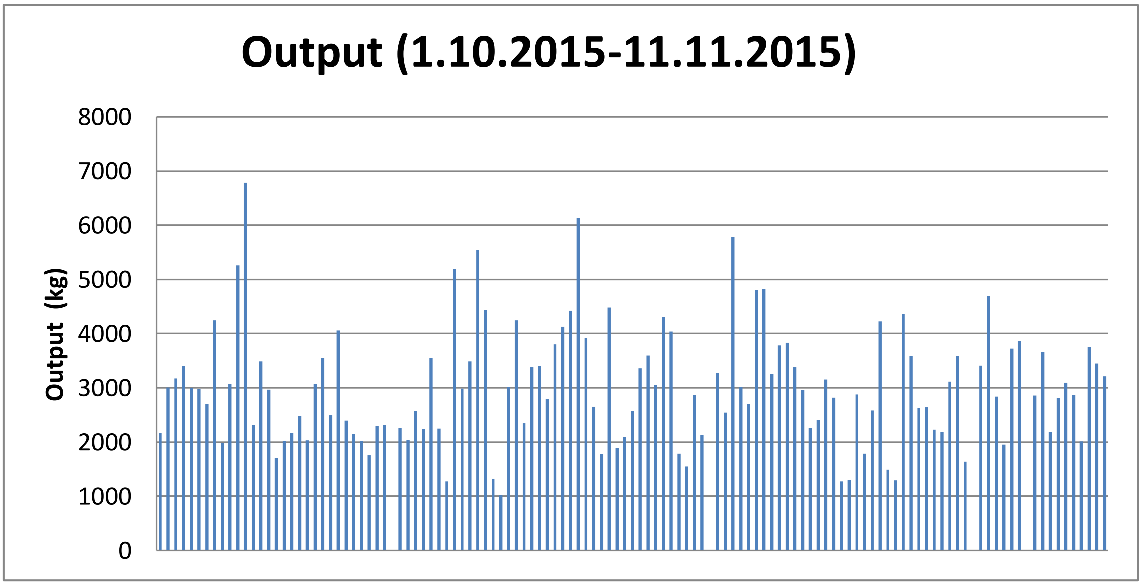

Figure 9. *Outputs of operators.*

Naturally the operators are not the only reason for the huge range. The order sizes vary a lot (see Figure 10), and the size of the orders plays a key role that affects the output. It takes almost as much setup time to produce a 20 kg weighting sample reel as ten pallets full of customer reels. Therefore, the output is much lower if there are many small orders in the queue. Moreover, the work is not standardized and there are no clear targets which the workers are encouraged to reach.

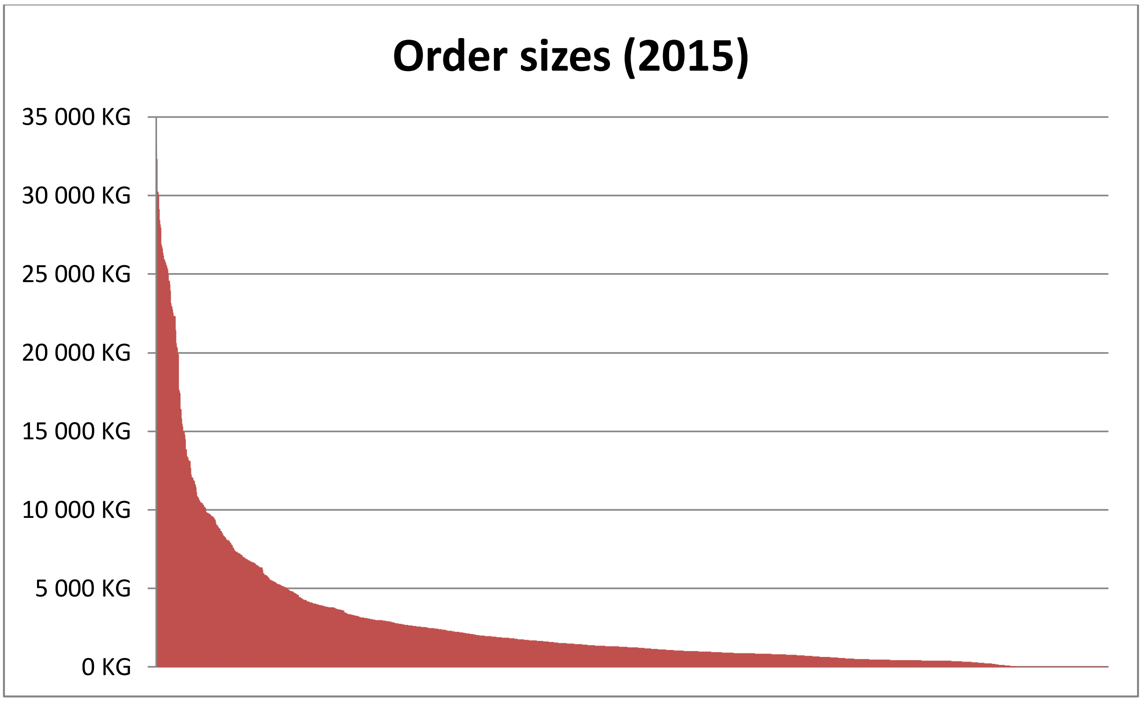

Figure 10. *The order sizes in 2015. Each customer order is one column.*

The workers who like to work really hard might also get bored if the workload is balanced. The most efficient workers would have to wait for previous steps to be able to continue working again. As a result, their output would be lower than before.

Another obstacle is that setups either at the slitting machines or at the film production lines might take more time when the FIFO method is applied. Now the sequential orders in the queues are planned to have minimal setup times but if the same plan was used in both production steps, some compromises might be needed. On the other hand, the difference should not be very significant and it can be evaluated before the change.

The layout of the factory does not support continuous flow very well. The factory is divided functionally into three areas: film production area, WIP inventory area and slitting area. According to Lean and QRM theories, cells that have all the machines to make finished products from raw materials for certain product families would be a better option. However, changing the layout would be really expensive and would take great amount of time to execute. Hence, it is not possible to change the layout in this work.

3.4 Current state VSM

Value Stream Map (VSM) is a tool for analyzing information and material flow in a factory (see Chapter 2.1.7). Material flow in current situation was evaluated by walking through the production and examining the average cycle times and uptimes of the processes. Information flow was investigated in production planning which is the center of the information flow. Current VSM for COEX2 and COEX3 is shown in Figure 11.

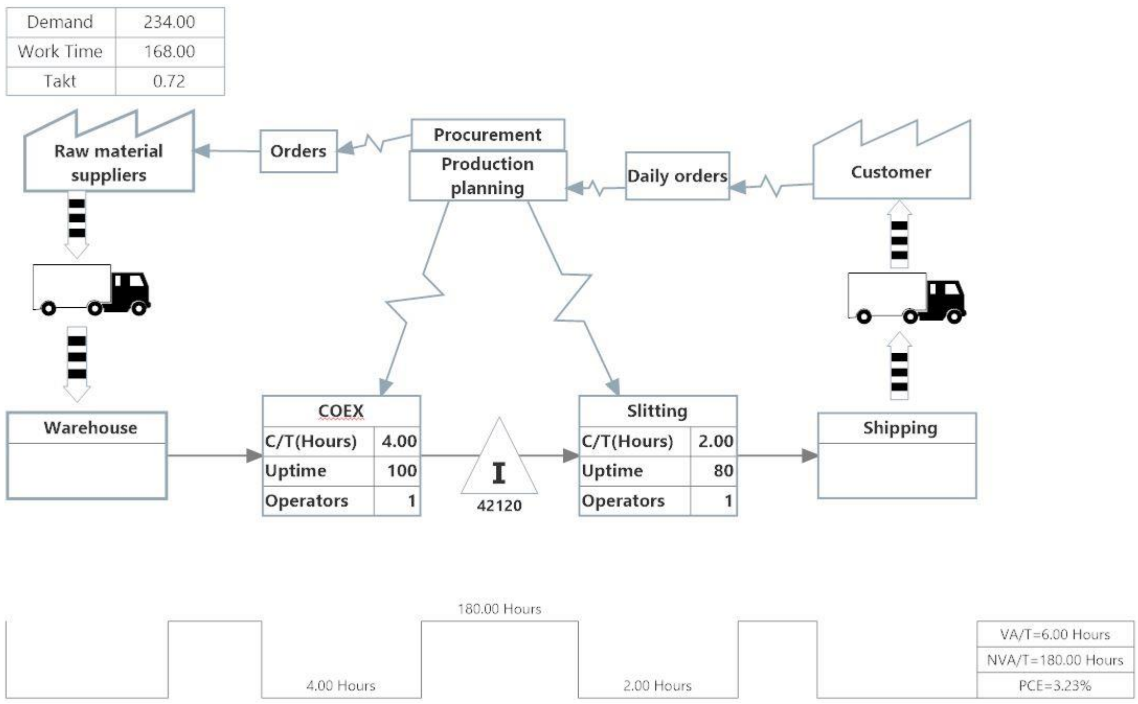

Figure 11. *Current Value Stream Map*

The calculations in this VSM were limited to concern only production operations because it was the most interesting part that needed to be measured in this work. Moreover, there is no valid data to estimate the times from receiving raw material to the film production and from a finished product to the shipping of the order. Measuring and improving those times could be two possible next steps after this work.

Cycle time in this VSM is defined for one mother reel. It has to be taken into account that during one cycle the COEX -line produces two mother reels at the same time. In slitting, one cycle is one slit mother reel. Hence, the production rates of the processes are the same. The time needed to produce and slit mother reels varies but 6 hours is a good average time to use for simplicity.

The average time the produced mother reels were in the WIP inventory between COEX -line and slitting machines (queuing time) was calculated manually. The ERP system records the dates when the film is produced. At the time of slitting, the amount of days the material has been in the WIP inventory can be counted. The queuing time of each order is presented in Figure 12.

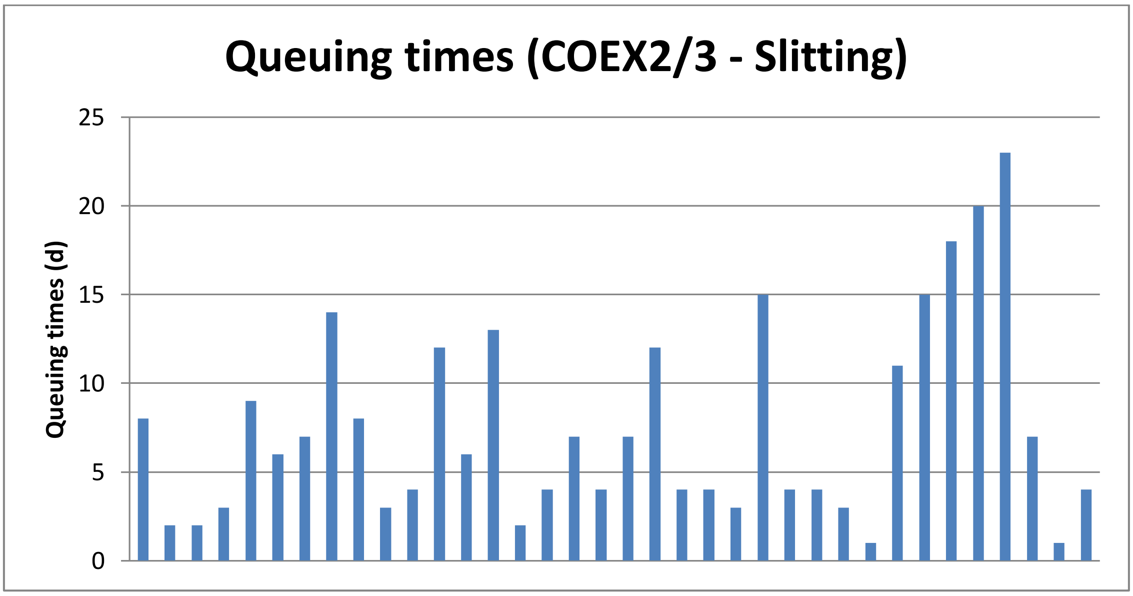

Figure 12. *Queuing times between film production and slitting in days.*

The average number of days during the monitoring was 7.50 which is 180 hours. The monitoring periods were quite short because of the limited time before the implementation, but they represent the typical situation very well.

The number of days the produced mother reels were in the WIP inventory between AF and slitting was calculated correspondingly. The queuing time for each order is presented in Figure 13.

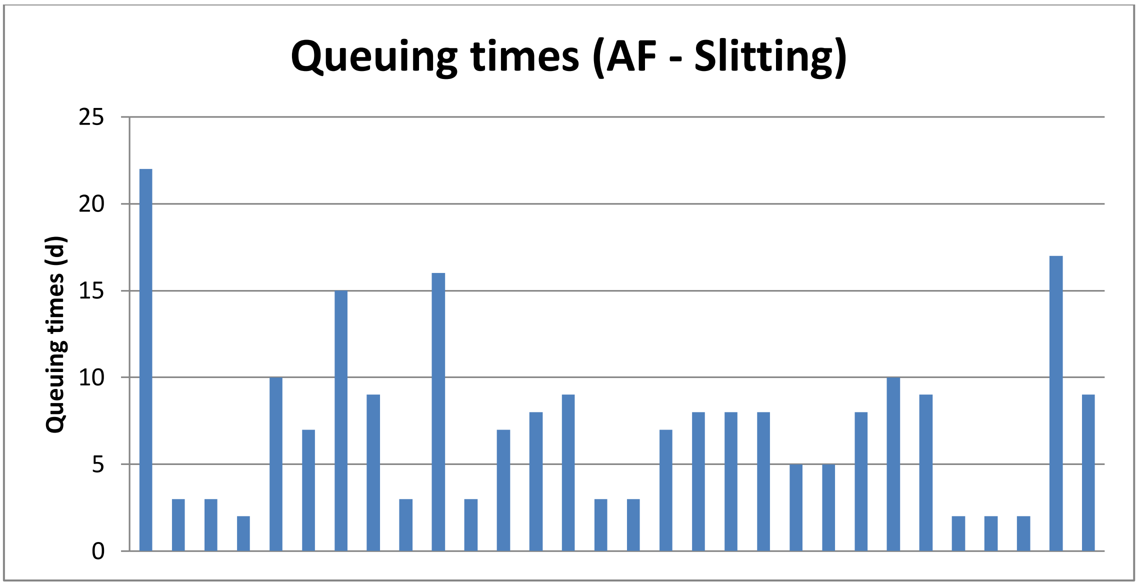

Figure 13. *Queuing times between AF and slitting in days.*

The average number of days was 7.43 which is 178 hours. The charts in Figures 8 and 9 do not include orders that were slit from old stock.

3.5 The targets of the flow efficiency

This work is limited to concern the period from the start of the film production to the end of the slitting at the slitting machines. Therefore, the calculations must only cover that period. The flow efficiency before the implementation is calculated directly by measuring actual lead times from the process. As mentioned earlier, the ERP system records the dates the film is produced and at the time of slitting, the days the material has been in the WIP inventory can be counted. The results are shown in the appendix A. The combined average lead time for this process at COEX2 and COEX3 was 186.0 hours which consist of 180.0 hours in the inventory and 6.0 hours of production. When these values are put into the formula 2 (see page 7), flow efficiency of 3.23 % can be calculated.

$$Flow\ efficiency = \frac{6.0\ hours}{186.0\ hours} \times 100\ \% = 3.23\ \%$$

A world-class flow efficiency or PCE (Process Cycle Efficiency), in a continuous process, is 30 % (George et al. 2005). To reach the world-class level, the factory should obtain a process lead time of 20 hours.

$$Target\ lead\ time = \frac{6.0\ hours}{30\ \%} \times 100\ \% = 20\ hours$$

George et al. (2005) suggest that if a process has a PCE of 5 % or more, the world-class level of 30 % should be set as a target. Even though the flow efficiency at the moment is less than 5 %, the target is still set to be 30 % because the process is rather simple with only 2 production steps.

The average lead time from the film production at AF –line to the slitting of the film was 178.0 h. This consists of 4.5 hours of production, 24.0 hours of maturing and 149.5 hours in the inventory. The flow efficiency is then

$$Flow\ efficiency = \frac{4.5 + 24.0\ hours}{178.0\ hours} \times 100\ \% = 16.0\ \%$$

If the target flow efficiency is set to be 30 %, the target lead time for this process would be:

$$Target\ lead\ time = \frac{28.5\ hours}{30\ \%} \times 100\ \% = 95\ hours$$

The lead time improvement would not be as significant as on the other lines. Therefore, the target for the average lead time was set to be less than 48 h, which would give the operators 19.5 h to slit the mother reels after the maturing time. This is a little longer than on the two other lines, but on the other hand, the output is also much greater on this line.

3.6 Future state VSM

Continuous flow and big improvement in lead time are not possible if the plant keeps on pushing mother reels from film production lines to the WIP inventory and then, in different order, from WIP inventory to the slitting machines. According to Lean theory, the implementation of FIFO lanes and continuous flow can help solving this problem. The evaluation of FIFO lanes will be discussed in more detail in Chapter 3.8. The VSM in the future, after implementing FIFO lanes, is shown in Figure 14.

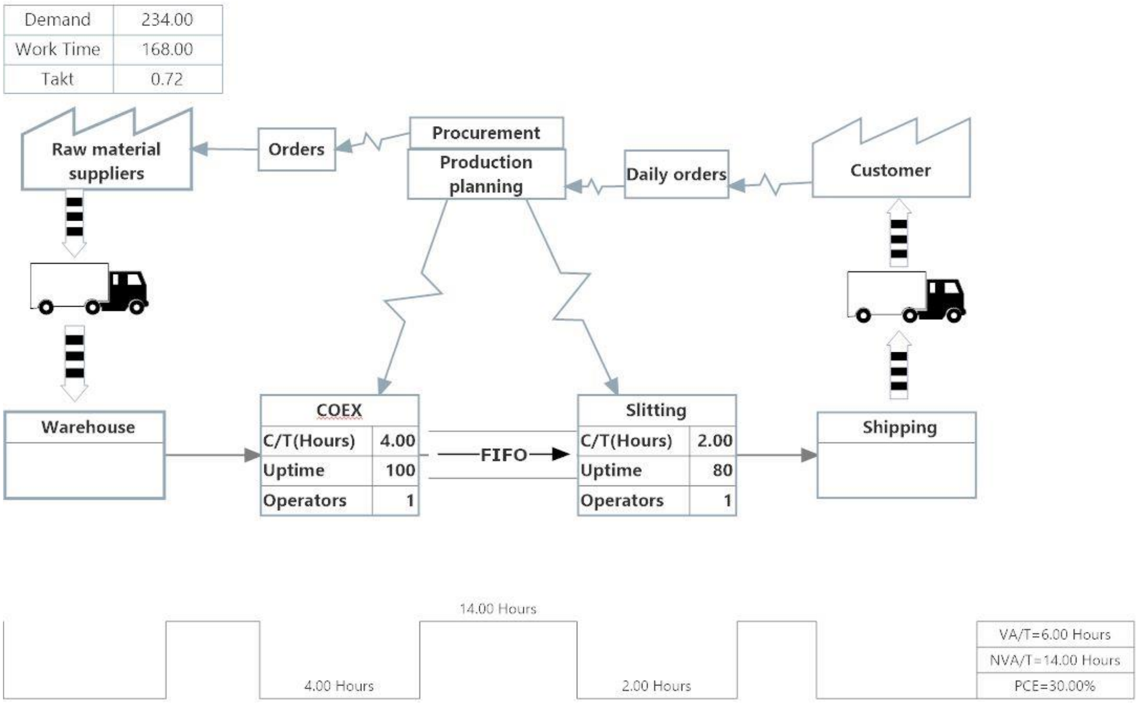

Figure 14. *Value Stream Map in the future.*

When the target flow efficiency (or PCE) is set to be more than 30 %, the lead time of the process has to be 20 hours or less. Therefore, the queuing time between COEX and slitting must be 14 hours or less. COEX2 produces 7 mother reels on average in that time and it means that the maximum number of mother reels in the FIFO lane has to be 7 reels to have a flow efficiency of 30 % or more. COEX3 produces 8 mother reels on average in 14 hours and that could be set as a target for the maximum number of mother reels on the FIFO lane after COEX3.

3.7 Orders confirmed as requested

Before the implementation, 38 % of all orders excluding sample orders were confirmed as customers had requested. Requested delivery times in weeks are shown in Figure 15 below.

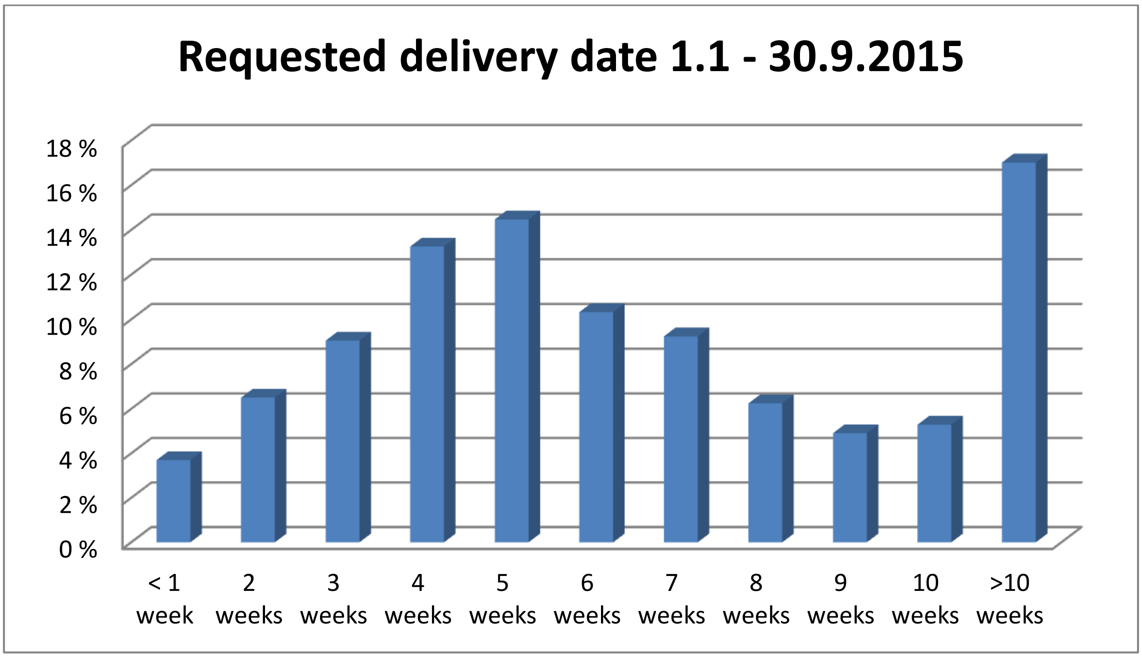

Figure 15. *Requested delivery times in weeks.*

If production planners were able to confirm all the orders to be delivered in 5 weeks, 67 % of all the orders could be confirmed as requested. That would be a far better service level than before and it would help retain the customers. This can be achieved if the queue before a film production line is three weeks or less. Then the dispatch department would have one week to plan the transportation and one week to transport the order. After this work, when the lead times are more predictable and accurate, one important improvement would be to minimize the time between finishing the production and shipping the order. After the improvement, it would be possible to confirm even more orders as customers have requested. The ultimate target has to be 100 % because of the earlier mentioned (see Chapter 2.1.5) goal to make orders just in time.

The confirmed as requested –percentage varies monthly and the percentages in 2015 are shown in Figure 16. Figure 17 shows the monthly customer demand in 2015.

Figure 16. *Confirmed as requested by month.*

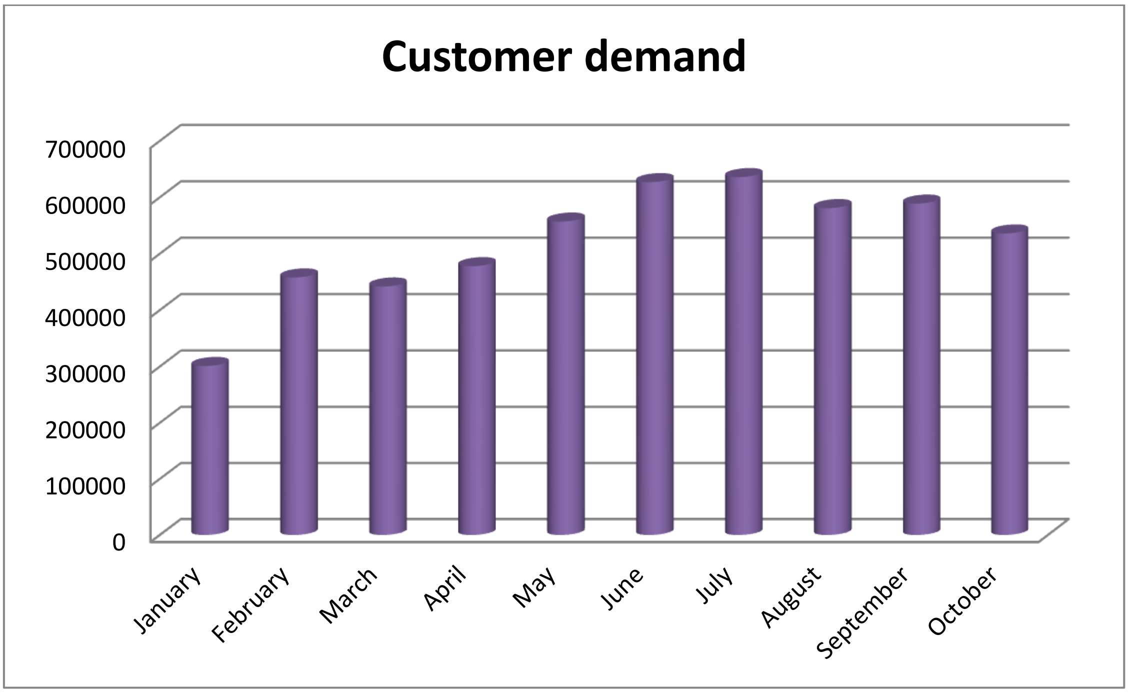

Figure 17. *Customer demand in 2015.*

As it can be seen in the figures 16 and 17, there is a clear connection between the customer demand and orders confirmed as requested: When the customer demand gets higher, fewer orders can be confirmed as requested. The paradox is that in July, when the customer demand is in its highest, some production lines are stopped because of summer holidays. Thus, the output is the lowest during the peak in demand and fewer orders can be confirmed as requested. To be able to serve customers better, the plant should make a long term plan on when each machine is running based on the previous demand. This could possibly be done with simulation software. Correctly done, a simulation model could help shorten the queues before the film production lines. Therefore, generating a proper simulation model is recommended to be one of the next steps after this work.

3.8 Workforce vs. workload

The workload is high in the beginning of the year because all the production lines are stopped for Christmas. During that stop the workload gets higher as the orders keep coming in. Hence, at least three film production lines are always started soon after the holidays. The average quantity these production lines produce together is ca. 160 000 kg/week. The customer demand in the first half of the year, however, is much lower than that as can be seen in Figure 13. For example, when the monthly demand is 458 000 kg, like it was in February, average weekly demand is only 114 500 kg. As a result, there is a point during spring when one film production line is stopped and annual cleaning of the line is performed.

The average quantity produced for slitting is 117 000 kg/week before the cleanup. One person slits 3000 kg on average during a 12 hour-shift and there are 14 shifts in a week. Hence, the needed number of operators at the slitting machines is

$$\frac{\frac{117000\ \text{kg/operator}}{3000\ kg}}{14\ \text{shifts}} = 2.79\ \text{operators/shift}$$

Because spare capacity is recommended when reducing lead times, the allocated number of operators in a shift should be three or more at the slitting machines. That would be enough even in the case of occasional absence of some of the workers. As three film production lines need three operators, there should be at least six operators together in one shift.

In Lean manufacturing the workload is balanced by setting the production takt-time to be equal with customer demand takt-time. The estimated customer demand at the slitting machines is 117 000 kg/week in a period from 1st to 10th week. Without the necessary cleaning stops it would be lower, but the stops must be taken into account. The average mother reel weights 500 kg, which means that the demand is around 234 slit mother reels in a week. This demand is put into the formula 3 to get a customer demand takt-time.

$$\frac{168\ hours}{234\ mother\ reels} = 0{,}718\ hours/reel$$

Since the goal is to always have three operators at the slitting machines, the takt-time in this production step is $3 * 0{,}718 = 2{,}15$ hours/mother-reel for each machine. This makes 5.57 slit mother reels during a 12-hour-shift, which is easily achievable. However, some orders are much faster to slit than others, and therefore it is not reasonable to have a fixed takt-time for all orders. Nevertheless, these calculations verify that it is possible to have the same takt-times between operations to achieve an efficient flow with the current production system.

Sometimes customer demand for slit orders is high and at times there are many orders that will not be slit but are sent straight to the customers. The balanced workload will help with the variance but if the demand for slit orders is very high for a long time, then also more flexible workforce is needed. These peaks in demand must sometimes be covered with overtime or agency workers in order to keep the flow efficiency high. Releasing fewer orders into the production is not an option in this kind of continuous process.

The needed workforce in different scenarios was tested with an excel simulation. In a typical situation, when some of the orders are needed as mother reels, it is possible to have an efficient flow even when some operators are absent. If all the lines produce film that have to be slit, the queues before slitting machines get longer with usual output. The simulation model suggests that the queues will get longer by 24 hours in a few days unless operators work either harder or overtime, or agency workers are employed. When the target is a flow efficiency of 30 % or more, more workforce must be requested in these occasions.

The simulation model can also be used to define how many operators will be needed in the near future. The production plan should always be rather fixed for the next few days. Thus, it is possible to compare the allocated number of operators with the needed number of operators the simulation model suggests. If there is a significant difference in the numbers, operators can be asked to change shifts, work overtime or additional agency workers can be requested to work in some shifts. In the case of absent workers, production planners and production manager can quickly use the simulation to check if they need to be replaced.

3.9 Methods that will be implemented

As the theory part indicated, better flow efficiency and shorter lead times have great advantages. It was also highlighted that the changes should be made one step at a time rather than changing everything at once. Therefore, the first change and the primary focus in this work, is to make the flow efficient between film production and slitting.

Efficient flow can be achieved by implementing FIFO lanes. In this case, it means that the first reel that comes from the film production line will be the first one to be slit at the slitting machines. This makes it also possible to minimize the time between the operations because it is no longer needed to gather similar jobs together to slit them one after another. Theoretically, it would be possible to reduce the time between these operations from 7 days to a few minutes if there was enough spare capacity at the slitting machines all the time. The supermarket, which is another Lean method for inventory, would not be practical in this plant because the number of item variants is so vast.

FIFO lanes were evaluated in a simple Excel simulation by copying the queues in film production lines and analyzing what the queues would be like at the slitting machines. The queues would not be as good as they were before, because the setup times would be longer. Still, with minor changes to the queues before film production lines, it would be possible to make reasonably good queues for the slitting machines. After these changes, the setup times would not or would only slightly increase but they would make it possible to improve the flow efficiency greatly.

The FIFO method requires fixed routes for the material families. The suggested way to do this, which was introduced in the QRM theory part, would be to create cells where all the resources needed to make finished products from raw materials would be dedicated and collocated in close proximity. However, that cannot be done in this work, but the routes can still be fixed and dedicated to certain material families. Usual situation nowadays is that there are only three film production lines in use at the same time, lines COEX2, COEX3 and AF. Therefore, there is a need for three fixed routes. The restrictions introduced in Chapter 5.3 make it impossible to create completely fixed routes for all the material families. Nevertheless, it is possible to create two routes that could always function. Third route can also be created but a few of the flow units in that route must be channeled to other slitting machines at times. The first planned routes after the implementation are shown in Figure 18. The route, which does not always function, is the one in the middle (COEX3 – Slitting 4).

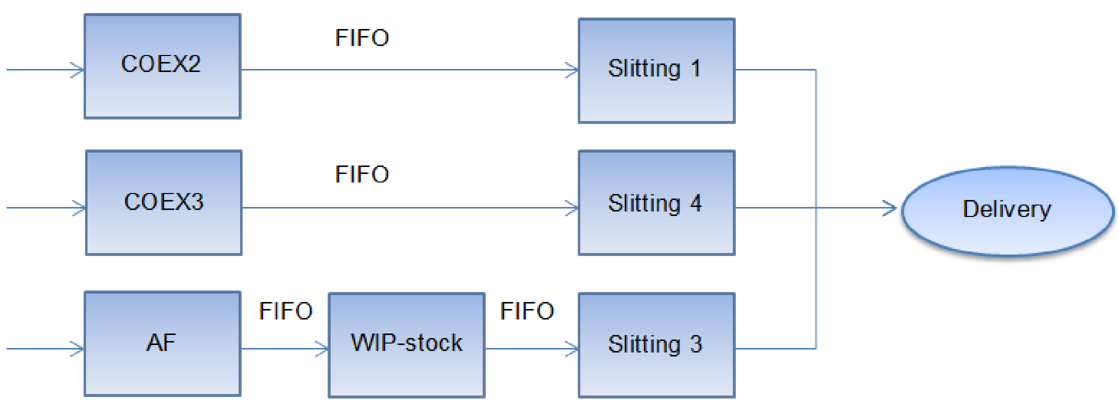

Figure 18. *Suggested material flow inside the factory after the implementation.*

The undermost route was an obvious option because AF never produces thin films and Slitting 3 is not good in thin films but great in thick films. On the contrary, COEX2 produces rather thin films and Slitting 1 is the best slitting machine for thin films alongside with Slitting 4. Slitting 1 is not good with films thicker than 200 µm. These thick films come from COEX3 and AF, and Slitting 1 is hence coupled with COEX2. Slitting 2 is inoperative, and therefore it is not used. It also has more restrictions than other slitting machines, which would make it hard to use it in standard routes.

This suggestion for new material flow was presented to the selected operators and managers in a workshop concerning the implementation. The operators all agreed that this new method could work like presented but they would rather change the routes slightly. In their suggestion Slitting 4 and Slitting 1 would change places. The reasons for this were that film produced in COEX2 has quality problems more often and Slitting 1 does not work as well with fluctuating quality as Slitting 4. All operators also agreed that Slitting 1 can be used for 250 µm thick films that is the thickest film produced in COEX3. Therefore, it was decided that the flow after the implementation would be following (Figure 19).

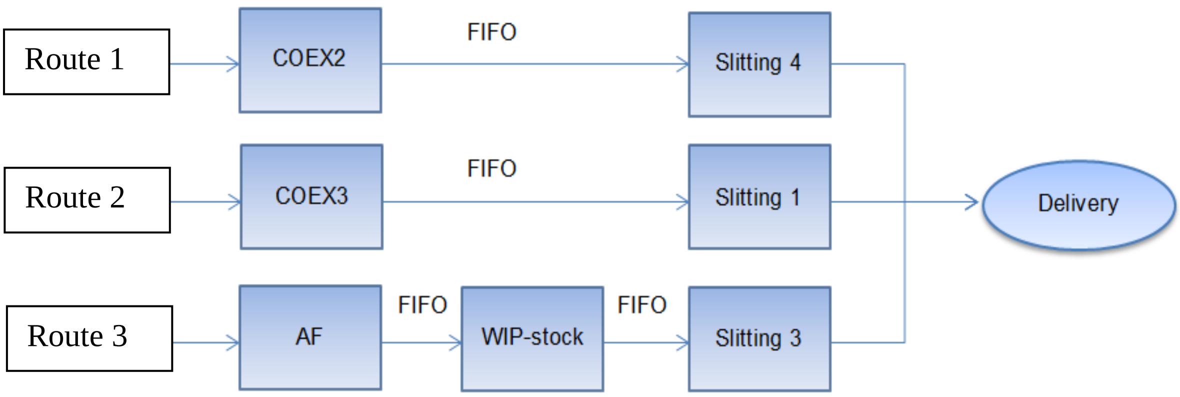

Figure 19. *Determined material flow after the implementation.*

With the succeeding process continuing the same plan when using FIFO lanes, it is necessary to make a production plan only once for the first process. Therefore, a production planner should plan the production for the complete route from the first process to the last. This is different from the current functional production planning system where one planner makes production plans for one function and another production planner plans the next function. The ideal responsibilities after the implementation are shown in Figure 20. The ideal responsibilities will not be implemented at the same time as all the other methods, because it requires more training.

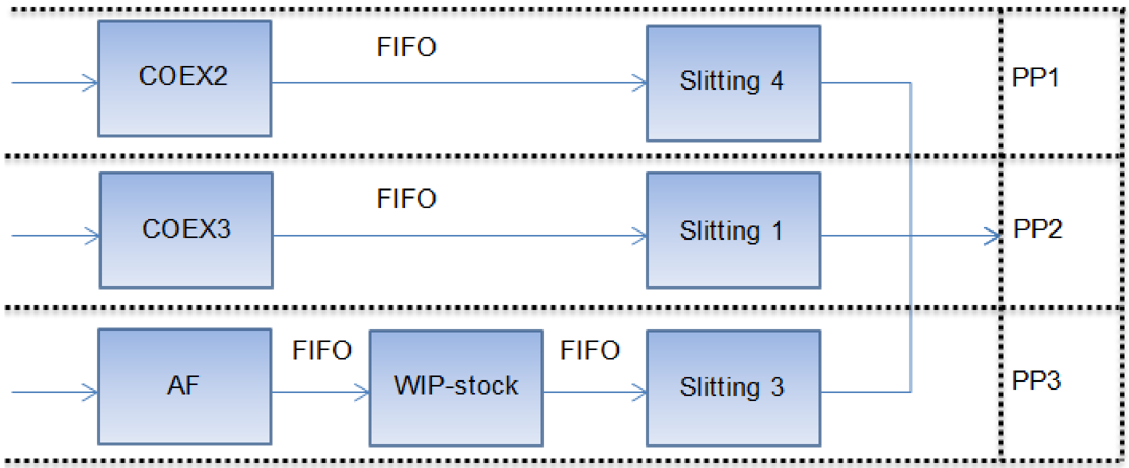

Figure 20. *Recommended areas of responsibilities in production planning after the implementation.*

The pull system was also evaluated in order to improve the FIFO flow. It became clear that it is not rational to implement complete pull system and perfect FIFO lanes. Part of the pull system is that previous step only releases orders when latter needs them, and machines must be stopped if the WIP or the number of reels in a FIFO lane increases over certain defined level. That cannot be done because film production lines are continuous processes and stopping the process after the WIP increases would be extremely expensive and would take lots of time. However, the slitting machines can start pulling the orders in better sequences, like it was mentioned before in this chapter. Making minor changes to the queues before film production lines makes it possible to have reasonably good queues at the slitting machines. Therefore, slitting plans have to be done before planning film production, but the sequences in slitting must be planned with the same terms as film production. On the other hand, if there is enough spare capacity at the slitting machines, it would be possible to slit everything that comes from the film production lines right away and, in that way, have a pull system.

These new procedures require balancing the number of the workers in each shift as well as more cross-training and teamwork. One important Lean method that was reviewed in Chapter 4.2.6 is the balanced workload. It requires that the resources are balanced as well, and for that reason, there should preferably be exactly the same number of workers allocated to each shift. To get this done, production manager was asked to balance the shifts so that the numbers of operators in shifts would be as close to each other as possible. In balancing, it was important for each shift to have at least either four film production line operators, or three film production line operators and one cross-trained slitting machine operator, and at least three operators who can operate slitting machines. The total numbers of operators before and after the implementation are shown in Table 3.

Table 1. *Number of operators in shifts.*

Shift	Quantity before	Quantity after
Shift 1	7	6
Shift 2	6	6
Shift 3	5	6
Shift 4	6	6
Shift 5	7	7

Whenever there are more workers than needed at the film production lines, the excessive workers should be helping the bottleneck operation. The bottleneck operation is typically slitting. Hence, cross-training is needed and film production line operators must be trained to use slitting machines. Luckily many of the operators already are cross-trained, which makes it possible to implement more efficient flow already with this level of cross-trained workforce and continue to cross-train more operators.

Cross-training also enables better teamwork between the operations. All the operators in one shift must be considered as one team and the goal of the team is to obtain efficient flow. In the beginning, this will be tested and controlled with one shift, while other shifts will be encouraged to work more like a team and to help other operations whenever they are waiting for something or having spare time. The controlled team will periodically change the machines the operators are operating.

As QRM theory suggests, also spare capacity should be added. One way to add spare capacity is to use agency workers. With agency workers the production can be made more flexible in order to be able to answer the uneven demand. These extra workers can be utilized if there are many absent workers, WIP inventory increases or in case that the demand increases. Hence, two agency workers were hired to help the plant succeed in implementing efficient flow.

Another way to add spare capacity is to add more machines. Film production lines already have enough spare capacity because there are four lines and only three of them are usually producing film at the same time. Slitting machines would have enough spare capacity if all the four slitting machines were operative. However, one of the machines has been inoperative for a long time. Repairing the machine was suggested in order to have more capacity when the queues get longer or machines break, but at this point, the management did not see it being worth the investment.

4. IMPLEMENTATION

The implementation of more efficient continuous flow and FIFO lanes was decided to take place at the beginning of the year 2016. It was a logical time to make a change because the plant was closed for the Christmas holidays. When the film production lines are being run down or up, they are not producing film. For that reason, it was possible to slit all the semi-finished MTO mother reels from the WIP inventory during that time.

4.1 Change management

Communicating with the decision makers to get the needed support for the change was the first change management action in this project. Dissatisfaction with the current state was first created by comparing current lead times with the lead times customers want. Decision makers were encouraged to give ideas and to strongly participate in planning the change. This helped to make better decisions and committed managers to the change, which is necessary in an improvement project. It also ensured that the change fits well in the organizational strategy.

The second action of the change management was the arrangement of an ideation meeting with the production planning unit. Production planners are in key roles when the change is implemented, and therefore it is really important that they are committed to the change. The first thing that was done in the meeting, was presenting information on why the change is needed and what the targets of the change are. Next, production planners were encouraged to present their ideas on how it is possible to get to the targets and what obstacles there will be on the way. Also the first draft of the future state was presented to the participants to get further suggestions and information on what problems the new system could bring to the surface.

It was pointed out in the ideation meeting that the biggest problem today, which would make it hard to implement the new system, is that there is great variation in the number of the workers in each shift. That would make the flow uneven and hard to control. One part of this problem is caused by an uneven allocated number of workers in the shifts and the other part of it is caused by the absence of the workers. Therefore, the third action of the change management was decided to be an ideation meeting with production supervisors, plant manager and production planners.

The goal of the ideation meeting with production supervisors and plant manager was to make an agreement about balancing the resources between the shifts. This goal was achieved. There was also discussion about how to get the FIFO flow through the production as quickly as possible using Lean and QRM methods. It was found possible to have more teamwork and cross-training between the production steps. Then the workers at the film production lines could help slitting whenever they have time. It was also agreed that a few agency workers would be hired to help keep the amount of workers in balance with the demand. The importance of spare capacity was also emphasized in the meeting and fixing Slitting 2 was suggested in order to get spare capacity. However, top management believed that bigger output can be achieved even with lesser machines, and hence fixing the slitting machine was not seen as being necessary.

To succeed in change management and to successfully implement all these changes there must be appropriate levels of participation in planning/implementing change, as stated in Chapter 8.1. Therefore, it was decided in the ideation meeting that a workshop day with production workers would be organized before the implementation.

The workshop was organized in a nearby University of Applied Sciences. Attendees consisted of three slitting machine operators, two film production line operators, one production technician, one plant manager, one production manager and three production planners. First, the current situation was presented and the need for the change was explained. Attendees were encouraged to think of reasons why current flow and lead times are not as good as they could be and to think of ideas of how to improve them. The need for change was well understood and the ideas that came up were very close to the methods that were found in the literature and which are already presented in this work.

The most important achievement in the workshop was that the suggested material flow was changed in order to make the slitting perform better. Another achievement was that production planning got a better understanding about the setup times both at the film production lines and at the slitting machines. Better understanding was formed during a FIFO training, where attendees were asked to put real customer orders in the best possible sequence, so that both film production and slitting could use the same sequence with minimum waste. The tasks in the training are in Appendix B. In the training, wasting material was seen as being more expensive than wasting time. It was also agreed that after the implementation of FIFO flow some small changes to current film production planning is needed to help slitting perform better.

In the workshop, the implementation was agreed to start at the beginning of the year 2016. The core ideas and changes in the production had to be explained to every shift before that. The short education meeting was held shift by shift after a morning meeting which is held every day in production. In the education meetings, the reasons behind the change were also explained and clear goals were informed.

As stated in Chapter 2.3, it is important to celebrate successes in the early stages of implementation. Therefore, the successes in the project were informed to everyone concerned in the morning meetings soon after the implementation started. Also, if some objectives were not reached at some point, the reasons behind the failure and the means of how to reach the goals were informed.

The improvements in flow efficiency, lead times and inventory levels were also presented in the morning meetings after there was reasonable amount of data for the statistics. The presentation consisted of visual and numerical statistics which were presented to everyone in production and production planning. The statistics were updated weekly so that everyone knew how well the plant was functioning at a given time.

4.2 The new way to plan queues

The first action for the implementation started two weeks before the implementation, which was planning the queues in a new way. The backbone for the film production schedules was first made just like before. Then slitting requirements were checked and the final scheduling for film production was fine-tuned so that the orders could be slit in the same order with minimum setup times. The queues were copied to the slitting machines in exactly the same order after that. The only exceptions were a few orders that were first produced in COEX2 but could not be slit in Slitting 4. These individual orders were put into the queue of Slitting 1. If the queue before Slitting 1 would have been much longer than the queue before Slitting 3, these orders could have been slit with the latter mentioned machine.

Slitting could have been scheduled also first and that was actually the recommended way to plan the production (see Chapter 3.9). When scheduling the slitting first, the production planner must arrange the material families in certain order, so that the waste at the film production lines would not be greater than before. This way there would be no need for fine-tuning when planning film production because the orders would be in exactly the same order right from the start. However, this method will be implemented later because some cross-training is needed in the production planning before that.

4.3 The beginning

The new continuous flow was implemented at the beginning of the year 2016. First, only one film production line was started. The started line was COEX2. COEX3 did not have enough load to be started and AF could not be started because the next raw material delivery had to be confirmed by the supplier before the start. Otherwise, there would have been raw material only for a few days. On the other hand, starting only one line made the implementation easier: There was a lot of spare capacity and the FIFO line on route 1 started functioning very well. Meanwhile, Slitting 1 was used for slitting some reels from the old stock as well as some returned reels for rework orders. Slitting 3 was under maintenance because of a problem that occurred when trying to start the line after long holidays.

The first problem with the efficient FIFO flow occurred soon after the implementation. The reels that are produced in the film production lines are automatically placed into a “quality stock” by the system. It means that they cannot be slit before the ERP system automatically releases the reels from the quality stock. Release happens two times in an hour, and therefore the maximum time to wait for the release is 30 minutes if the flow efficiency (or PCE) is 100 %. The reels can be released from the quality stock manually, but manual releasing increases unnecessary work which could be categorized as waste.

AF was the next film production line that was started. However, the planned flow could not be started on route 3 because Slitting 3 was still broken. The first problem with the machine was fixed but it was followed with another problem that made running the machine possible yet very slow. Because there were only two lines producing film, it was possible to change the flow. Some of the orders produced at AF went temporarily to Slitting 1 and some of the orders went to Slitting 4. Latter mentioned was only used when COEX2 was producing reels that went straight to customers as mother reels, so that the flow would not be interrupted. Some of the orders had to be slit with Slitting 3, even though it was slow and hard to operate it, because it was the only machine capable of slitting some films. This problem would have been a lot easier to handle if Slitting 2 was fixed earlier. That shows the importance of spare capacity. It would be impossible to handle the flow efficiently with only two slitting machines if three or four film production lines were in use. The lead times would increase significantly in such case. That is why it is still highly recommended for the plant to invest in spare capacity or to start using methods that prevent down time.

The first operative route using FIFO flow functioned very well in the first week. Resource efficiency was over 90 % all that time. After the first week, the flow in this route had to be interrupted for two days because Slitting 3 was still broken. Finally, nine days after the implementation started, all of the needed 3 slitting machines were operative and it was possible to start using the originally planned FIFO routes.

4.4 All needed machines operative

When the use of originally planned FIFO flow started, the need for the workforce simulation model (explained in Chapter 3.8) aroused. The simulation model suggests how many workers will be needed in each shift for the next 6 days. The output of the model will then be reviewed with the production manager who is responsible for the workforce at the slitting machines. This way the production manager will always be aware of the needed workforce and the decisions about workforce can be based on facts rather than guesses.

Starting at the end of week 2, there was an interesting occasion when all 3 film production lines were producing films that needed to be slit. This occasion lasted for almost a week. Still, it was possible to obtain good flow efficiency and even improve it on two routes. This indicates that the new system functions with the current workforce even when the output is in its highest.

The next interesting occasion was right after the previous one, when all film production lines were producing mother reels that were sent straight to the customers without slitting. These occasions, when the load at the slitting machines is very low, are great for performing 5S tasks and cross-training operators. With the help of the simulation model, this occasion was foreseen beforehand when the load was still very high at the slitting machines. Hence, it was understood that no overtime work or extra workers were needed during the peak, and there was enough time to arrange additional work for the low load period.

One additional work was a rework of which slitting was scheduled to be done during the coextrusion of mother reels that did not need slitting. The rework took much longer than anticipated (48 hours), and therefore the queues before Slitting 1 grew longer and flow efficiency dropped (see Figures 23 and 24 in Chapter 5.1.2). Meanwhile, the flow efficiency at Slitting 3 also dropped but Slitting 4 had very high flow efficiency. There was an excessive load of 24 000 kg in the queues, which meant that there was work for 8 extra man-shifts. Therefore, production manager was informed about the situation and asked to get extra workers to cover absent operators.

The situation with absent workers started looking bad at the beginning of the week 4. Agency workers were not willing to work to cover absent workers but fortunately the production manager was able to get overtime workers to cover some shifts. Because of that, it was eventually quite easy to catch up the queue on route 2. On route 3, however, the queue got longer and flow efficiency got lower. At the end of week 4, COEX3 started producing film that went straight to the customer without slitting and at that point it was possible to start catching up the queue on the route 3 as well. To help catching up the queue, one big order was moved from Slitting 3 to Slitting 1 which did not have any work in line.

At the very end of week 4, Slitting 4 broke down and the flow had to be changed. The new temporary route was COEX2 – Slitting 1. COEX3 was still producing film that went straight to the customer. For that reason, this arrangement did not interrupt the continuous flow. The temporary route, however, had low flow efficiency right from the beginning because of the one big order that was moved from Slitting 3 to Slitting 1 just before the breakdown.

Slitting 4 was fixed and so it was possible to start using the normal routes at the end of week 5. There were 6 operators almost in every shift and they were able to slit more film than film production lines were producing film that needed slitting. The queues got shorter because of that, and finally at the end of the week the queues were as short as possible.

The last three weeks of the monitoring period went more or less like the previous five weeks. The queues got sometimes longer for some obvious reasons, and flow efficiency dropped correspondingly. There were no more breakdowns or the combinations of high loads and absent workers, and hence, there were no more major drops in the flow efficiency. On the other hand, there were a lot of orders that went straight to the customer on COEX3, which meant that sometimes operators at the slitting machines had nothing to do.

4.5 Lessons learned

The most important notice during the two months of monitoring was that it is feasible to use standard routes and FIFO lanes in the production. The monitoring period also showed that the new system is flexible. The routes can be temporarily changed if the machines break down or if some orders on certain route cannot be slit at the slitting machine that belongs to that route.

Route 3 is the most challenging route because the output is greatest there. Nevertheless, it is possible to always use this route for all the orders that need to be produced at AF with increased teamwork. There is also a chance to move some orders to another slitting machine, especially if other film production lines are producing films that do not need to be slit and there are enough operators in the shifts. This way, it is faster to catch up the queue if it happens to be long at that point.

According to operators, the implemented continuous flow functions well and it is even more pleasant to work than before. The most serious drawback is that especially in one shift there is one worker who tends to reserve the slitting machine that has the lightest load (Slitting 4). Moreover, when this operator has done everything that can be done on that machine, he does not help at the machine with the highest load but has breaks while waiting for the next reel. As a result, other operators have lower motivation to work at the machines that have greater loads.

One threat to this planning method is the breakdowns of the machines. The threat is biggest on route 3 as there are no alternative slitting machines that can slit the thickest films if Slitting 3 breaks down. In that case, the flow would be heavily interrupted. This monitoring time also indicated that there might not necessarily be replacement parts available for the slitting machines, or the repair might take a very long time. This has to be taken into account in the future and one way to improve the performance of the plant in such occasions is to start using some method to prevent long maintenance breaks. One well known method would be a Lean method called TPM (Total Productive Maintenance). This method will be briefly introduced in Chapter 7.5.

5. RESULTS

The results of the implementation are presented in this chapter. The world class level (30 %) in flow efficiency was exceeded on every route and each measured parameter was better than before the implementation.

5.1 Queuing time and flow efficiency after the implementation

Two of the most important values that needed to be monitored after the implementation, were queuing time and flow efficiency. Queuing time reveals if the targeted lead time reduction of one week is achieved. The graphs of these two values during the monitoring period are presented one route at a time, starting from route 1.

5.1.1 Route 1

The average monitored queuing time before the implementation was 180.0 h (7.5 days). After the implementation, the average queuing time was 6.9 hours. Lead time was then 173.1 hours (7.2 days) shorter than before and the reduction of 7 days was achieved. The graph of the queuing times on the first route is presented in Figure 21. The corresponding flow efficiency is presented in Figure 22.

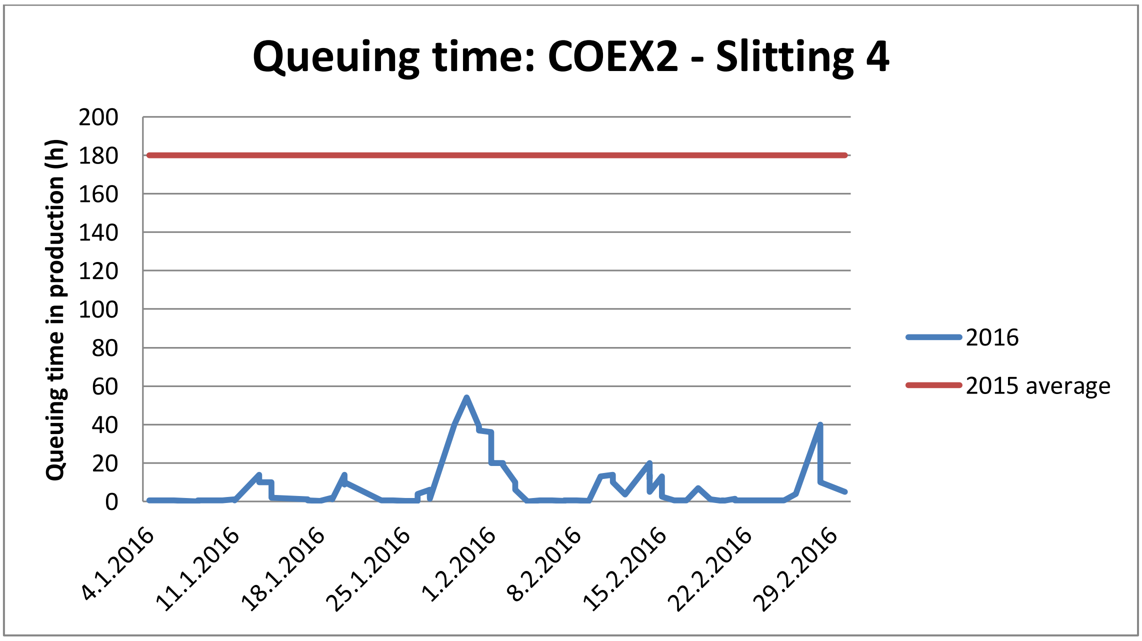

Figure 21. *Queuing time on route 1.*

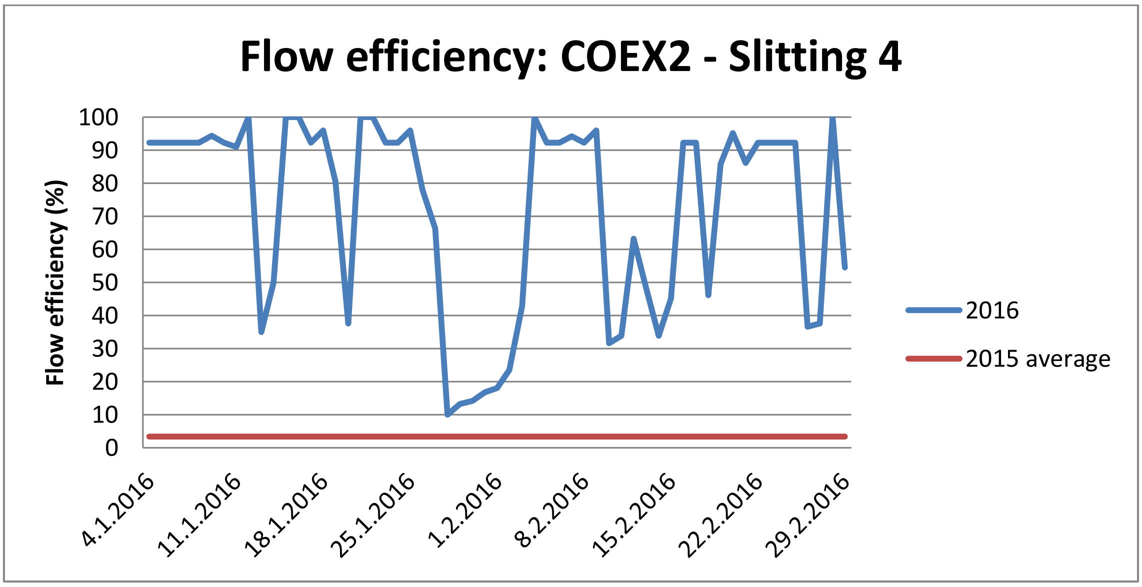

Figure 22. *Flow efficiency on route 2.*

The average flow efficiency after the implementation was 67.1 %. The targeted flow efficiency of 30 % was well exceeded. The variation is greatest when the flow efficiency is close to 100 % due to the formula of flow efficiency. For example, one absent worker causes the graph to drop from 100 % to 33 %.

5.1.2 Route 2

There were a lot of orders on route 2 that went straight to the customer without slitting. Therefore, queuing time at the slitting machine was often 0 hours and flow efficiency 100 %. The average queuing time was 12.6 hours on this route, which is 167.4 hours (7.0 days) shorter than before. This value consists of orders that went through both production steps, and for that reason, the long periods when the queuing time was 0 hours do not affect it. The graph of the queuing time and the corresponding flow efficiency graph are presented in Figures 23 and 24.

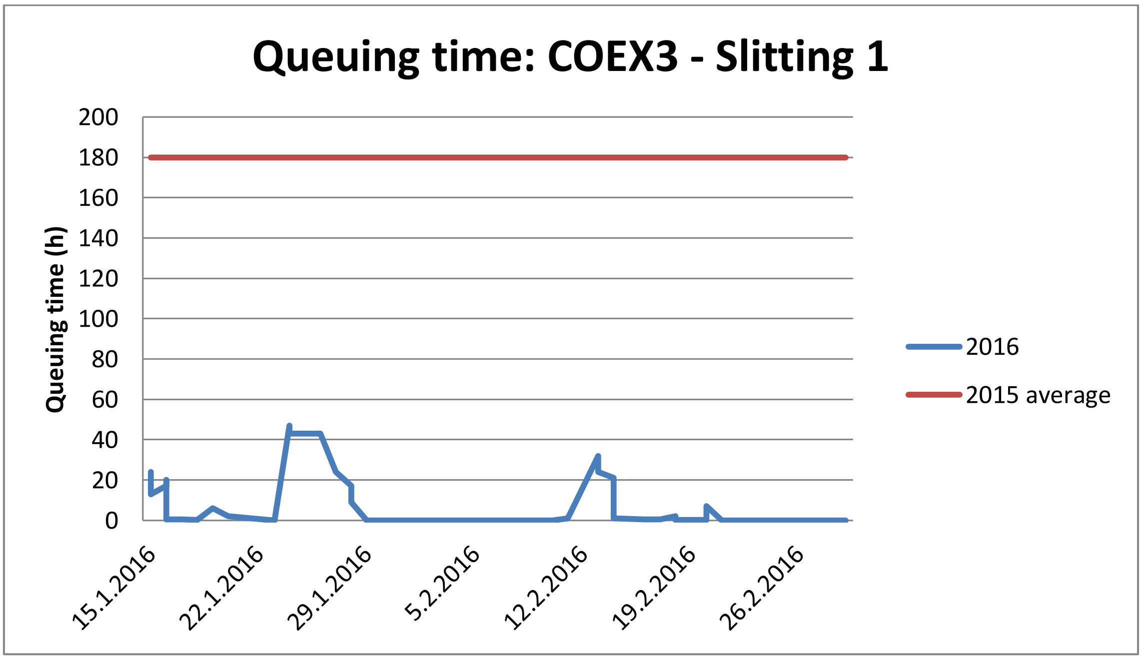

Figure 23. *Queuing time on route 2.*

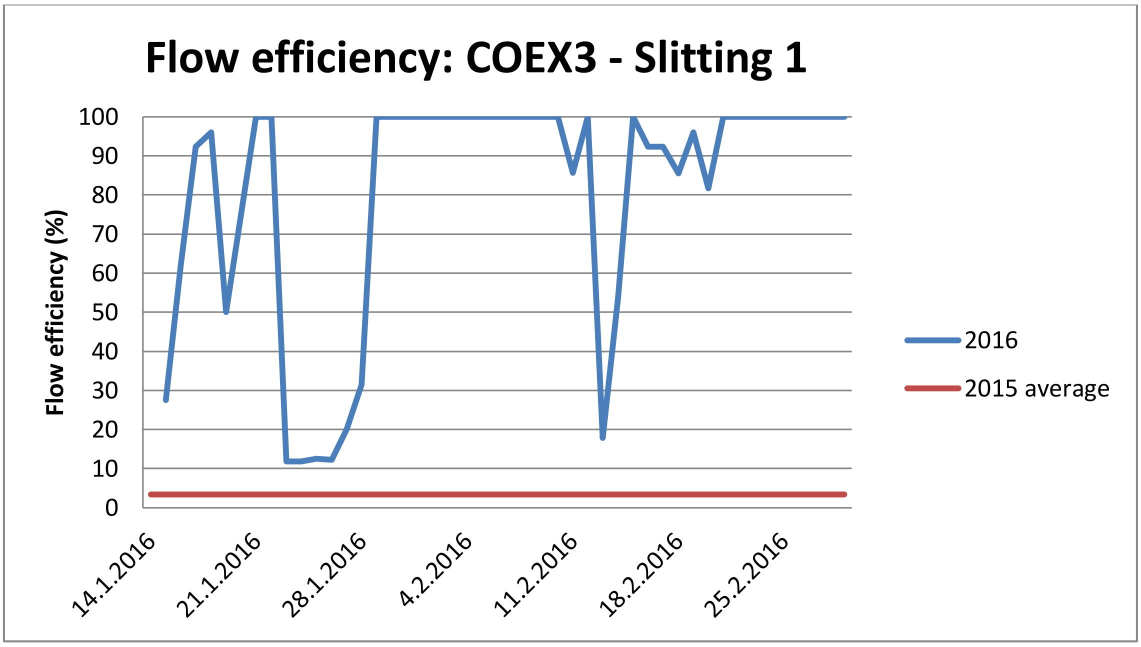

Figure 24. *Flow efficiency on route 2.*

The average flow efficiency after the implementation was 56.2 % and the target of 30 % or more was achieved. When the queuing time gets close to 48 hours (2 days) and the flow efficiency drops below 13 %, it may take almost a week to get back to the targeted level. However, this project indicated that it is possible to get there even without allocating extra workers.

5.1.3 Route 3

Route 3 was the most interesting route in this development project because it has the highest workload and there is a minimum time of 24 hours when the reels have to mature in the semi-finished goods inventory before slitting. The graph of the time between film production and slitting and the corresponding flow efficiency graph are shown in Figures 25 and 26.

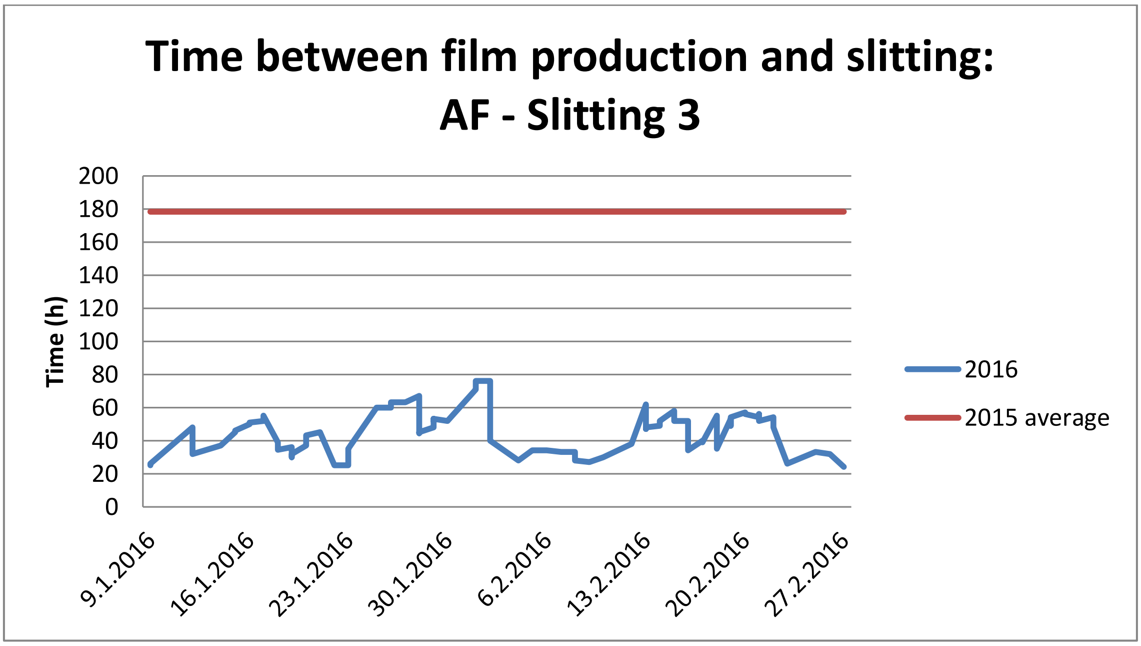

Figure 25. *The time between film production and slitting on route 3.*

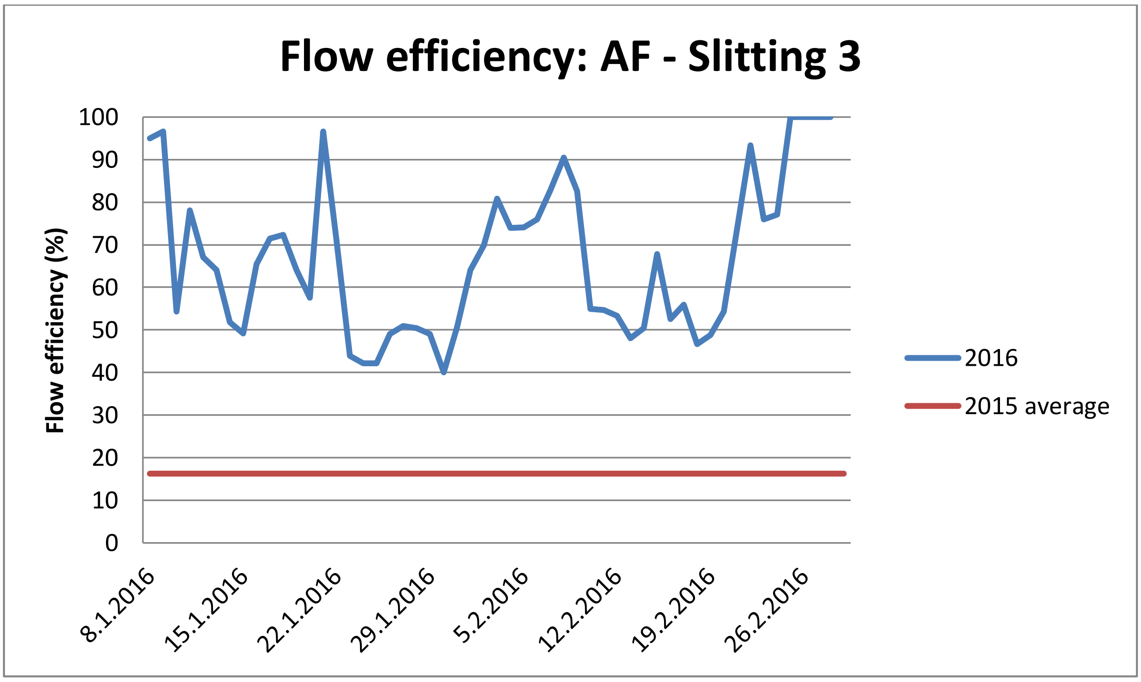

Figure 26. *Flow efficiency on route 3.*

The average time between film production and slitting was 42.9 h which is 135.4 h less than before the implementation. The goal was to have an average lead time of less than 48 h and that was achieved. The average flow efficiency was 65.2 % that was also well over the target of >30 %. The flow efficiency is relatively high although the lead times are longer than on the two other routes because the long maturation time is calculated as value-added time.

5.2 Orders confirmed as requested after the implementation

One measured value in this work was the percentage of orders confirmed as requested, because the value for the customers should always be evaluated when Lean projects are executed. It is the only thing that both changes and can easily be measured in customer's perspective in this work. Lead time reduction should increase the value for the customer, and 'orders confirmed as requested' -value can verify this because these two values go hand in hand. The chart of the orders confirmed as customers had requested is shown in Figure 27.

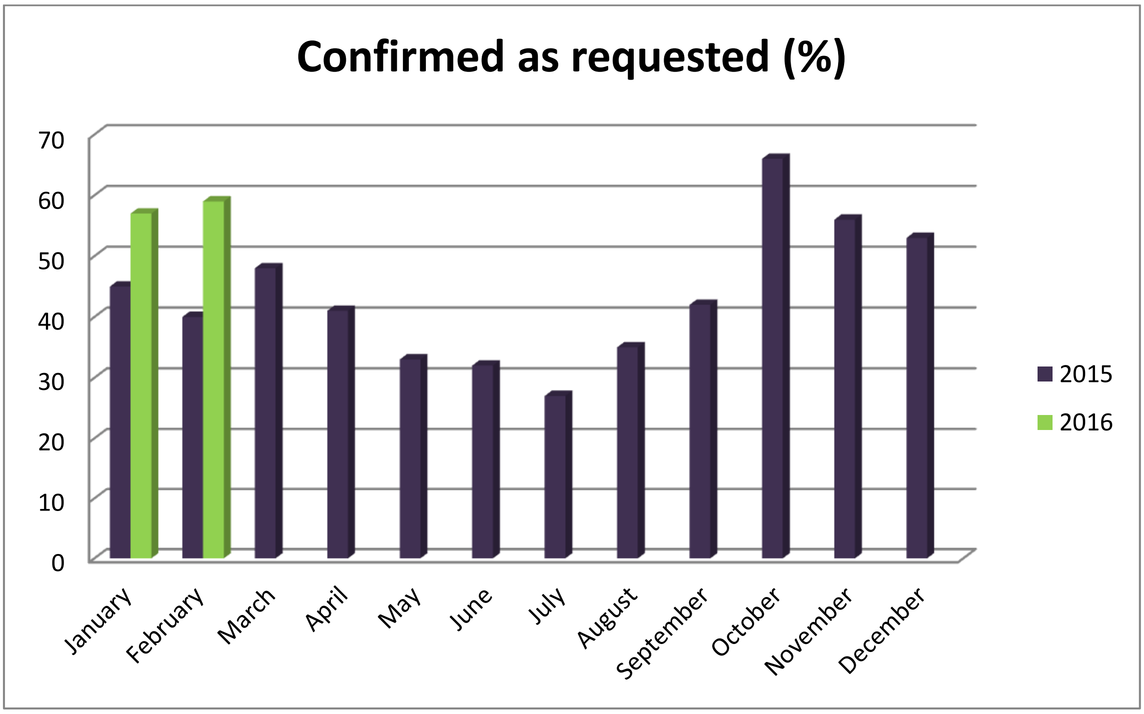

Figure 27. *Orders confirmed as customer requested.*

The percentages in the graph are significantly better than in previous year. In January 2016, the proportion was 57 %, which is 26.7 % better than in January 2015 (when the proportion was 45 %). In February 2016, the proportion was 59 %, which is 47.5 % better than in February 2015 (when the proportion was 40 %). Hence, the lead time reduction has had a truly positive effect in customer's perspective. The combined proportion was 43 % during two first months in 2015 and 58 % in 2016. The improvement was 36.9 %.

5.3 Lead time from firm to last step of production

Thus far, the lead time has included the time from the beginning of the production to the last step of production. Now it will be examined how the lead time reductions in the production have affected the lead time in a longer scope. The longer scope includes the time from firming the order to the last step of production. The results are shown in Figure 28.

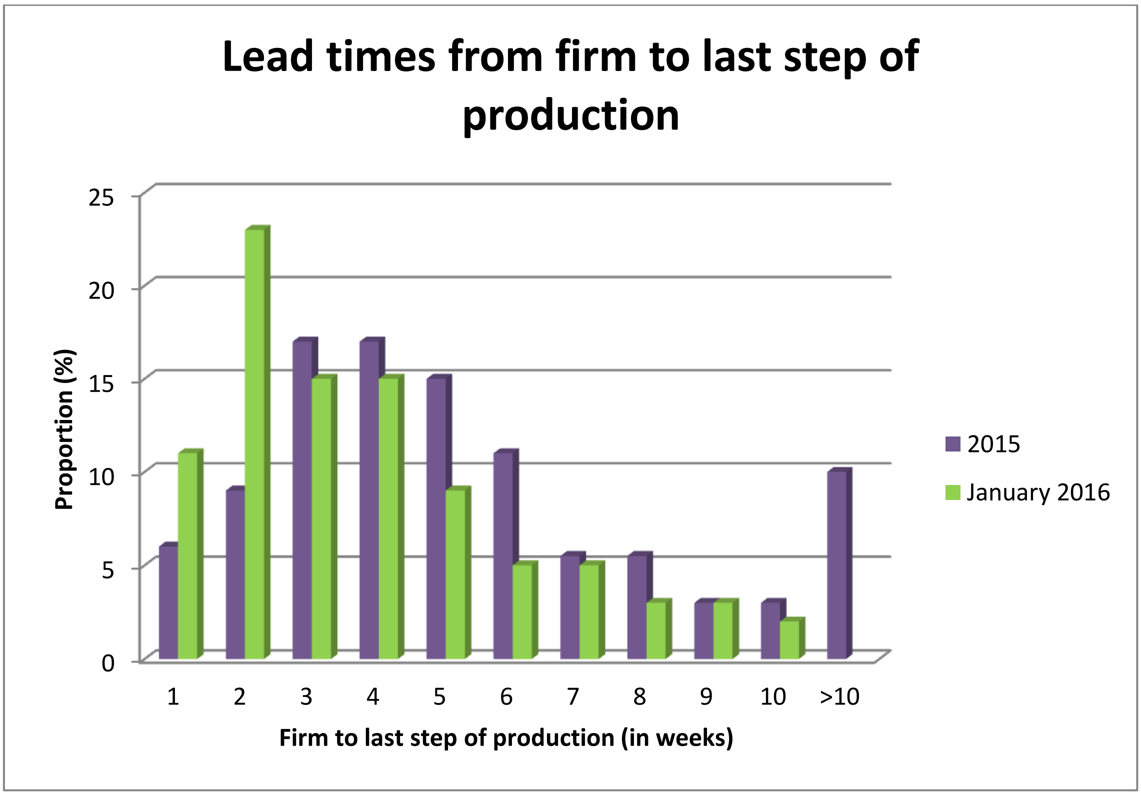

Figure 28. *Lead times from firm to last step of production.*

The graph visibly shows that the lead times in this scope have also improved. The most remarkable change is in orders that are ready in one or two weeks after firming the order. At the same time, the proportions of orders that are ready in five or six weeks have significantly reduced. The orders that were firmed in January 2016 and are not ready yet are not in included in this graph. Still, the graph can be used to evaluate the relative differences between the first six weeks. The average lead time in this scope after the implementation was 3.44 weeks (compared with 4.38 weeks in 2015) which is 21.5 % shorter than before.

5.4 Inventory levels

One of the goals of this development project was to reduce WIP inventory. The level of WIP inventory should stay rather stable when the flow is continuous and constant. There were 111 000 kg of semi-finished goods in the inventory in the beginning of the year that did not have demand at that moment. The goals were to keep the level of semi-finished goods steady and to use the old stock whenever possible. The inventory levels in 2015 and 2016 are shown in Figure 29.

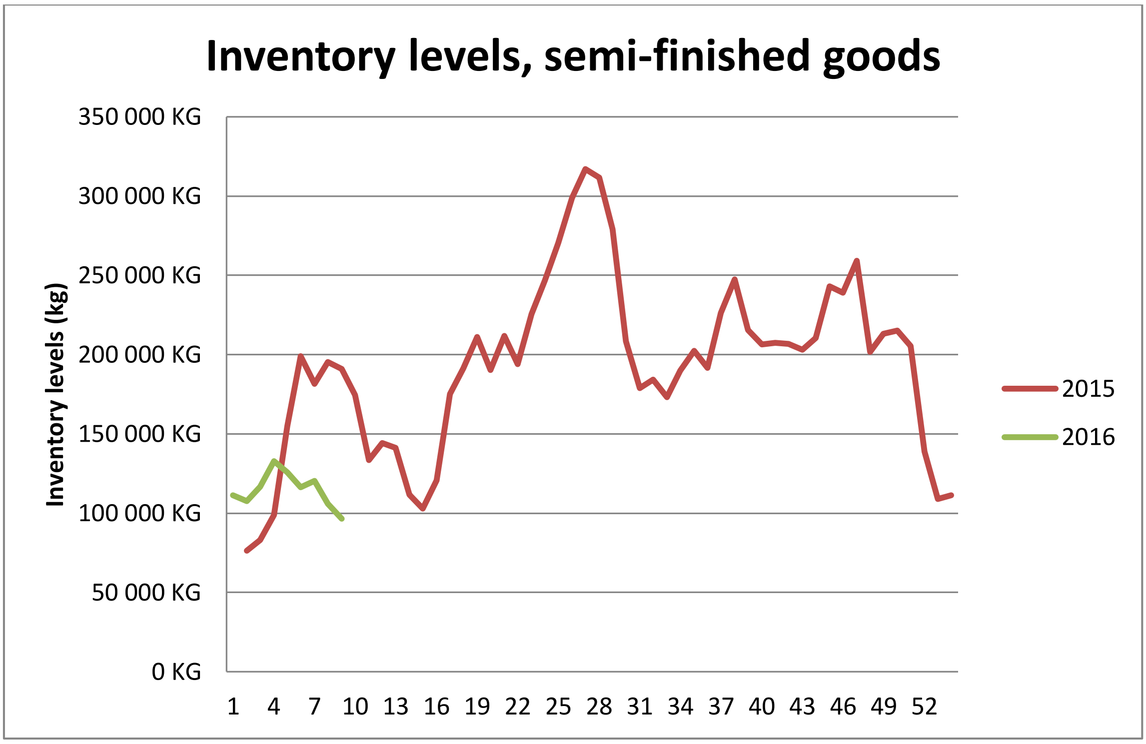

Figure 29. *Inventory levels of semi-finished goods.*

In previous year, the level of semi-finished inventory started increasing right from the beginning of the year. There was 76 000 kg of old stock that did not have demand in the inventory at the beginning of the year 2015. The inventory level increased rapidly until it reached 200 000 kg. At that point, it was possible to start using the old resource efficient production planning to keep the inventory level steady. Soon after that, the level dropped temporarily because one film production line was run down for annual cleaning. There was also a peak in the inventory level that started from week 24 because great amount of film was intentionally produced to stock before the summer holidays started. Some film production lines are run down for the summer holidays and customer orders can be slit from the excessive stock during that time. Apart from these exceptions, the usual inventory level is approximately 200 000 kg.

The inventory level stayed rather constant after implementing the continuous flow. The maximum level of WIP inventory in the queues altogether was almost 24 000 kg in week 3, but apart from that, the WIP inventory level was very low. The biggest challenge is to find use for the old stock. At the end of the monitoring period, there is a decreasing trend which indicates that some of the old stock is successfully used for new orders. Before the implementation, the reduction in inventory level only happened when a production line was run down (for example weeks 9-15 in 2015), but this time all three lines were running. If the plant is able to use most of the old stock for new orders, it is feasible to reach a very low level in the semi-finished goods inventory. Therefore, reducing the level of old stock is one of the recommended targets after this project.

5.5 Estimated savings

It is often hard to estimate cost savings that lead time reductions results in. However, the savings in inventory carrying costs is one obvious consequence. The average value of the semi-finished goods inventory in 2015 was 482 103 € and after the implementation 288 211 €. The difference between the values is 193 892 €. The estimated inventory carrying cost is 12 % in a year, and hence, the estimated yearly savings are 23 267 €.

Suri (2010) suggests that estimated savings can be calculated with a “power of six” rule. In this rule, the cost ratio (CR) after the lead time reduction can be calculated by raising the MCT ratio (lead time ratio) to the one-sixth power. The MCT ratio (MR) is the MCT after implementing QRM divided by the MCT before the implementation.

$$CR = (MR)^{1/6} \tag{5}$$

The average lead time from receiving the order to the shipment of the order was 38.6 days in 2015 and 32.1 days in January 2016. MR is then 0.83. When this is put into the formula 5, CR receives a value of 0.97, which means that the cost savings are 3 % in a year.

This estimation seems to be very optimistic since the savings would be more than 500 000 € in a year. However, there is a reason to believe that significant cost savings will follow in the long run. For example, planning the production is easier after the implementation. It might be even possible to have one planner less in the future or cope with greater demand without extra workers or over time work. There is also less unnecessary work in the production when the new system is used. In January 2016, there were 31 operators in the production which was well enough to keep the flow very efficient. There have been up to 33 workers in the production previously, but the plant will most probably manage with 30 operators if the volume of orders does not increase. It is possible because the amount of unnecessary work in the production has decreased and currently there are times when operators have to wait for reels to be ready. The savings can also be realized if the volume of orders increases, because the current workforce would still be enough. There should also be less unnecessary work at the sales but it is hard to estimate the effects there.

In summary, the estimated combined savings in the organization are somewhere between 120 000 € and 500 000 €. Most of the savings will be realized if the volume of orders increases. Because the system is now more efficient than before, there will not be a need to hire new employees when it happens.

6. EVALUATION OF THE DEVELOPMENT PROJECT

This project had a clear set of goals and the options to reach those goals were thoroughly investigated. The goals were reached soon after the implementation, and hence, the project was successful. The targets and the results are presented in Table 4 below.

Table 2. *Targets and results of the development project.*

	Target	Result
Flow efficiency (all lines)	>30%	Achieved
Lead time reduction (CO-EX lines)	168 hours (7 days)	Achieved
Inventory level (Semi-finished goods)	Lower than previous year. Does not rise from the beginning of the implementation.	Achieved
Orders confirmed as customer had requested	Higher proportion than previously	Achieved

The most important goals with exact values were flow efficiency improvement and lead time reduction, because these values are not affected by other significant variables that can change the result. Inventory levels and the proportion of orders that were confirmed as requested were targets without exact values, because there are some other variables that affect these results. These variables will be discussed in the next chapter (Chapter 6.1).

6.1 Validity and reliability

The values measured in the results chapter reflect the researched problem very well. The improvement in the flow can only be measured by calculating the flow efficiency. The overwhelmingly biggest part of the process cycle was the queuing time between the film production and slitting that includes the transportation between the steps. In this work, that part is the only part that is considered as non-value-added time. To get even more accurate results and to further improve the process, every single move and action an operator makes while a flow unit is being processed could be categorized as value-added or non-value-added time. The possible further lead time reductions in this scope are, nonetheless, much smaller than already achieved reductions.

Measuring the inventory levels is also a valid measurement to use when flow efficiency is being improved. One of the goals of the continuous flow is to reduce the time the flow units are in the inventory. As a result, the inventory levels should decrease, which is indeed the result of the better flow efficiency. However, there are also other things that affect the inventory levels. Such things include test runs that will not be slit right away but are still semi-finished goods and mistakes in either planning or production that causes the produced quantity to be too big. On the other hand, the impact of these is rather small: approximately from 1-5 % on a monthly basis. For that reason, it does not reduce the validity of the metric that much.

The improvement in the orders that are confirmed as the customers had requested correlates to the lead time reduction because shortening the lead times is the only way to improve the values in the metric. Therefore, it is a valid metric to use to measure the change from customers' perspective. On the other hand, the volume of orders and the requested delivery times vary and they also affect this metric. Nevertheless, the documented 5-7 -day reduction in lead time should make a great impact and this metric proves that.

The "from firm to last step of production" –metric gave expected result as well. The time from firm to last step of production should be from 5 to 7 days shorter on average but the volume of orders can distort the results if it is much higher or lower than before. The volume of orders, however, was very similar to the previous year (the combined volume of orders between December and February). Hence, the results of the metric were valid.

Because the results in the metrics were expected and they reflect the problems well and there were no other significant variables that could have affected the results, the results are valid. The research was also reliable, because the methods used in this work are tested in many organizations and the results are almost always homologous. If the plant went back to the original way to plan production, the performance of the plant would most probably be the same as before the implementation.

6.2 Impact and effectiveness

As a result of this project and improved flow efficiency, lead times and queuing times got shorter, more orders were confirmed as requested and inventory levels got lower. Thus, the project had great impact on the performance of the plant.

This project also led to some significant cost savings. Easiest cost saving to measure was the reduced inventory carrying costs. There are always some indirect cost savings as well that are more difficult to measure when lead times are reduced. These indirect cost savings arise from reduced amount of unnecessary work in production, production planning and sales (explained more thoroughly in Chapters 2.1 and 5.5).

Now customers can also be served faster and better. As a result, there will be less lost sales and more satisfied customers. Even the sales are likely to increase later when customers learn that the plant is capable of quickly respond to a demand. All in all, the project succeeded so well that the plant will continue using the new implemented flow and the new way to plan production.

7. FUTURE WORK

Continuous improvement is an important Lean method that aims for perfection. This work has created a possibility to further improve the performance of the plant and the company. Hence, some of the possible next steps are presented in this chapter.

7.1 Reduce the semi-finished goods inventory

After the implementation, the level of semi-finished goods has not increased from the beginning of the year, like in previous years. On the contrary, it has decreased. The amount of semi-finished goods that did not have direct customer orders was 92 000 kg at the end of the control period. It is more than 88 % of the total semi-finished goods inventory, and it consists of test productions and over productions which were done before the implementation.

The best way to further reduce the semi-finished goods inventory is to use the reels for customer orders whenever possible. If there are reels that do not have demand in the following year, these reels should be thrown away. A good target level that could be reached after one year is 40 000 kg. This includes 20 000 kg of WIP inventory and 20 000 kg of test production, and over production that is intentionally produced. Intentionally produced over production is sometimes (although rarely) run when an economic batch quantity is bigger than ordered quantity and there is constant demand for that material.

7.2 Shorten the queuing time before film production

The queuing time before film production is typically from two to four weeks. It is reasonable to have long queues so that a production planner is able to plan the production cost efficiently. The current system, however, is only based on actual customer orders and forecasts are not made.

If the plant started using forecasts that are based on previous orders in previous years to make rough planning, lead times could be significantly reduced. These forecasts and rough plans have to be properly evaluated with a simulation model to discover if they would really work in real life. Making forecasts and more accurate rough planning takes time from production planners, and therefore it has to be evaluated whether the customers really need a quicker response. If the quicker response is needed, it is strongly recommended to start using forecasts to reduce lead times.

7.3 Shorten the time from the last step of production to shipment

One of the next steps should be to study how to shorten the time from the last step of production to the shipment. Before the implementation of continuous flow, the queues at the slitting machines often changed. For that reason, the dispatch department was able to start planning transportation only after the order was completely ready from the production. Now these queues do not change unless queues before the film production change. If the production plan was frozen for the next few days, it would be possible to give information for the dispatch department beforehand. Then they would know the actual dates when each order would be ready from the production. The transportation could be planned beforehand, and the time from last step of production to the shipment would be much shorter.

7.4 Create a system to balance workload between the operators

One problem that aroused during the monitoring period was that some operators take advantage of the system by reserving the slitting machine with the lightest load. Moreover, they are not willing to help others to balance the workload. Therefore, it is recommended to take actions to balance the workload between the operators. The first step could be to discuss with the operators in question and to insist them to occasionally run other slitting machines. They could also be asked for their opinions about how the workload could be balanced.

If discussion does not work, another way is to circulate operators between the slitting machines. Then they would not have the possibility to choose which machine to operate. However, this would be a step back in the progress where the target is to increase teamwork and to give accountability to the teams.

7.5 Prepare for machine breakdowns

At the moment, the plant is not well prepared for machine breakdowns. It may often take several days or even weeks to fix a problem if a component breaks down. Many of the machines are fairly old and it is sometimes challenging or even impossible to get spare parts.

A recommended solution for this problem is a proper evaluation and implementation of Total Productive Maintenance (TPM). TPM is a Lean tool used to prevent down time of the machines. According to Wireman (2004) TPM focuses on maximizing the overall equipment effectiveness of any asset utilized in the production of goods. In a good TPM program, standard processes that establish the method of determining what parts to keep on hand should be developed (Wroblewski 2010). According to Wroblewski (2010), critical parts can be identified as “recent chronic problem areas” and “difficult to obtain within 24 to 48 hours”. Wroblewski states that if the chance of a problem is high and the plant is left waiting days or weeks for the parts to come in, it is better to keep these parts on hand no matter what the cost of the part is. Lost business and customer disappointments should be taken into account when making these decisions. All in all, TPM might solve the problem of long downtimes of the machines and should therefore be properly evaluated.

7.6 Perform a shrinking test for films produced at AF

One improvement that should be evaluated is slitting the mother reels produced at AF instantly after film production. A shrinking test should be performed before that. The shrinking test would determine whether the reels could be slit instantly and how much wider the slitting width should be so that the film would be wide enough after the shrinkage.

If the shrinkage is not significant, the mother reels can be slit sooner than currently allowed. If the shrinkage is significant, it could be evaluated whether it is possible to slit the reels always from one to two hours after the film production. It could be done by setting the route 3 as the first priority. This way the shrinkage would be under control and some unnecessary work would be avoided. The avoided unnecessary work includes transporting the mother reels into the WIP inventory and from there to the slitting machine.

7.7 Copy the best practices to other plants

Because of the good results achieved in this project, it is recommended to evaluate whether the best practices could be copied to other plants. If the relentless focus on lead time reduction or on continuous flow is not one of the most important targets in production planning on other plants, then it should be set as one. The potential advantages and cost savings of continuous flow and shorter lead times have to be understood in each plant. After that, the methods of shortening the lead times should be first evaluated and then implemented.

The implementation on other plants should be done in a similar manner to the implementation in this work. This implementation method has proven its effectiveness, and by following the same steps other plants can achieve similar results.

8. CONCLUSIONS

The goal of this thesis was to decrease the lead time by implementing more efficient continuous flow. The development project was successful and the targets were reached. The most important results before and after the implementation and the relative improvements are presented in table 5 below.

Table 3. *Summary of the results.*

	2015	2016	Improvement
Queuing time			
COEX2 - Slitting 4	180 h	6.9 h	96.2 % shorter
COEX3 - Slitting 1	180 h	12.6 h	93.0 % shorter
AF - Slitting 3	178.4 h	42.9 h	76.0 % shorter
Flow efficiency			
COEX2 - Slitting 4	3.2 %	67.1 %	2097 % better
COEX3 - Slitting 1	3.2 %	56.2 %	1756 % better
AF - Slitting 3	15.6 %	65.2 %	418 % better
Average inventory	192 841 kg	115 284 kg	40.2 % less
Confirm to request	43 %	58 %	34.9 % more
Firm to last step of production	4.38 weeks	3.44 weeks	21.5 % shorter

The improvements in the queuing times and flow efficiencies were reached by implementing continuous flow, FIFO lanes and standard routes. The routes were fixed and dedicated to certain material families with as little exceptions as possible. It is important to notice that the final routes were different from the routes that were planned in the first place. The planned routes were changed because of the consensus created in the workshop with production operators and managers. That shows the importance of making decisions together with the people who are most affected by the consequences.

In implementation, the old push system was replaced with an adapted pull system. It was not practicable to implement full pull system that requires stopping the lines when WIP increases. This is because film production lines are continuous processes and stopping the process after the WIP increases would be extremely expensive and would take a lot of time. Nevertheless, the slitting machines started pulling the orders in better sequences. Slitting was so efficient after the implementation that operators often had to wait for the previous production step to finish so that they could pull the output directly to further processing.

Continuous flow also required cross-training, teamwork and balancing the workforce. Balancing the workforce was needed because the allocated amount of operators in shifts varied too much. After balancing, each shift had 6 operators apart from one shift that had 7. This change made it possible to slit everything that was produced at the film production lines continuously. Cross-training had already been started before this project, but now its significance increased and together with increased teamwork they made the continuous flow possible.

One threat in continuous flow is the breakdowns of the machines. A recommended way to deal with this threat is a proper evaluation and implementation of Total Productive Maintenance (TPM) which is a Lean tool used to prevent down time of the machines. Other suggested future steps include shortening the queuing time before the film production lines and the time from the last step of production to the shipment, further reduction of the inventory levels, and most importantly, copying the best practices to other plants to achieve great cost savings on many levels of the organization.

The new continuous flow will result in major cost savings in the long run. This project alone will have an estimated yearly cost savings of 120 000 € – 500 000 €. Some of the savings are immediate but some of them will be realized when the volume of orders increases. The most important reason behind the savings is the reduced amount of unnecessary work on many levels of the organization. A good example is that it is no longer needed to transport the reels from the first production step to the inventory and later to spend a lot of time searching for these reels in the inventory. It also takes less time to plan the production because the subsequent production steps do not need to be planned separately any longer. On the contrary, the same plans apply to both production steps and they only need to be copied. There are also many other advantages that shorter lead times create and together these can have a great impact on cost savings. It is important that the organization understands the possibilities and the vast effects that shorter lead times and quick response may lead to if the same principles are successfully copied to other plants.

REFERENCES

Anderson, D. & Anderson, L.A. (2002). Beyond Change Management: Advanced Strategies for Today's Transformational Leaders (1), Pfeiffer, San Francisco, US.

Burton, T.T. & Boeder, S.M. (2003). The Lean Extended Enterprise: Moving Beyond the Four Walls to Value Stream Excellence, J. Ross Publishing, Inc., USA, 271 p.

Carreira, B. (2004). Lean Manufacturing That Works : Powerful Tools for Dramatically Reducing Waste and Maximizing Profits, AMACOM Books, Saranac Lake, NY, USA.

Fernandes, N., & Silva, S. (2006). Generic POLCA—A production and materials flow control. International Journal of Production Economics , pp. 74–84

George, M.L., Rowlands, D., Price, M. & Maxey, J. (2005). Reducing Lead Time and Non-Value-Add Costs, in: The Lean Six Sigma Pocket Toolbook, McGraw-Hill, New York, pp. 197-240.

Hammer, M., & Champy, J. (1994). Reengineering the corporation. HarperCollins. New York.

Hirano, H. (1996). 5S for Operators: 5 Pillars of the Visual Workplace, Productivity Inc., USA.

Krieg, G.N. (2005). Kanban-Controlled Manufacturing Systems: Basic Version and Variations, Springer, Germany.

Liker, J.K. (2004). Toyota Way: 14 Management Principles from the World's Greatest Manufacturer, 1st ed., McGraw-Hill Education, New York.

Liker, J., & Morgan, J. (2006). The Toyota Way in Services: The Case of Lean Product Development. Academy of Management Perspectives , 5-20

Locher, D. (2008). Value Stream Mapping for Lean Development : A How-To Guide for Streamlining Time to Market, Productivity Press, Portland, OR, USA.

McLachlin, R. (1997). Management initiatives and just-in-time manufacturing, in: Journal of Operations Management, pp. 271-292.

Melton, T. (2005). The Benefits of Lean Manufacturing: What Lean Thinking has to Offer the Process Industries, Chemical Engineering Research and Design, Vol. 83(6), pp. 662-673.

Modig, N. & Åhlström, P. (2013). Tätä on Lean - Ratkaisu tehokkuusparadoksiin, 3rd ed., Rheologica Publishing, Stockholm, 7-157 p.

Nadler, D.A. & Tushman, M.L. (1997). Implementing New Design: Managing Organizational Change, in: Managing Strategic Innovation and Change, 2nd ed., Oxford University Press, pp. 552-563.

Nash, M.A. (2008). Mapping the Total Value Stream : A Comprehensive Guide for Production and Transactional Processes, Productivity Press, Portland, OR, USA.

Roser, C. & Nakano, M. (2015). Guidelines for the Selection of FIFO Lanes and Supermarkets for KanbanBased Pull Systems – When to Use a FIFO and When to Use a Supermarket, accessed 26.11.2015, pp. 1-5.http://www.allaboutlean.com/wp-content/uploads/2015/09/Roser-and-Nakano-2015-Guidelines-for-the-Selection-of-FIFO-Lanes-and-Superm-PREPRINT.pdf.

Rother, M. & Shook, J. (1999). Learning To See – Value Stream Mapping to Create Value and Eliminate Muda, The Lean Enterprise Institute, Massachusetts, USA.

Santos, J., Wysk, R.A. & Torres, J.M. (2015). Improving Production with Lean Thinking (1), Wiley, Somerset, US.

Schienmann, W. (1992). Why change fails. Across the Board (April): pp. 53– 54.

Schonberger, R. (1982) Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity, 1st ed., The Free Press, USA.

Sims, R.R. (2002). Changing the Way We Manage Change, Greenwood Press, Westport, US.

Speh, T. (2009). Understanding Warehouse Costs and Risks, in: Warehousing Forum. Vol. 24(7).

Stevenson, W.J. (2014). JIT and Lean operations, in: Operations Management, 12th ed., McGraw-Hill Education, Berkshire, pp. 604-647.

Suri, R. (2010). It's about time - the competitive advantage of quick response manufacturing. CRC Press, New York.

Thomke, S. & Reinertsen, D. Six Myths of Product Development, Harward Business Review, web page. Available (accessed 20.11.2015): https://hbr.org/2012/05/six-myths-of-product-development.

Vukotich, G. (2011). 10 Steps to Successful Change Management, Association for Talent Development.

Wilson, L. (2010). How To Implement Lean Manufacturing, The McGraw-Hill Companies, Inc, New York, USA.

Wolfsmith, H., Kaiser, M., Adams, M., & Johnson, H. (2000). Transferring learning from one change project to another. Loyola University, Chicago.

Wireman, T. (2004). Total Productive Maintenance, 2nd ed., Industrial Press, Inc, New York, USA.

Womack, J., Jones, D. & Roos, D. (1990). The Machine That Changed the World, 1st ed., Massachusetts Institute of Technology.

Womack, J. & Jones, D. (1996). Lean Thinking: Banish Waste and Create Wealth in Your Corporation, Simon & Schuster, New York, USA.

Wroblewski, M. Why you need to create a standard process for spare parts, web page. Available (accessed 7.3.2016): http://www.reliableplant.com/Read/26764/standard-process-spare-parts .