LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY LUT
School of Engineering Science
Industrial Engineering & Management

Mikko Kivelä

EFFECT OF TIME BETWEEN PRODUCTION AND DUE DATES ON INVENTORY LEVELS IN BOARD INDUSTRY

Examiner: Professor Timo Pirttilä

ABSTRACT

Author: Mikko Kivelä

Subject: Effect of time between production and due dates on inventory levels in board industry

Year: 2021 **Place:** Lappeenranta, Finland

Master's thesis. Lappeenranta-Lahti University of Technology LUT, Industrial Engineering and Management.

85 pages, 28 figures, 2 tables and 2 appendices.

Examiner: Professor Timo Pirttilä

Keywords: Time between production and due dates, performance measurement, cyclical production, inventory effect, board industry

Balancing supply and demand is one of the most important processes in operational management of a company. Production in board industry is cyclical and as a result there are orders produced in every production cycle with due dates in the future. These orders will stay in inventory until the due date and are then shipped to the customer using various shipping methods.

In this research factors influencing development of time between production and due dates are studied and inventory effect caused by timing of the production is analyzed. Also, a performance measure is developed to measure development of time between production and due dates in the target company. In addition, variables influencing values provided by the performance measure are analyzed as a part of the research.

Development of time between production and due dates is dependent on imbalance of demand and supply, production planning policies, production efficiency, and transportation schedule. The developed performance measure is based on order data report available in the target company's ERP system, which lists all produced and future orders for single production unit for selected period. The time between production and due dates is calculated automatically from the data set using macro developed for Microsoft Excel Visual Basic for Applications -program. The most crucial variables regarding the performance measure are validity and determining process of production and due dates, possible data errors in the data system as well as production planning policies.

TIIVISTELMÄ

Tekijä: Mikko Kivelä

Työn nimi: Tuotanto- ja eräpäivien välisen ajan vaikutus varastotasoihin kartonkiteollisuudessa

Vuosi: 2021 **Paikka:** Lappeenranta, Suomi

Diplomityö. Lappeenrannan-Lahden teknillinen yliopisto LUT. Tuotantotalous.

85 sivua, 28 kuvaa, 2 taulukkoa ja 2 liitettä.

Tarkastaja: Professori Timo Pirttilä

Hakusanat: Tuotantopäivän ja eräpäivän välinen aika, suorituskykymittaus, syklinen tuotanto, varastovaikutus, kartonkiteollisuus

Tuotannon ja kysynnän yhteensovitus on yksi keskeisimpiä prosesseja yrityksen operatiivisen toiminnan hallinnassa. Kartonkiteollisuudessa tuotanto on syklistä, jonka seurauksena jokaisessa tuotantosyklissä tuotetaan tilauksia, joiden eräpäivä on tulevaisuudessa. Nämä tilaukset odottavat varastossa eräpäivään asti, kunnes ne lähetetään asiakkaalle eri kuljetusvälinein.

Tässä tutkimuksessa selvitetään, mitkä asiat vaikuttavat tuotantopäivien ja tilausten eräpäivien välisen ajan muodostumiseen, sekä arvioidaan, kuinka suuri varastovaikutus tuotannon ajoituksella on. Lisäksi työssä laaditaan kohdeyritykselle suorituskykymittari, jolla tuotanto- ja eräpäivien välisen ajan kehitystä voidaan seurata. Myös suorituskykymittarin tuloksiin vaikuttavia muuttujia on arvioitu osana tutkimusta.

Tuotanto- ja eräpäivien välisen ajan kehitys riippuu kysynnän ja tarjonnan epätasapainosta, tuotannonsuunnittelun periaatteista, tuotantotehokkuudesta ja lähetysaikatauluista. Kehitetty suorituskykymittari perustuu kohdeyrityksen toiminnanohjausjärjestelmästä saatavaan tilausraporttiin, joka listaa kaikki tietyn tuotantolinjan tuotetut tilaukset sekä tulevaisuudessa tuotantoon tulevat tilaukset tietyllä aikavälillä. Tuotanto- ja tilauspäivien välinen aika lasketaan tilausraportista automaattisesti Microsoft Excel Visual Basic for Applications -ohjelmalle luodulla makrolla. Suorituskykymittarin toiminnan kannalta tärkeimpiä muuttujia ovat tuotanto- ja eräpäivien määrittäminen ja oikeellisuus, mahdolliset datavirheet tietojärjestelmässä sekä tuotantosuunnitelman laatimisperiaatteet.

ACKNOWLEDGEMENTS

Up until this point I have always known what comes next in my life and for the past 18 years of my life I've been studying and learning valuable skills. Now it is time to step up the game, use my competence in practice and take the next big step in my life.

I would like to thank my employer for giving me this opportunity to show my skillset in practice with this master's thesis. Special thanks for Samuli Toikka for supervising my work at the company and Professor Timo Pirttilä from LUT University for guiding me through the process. I would also like to thank my colleagues for answering my questions and supporting my work at the company.

Finally, I would like to thank my friends, family and girlfriend who have always been there for me and brought me joy and stress-relief during my progress with the thesis. Without the balance between work and social life this journey would have been a lot harder to accomplish.

Lappeenranta, 15.2.2021
Mikko Kivelä

TABLE OF CONTENTS

FIGURES

TABLES

ABBREVIATIONS & CONCEPTS

ATO	Assemble-to-order
BDS	Fenix Basic Data System
Closing	Date when lot should be ready for loading at the port
ETO	Engineer-to-order
ERP	Enterprise resource planning software
Ex-mill	Date when lot should be ready for loading at the mill
Fenix	Enterprise resource planning software used at the target company
IE	Inventory effect
IMBM1	Imatra Board Machine 1
IMBM2	Imatra Board Machine 2
IMBM4	Imatra Board Machine 4
IMBM5	Imatra Board Machine 5
IMPE2	Imatra PE-coating Machine 2
IMPE3	Imatra PE-coating Machine 3
IMPE5	Imatra PE-coating Machine 5
IMPE6	Imatra PE-coating Machine 6
MTO	Make-to-order
MTS	Make-to-stock
OPP	Order penetration point
OTIF	On Time and In Full
PE	Polyethylene
RPP	Fenix Rough Production Planning
Seitti	Mill system software used at the target company
SELSP	Stochastic economic lot scheduling problem
SP	Surplus
S&OP	Sales & operations planning process
TBPD	Time between production and due date
VBA	Visual Basic for Applications
1DCSP	One-dimensional cutting stock problem

1 INTRODUCTION

This introduction chapter presents background of the study and creates basis for the research by defining objectives, scope, and methodology. Research questions are presented to which the paper will aim to answer. The introduction also briefly presents structure of the report and how the study will be carried out.

1.1 Background

In board industry large amount of company's working capital is tied to the inventory as the production volumes are extremely high – this emphasizes importance of efficient inventory management and balancing supply with the demand to stay financially competent. Inventory consists of customer lots waiting to be delivered, surplus stock of usable leftovers, and various raw materials for coating and sheeting. In addition, secondary grade and waste make up a big share of the inventory.

Inventory has a role of being buffer for cyclicality and uncertainty of the production. In general, changes in the inventory levels are being measured and monitored, but underlying causes are often unnoticed. Inventory level changes may be caused by several factors including imbalance of demand and supply, production efficiency, changes in production sequencing, and production issues. In the board industry, production lots are sometimes produced significantly in advance to keep the process going – this will increase inventory levels until the production lot has been shipped. Customer lots cover most of the inventory, thus their effect on required working capital is greatest.

According to Berends and Romme (2001) board industry profitability is very cyclical driven by supply and intensified by demand fluctuations. They say that in highly capital-intensive industries like board industry individual companies try to keep the machines running, which pushes the pricing down. Especially during crisis when demand fluctuations are amplified it is important to manage working capital effectively to ensure sufficient cash flow and to avoid obsolete inventory.

One goal in the target company is to increase understanding of different shares of the inventory and to avoid using overall inventory levels as an only source of inventory information for balancing decisions for demand and supply. Timing of the production is the biggest reason for inventory development in the board industry as cyclicality and high machine utilization dictate the production process, which results to majority of the production lots to stay in the inventory waiting for transportation. After clarifying causality of timing of the production to inventory levels, time between production and due dates (*TBPD*) can be used to estimate inventory effect of current production timing, which helps understanding the overall situation of production and inventory development at the production mills. Time between production and due dates is defined in this study as time the order is produced in advance and it is measured in days. It can also be described as wait time how long the order needs to wait in the inventory until the transportation process to the customer begins.

One major problem in the target company has been visibility from operational level to administrative level. Production planners usually have a clear vision how the production is going and what is the status of the board machines, but the knowledge isn’t visible to the administrative levels. As a part of this research a performance measure for measuring time between production and due dates is developed for the target company. The performance measure will be used for analyzing historical data of production timing to reflect how taken corrective actions effect the development of time between production and due dates, and to detect opportunities for improvement in production scheduling policies. Also, the performance measure can be used for forecasting short-term future development of time between production and due dates to recognize upcoming problems. The information provided by the developed performance measure can be used in master planning and operational decision-making. The information can also be utilized by business line organization and financial controllers.

When time between production and due dates is developing to unwanted direction, corrective actions can be taken for balancing demand and supply as well as for reducing or increasing inventory to the desired level. These corrective actions can be market curtailments to reduce supply, quota restrictions or customer allocations to reduce demand, and activating sales fillers or producing stock lots to increase demand. Also, short-term changes in production sequencing can have major impact on development of time between production and due dates. By rescheduling production, it might be possible to produce orders closer to the due dates, thus reducing the inventory effect of production timing. In addition, sometimes rerouting orders to different production mills or using different means of transportation can help in balancing the situation.

1.2 Research objectives and scope

Aim of this research is to clarify causality of time between production and due dates to inventory levels, and to analyze which factors influence the development of it. Also, a performance measure is developed to measure time between production and due dates. Three research questions were determined for this study, which are:

1. *How does the time between production and due dates effect on inventory levels in board industry?*
2. *Which factors influence the development of time between production and due dates?*
3. *How to measure the time between production and due dates and which variables are critical for measuring it?*

The study is targeted for Stora Enso Oyj Packaging Material division. Other divisions including pulp and paper manufacturing are out of the scope. Also, the research focuses only on prime quality board production, so second grade and waste are not taken into consideration. Imatra Mills are used as a perspective point in this study for analyzing current production planning and order handling methods.

However, the developed performance measure will be designed to be utilized throughout the division in other production mills.

1.3 Research process & methodology

This research paper can be divided into two parts. First part of the research is literature review which allows the reader to understand the prevailing operating environment. In the literature review concepts, methods and related theory will be described to create a theoretical framework. Theoretical references will be peer reviewed scientific articles and books.

The second part of the research is an empirical study based on the target company's training and instructional material, inventory reports and data available from the ERP system, and interview material from company's experts and supervisors. This data will be used to determine current state of the production planning, order handling and inventory management, to analyze causality of timing of the production to inventory levels, and to create a performance measuring process for measuring it. Also, critical variables for developed performance measure will be analyzed and variations of the performance measure are presented. Research process is illustrated in figure 1.

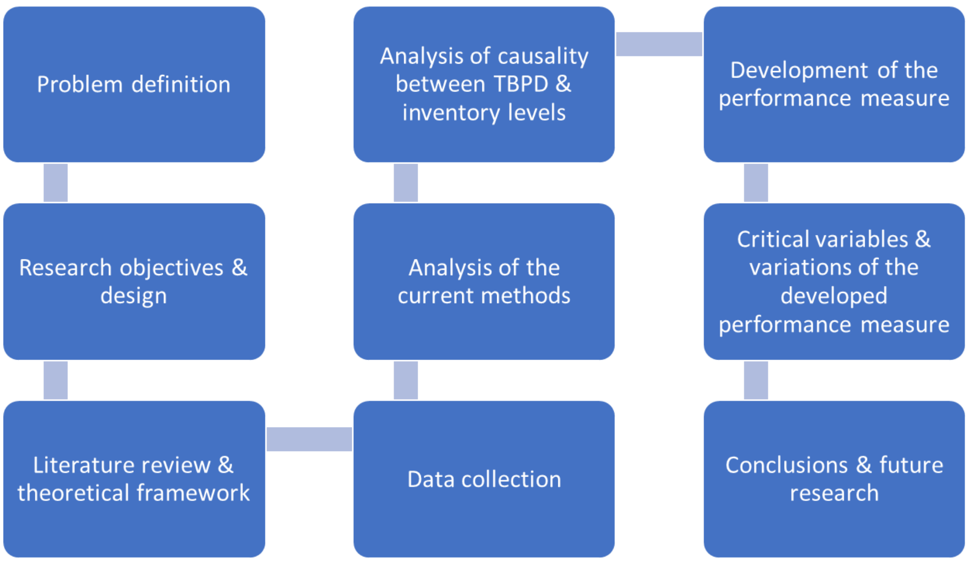

Figure 1. Research process of the study.

The research process is scheduled for six months. The first two months are used for defining the problem, objectives, scope and for creating a theoretical framework based on academic literature available. The next two months are used to collect data from the target company with interviews, data reports from ERP system, and available instructional material. During the last two months of the research the performance measure is developed and tested in use.

1.4 Structure of the report

The report consists of introduction, five main chapters and conclusions. In the introduction research background, objectives and scope, methodology, and structure of the report are presented. Chapters two and three are based on literature review and are used to create theoretical framework of prevailing operating environment. In chapter two theory behind production and inventory management in board industry is described. The chapter focuses on describing how the production works in board industry, how the inventory forms in board industry production environment, and which concepts are relevant regarding inventory and production management. Chapter three presents sales and operations planning process to increase understanding of the motives of the study. Also, performance measuring systems are presented including criteria for comprehensive performance measures and a process for developing performance measures. Chapters four, five and six are empirical study based on gathered data from the target company. In chapter four production and inventory management processes in the target company as well as order handling process are presented. Understanding these processes is necessary to analyze factors effecting development of time between production and due dates and to understand inventory effect caused by it. In chapter five causality of time between production and due dates to inventory levels is clarified, factors effecting development of timing of production is analyzed, and a performance measure to measure it is developed. Also, reference values for the measure are defined. In addition, chapter five describes how historical data regarding time between production and due dates can be utilized and how using the performance measure for forecasting can help with decision-making. In chapter six the developed performance measure for measuring time between production and due dates will be reviewed critically and the most important variables as well as variations of the developed performance measure are determined. In addition, the impact of these critical variables is described to further increase understanding of the measuring process and its requirements. In the last chapter the study is concluded, and research questions are answered. On top of that, the last chapter includes discussion regarding the study. Structure of the report is presented as input/output chart in figure 2.

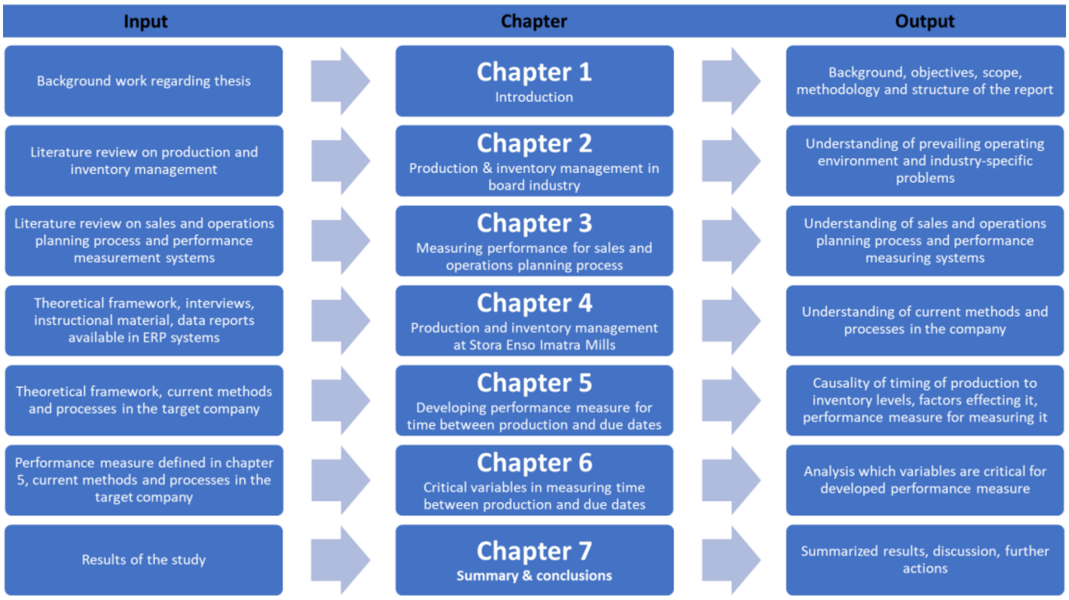

Figure 2. Input/Output chart of structure of the report.

2 PRODUCTION AND INVENTORY MANAGEMENT IN BOARD INDUSTRY

This chapter focuses on findings of earlier studies and literature regarding production and inventory management in board industry. Concepts and industry-specific problems as well as basic understanding of prevailing operating environment are presented. Topics discussed in this chapter are order penetration point and manufacturing strategies, cyclic production planning and control, inventory in make-to-order production, one-dimensional cutting stock problem as well as distribution management and logistics process.

2.1 Order penetration point and manufacturing strategies

Order penetration point (OPP) can be defined as a point where product is linked to a specific customer order (Olhager 2003). The order penetration point determines which kind of inventory will be held by the manufacturing company (Fogarty, Blackstone & Hoffmann 1991, p. 2). Different manufacturing strategies are linked to different OPP positioning – this is illustrated in figure 3. Common options for manufacturing strategies are make-to-stock (MTS), assemble-to-order (ATO), make-to-order (MTO) and engineer-to-order (ETO). Make-to-stock strategy allows immediate delivery from finished goods inventory, which company manages. In assemble-to-order strategy company maintains inventory of standardized components and subassemblies from which products are assembled and then delivered. In make-to-order strategy company provides ability to produce customized products and production begins after customer has placed an order. In make-to-order strategy company usually maintains a raw material inventory. Engineer-to-order strategy differs from make-to-order by including design process of the product in the production strategy. (Olhager 2003; Fogarty, Blackstone & Hoffmann 1991 pp. 2-3; Lehtonen & Holmström 1998)

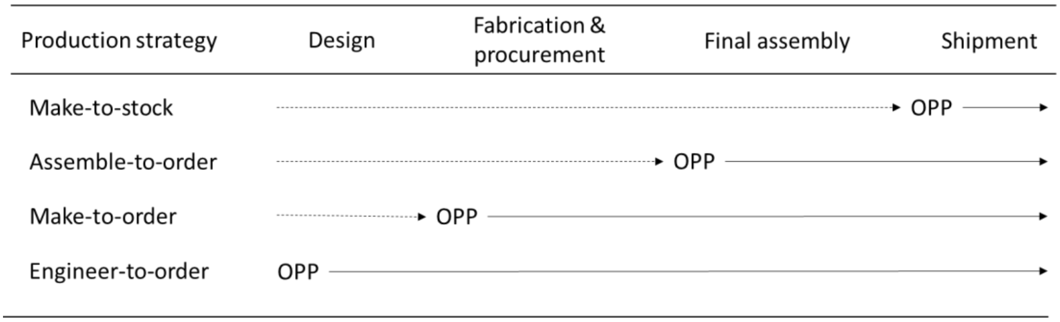

Figure 3. Different OPP positioning related to different production strategies. (Olhager 2003)

The critical factors for deciding order penetration point are manufacturing lead time, accepted delivery time by customer, and degree of customization desired by customer (Fogarty, Blackstone & Hoffmann 1991, p. 2; Lehtonen & Holmström 1998). Current trend shows that customers demand highly customized products in many industries, which leads companies offering a big variety of products to satisfy customer needs and stay competitive (Beemsterboer, Land & Teunter 2017). According to Lehtonen and Holmström (1998) order penetration point in paper and board industry can be either at call-off stock (make-to-stock strategy) or at the production machine (make-to-order strategy). In general, make-to-order strategy is more desired strategy for manufacturers to lower inventory levels and inventory holding costs, and to avoid obsolete inventory (Fogarty, Blackstone & Hoffmann 1991, p. 2; Beemsterboer, Land & Teunter 2017). According to Keskinocak et al. (2002) most paper and board manufacturers produce to order because it is impractical to stock large number of possible combinations of product types and roll dimensions: each customer order specifies quantity, product type, roll width, roll diameter, due date and shipping destination.

However, make-to-order strategy cannot react to volatile demand very well – during demand peaks delivery times lengthen and risk of order delays rise whereas during low demand maximizing capacity utilization is challenging (Beemsterboer, Land & Teunter 2017). To counter these disadvantages Beemsterboer, Land and Teunter (2017) suggests hybrid production strategy where some of the products are made to stock during low demand periods. They suggest producing low-valued, standardized products with regular demand to stock while producing high-valued or customized products with irregular demand to order. Planning production for systems like this is challenging, because control parameters vary a lot between MTO and MTS strategies. Flexible lot sizing on MTS production is suggested to help timely delivery of MTO orders while keeping production machine utilization high. In addition, Beemsterboer, Land and Teunter (2017) state that their mathematical model is not easily adopted in large, real-life applications, but in order to achieve good performance in terms of holding and lateness costs it is crucial to be able to adapt lot sizing at any time in response to demand changes. Hybrid MTS/MTO -production strategy can be adopted in board industry to some extent, but considering high customization required by customers, finished goods storage options are limited as presented in chapter 2.2. When utilized in board industry, some orders will be produced to stock in advance to keep the production machine utilization high. These stock lots and reasoning behind them is further discussed in chapter 2.3.

2.2 Cyclic production planning and control

Board machine produces large rolls of board called reels or jumbo reels. Each board machine has fixed reel width dependent of the machine. Reels are then taken through rewinder to slit the reel into smaller rolls. These rolls are specified by customer orders in diameter and width. (Keskinocak et al. 2002)

In board industry maximizing production machine utilization is important due to significant fixed costs and long sequence-dependent setup times. Stochastic demand and limited finished goods storage options add complexity to production planning and control. Board machines have finite capacity which must be balanced between multiple products while aiming to minimize inventory holding costs and achieve targeted service level. This scheduling problem is called stochastic economic lot scheduling problem (SELSP). (Briskorn, Zeise & Packowski 2016)

In general, most of the developed mathematical solution models regarding SELSP assume the production strategy to be make-to-stock (e.g. Sox et al. 1999; Winands, Adan & van Houtum 2011; Briskorn, Zeise & Packowski 2016) which makes those mathematical models not directly applicable to the make-to-order production systems commonly present in board industry. However, the characteristics of the problem are identical with board industry production planning. Also, producing orders earlier than required due date can be viewed as producing those orders to stock, even though they will be eventually shipped to the customer. Inventory in make-to-order strategy is further discussed in chapter 2.3.

Winands, Adan and van Houtum (2011) present three different production planning approaches for SELSP: dynamic production sequence, fixed production sequence with a dynamic cycle length, and fixed production sequence with a fixed cycle length. Fixed production sequence can be defined as a pre-determined order and frequency of production of different products while in dynamic production sequence the production order might change depending on demand fluctuations. An example of cyclical production sequence is illustrated in figure 4. In board industry both fixed and dynamic production sequences can be used, and their usage differs from machine to machine. In addition, Winands, Adan and van Houtum state that production policies which define necessary actions during different production states are needed in environment like this. Production policies dictate whether to continue producing current product, switch to producing other product or idle the machine in any given production state. Primary goal of production policies is to optimize predefined performance measure, which could be for example minimization of expected total costs, average stock level or waiting time of customers.

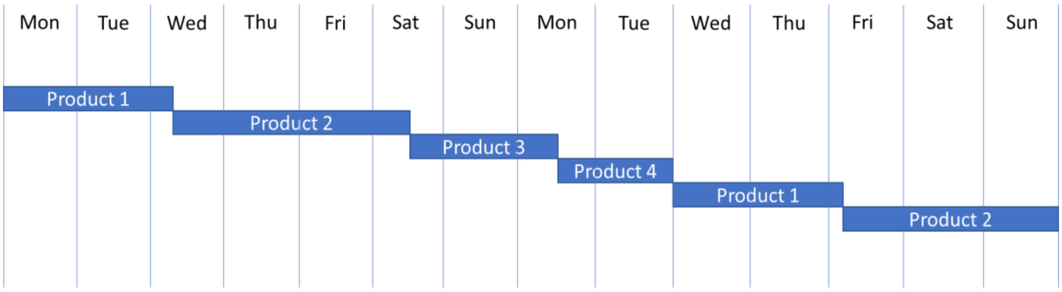

Figure 4. Cyclical production sequence.

2.3 Inventory in make-to-order strategy

Safety stock can be defined as additional inventory held as a protection against forecast errors, short term changes in the backlog or fluctuations in demand and/or supply (Fogarty, Blackstone & Hoffmann 1991, p. 842). In make-to-order production strategy safety stock is not kept in general, but production lots comparable to safety stock might be produced. In board industry these lots can be overproduction on purpose to avoid insufficient customer lots due to quality issues especially in longer machine chains, producing lots earlier than required to keep production machine utilization high or producing side runs to have an efficient trim solution. Machine chain can be defined as a route for product to be fully produced through multiple production machines chained together. Trim solutions in board industry are further discussed in chapter 2.4.

According to Berk and DeMarzo (2014, p. 897) mismatch of customer demand and the most efficient production cycle is one of the reasons for holding inventory. This applies to board industry as well – most of the inventory in board industry is from customer lots waiting for transportation. As stated in chapter 2.2 production is cyclic whilst customer order due dates vary depending on customer needs. As certain products are produced only for several days per full production sequence, usually a gap exists between production date and shipping date. During this period the customer lot will stay in inventory waiting to be shipped. To decrease overall inventory significantly in board industry customer lots should be produced as close to shipping date as possible. However, it is often not possible due to cyclicality of production and the need to keep the production machine utilization high.

Holding inventory causes several problems including chance of obsolescence and holding costs. Costs caused by inventory can be categorized into acquisition costs from acquiring the inventory, which includes raw material and production costs, and carrying costs, which includes storage costs, insurance, taxes, obsolescence and opportunity cost (Berk & DeMarzo 2014, pp. 897-898). Reducing overall inventory levels while maintaining desired service level can significantly increase company's profitability.

2.4 One-dimensional cutting-stock problem

One-dimensional cutting stock problem (1DCSP) is an industry-specific problem for cutting set of objects available in stock to produce smaller pieces in specified quantities (Cherri et al. 2014). In board industry this problem occurs at board machine rewinder when slitting jumbo reels to smaller rolls of various sizes to meet specific customer orders (Chauan, Martel & D'Amour 2008). Research regarding the problem presents multiple mathematical models (e.g. Chauan, Martel, & D'Amour 2008; Cherri et al. 2014; Tomat & Gradišar 2017) and the problem can be solved multiple ways: minimizing trim loss, minimizing overproduction or minimizing production costs (Cherri et al. 2014). Items shorter than certain threshold are considered trim loss as they can't be used in future orders, whilst items longer than the threshold are usable leftovers (Tomat & Gradišar 2017).

In board industry solving cutting stock problem is routine work for production planners when trimming board machines. Trimming can be defined as creating production plan which contains set of cutting patterns of varying frequencies (Keskinocak 2002). This plan determines how the jumbo reels will be slit into smaller customer rolls at the rewinder. Sometimes decent trim is impossible to create – in cases like this production planner might try to improve the trim by advancing some orders from later production cycles as a trim help. This has an effect of increasing inventory levels temporarily until the orders produced in advance are shipped. Also, sometimes orders are overproduced for trim reasons because order is impossible to trim to the quantity customer requested. An example of case like this is illustrated in figure 5.

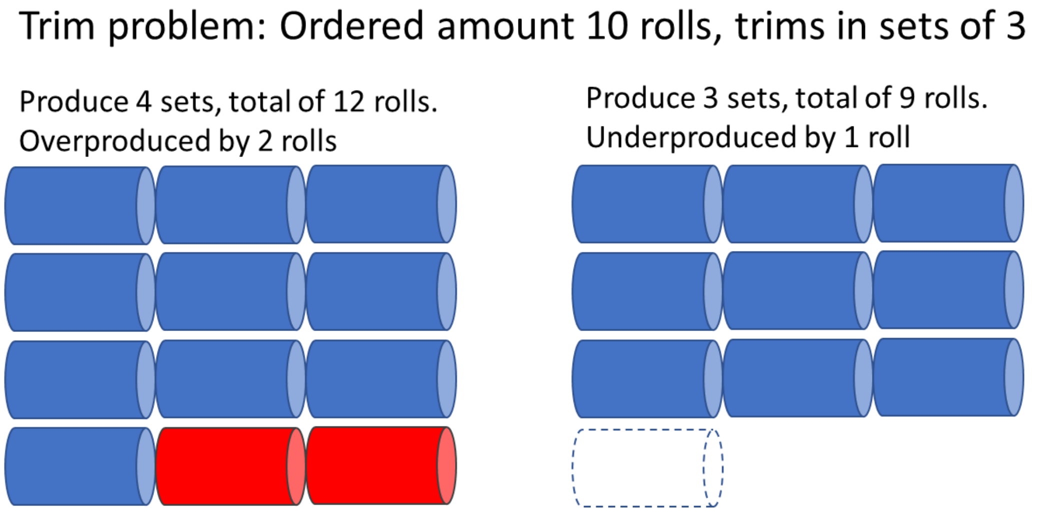

Figure 5. Order cannot be trimmed to the customer requested quantity.

One-dimensional multi-stage cutting stock problem is specific case of cutting stock problems where reels are cut into finished rolls in more than one stage due to technical reasons, such as processing capacity or nature of the production process (Muter & Sezer 2018). In board industry case like this is very common when the finished product requires additional processing such as PE-coating or sheeting. According to Muter and Sezer (2018) in one-dimensional multi-stage cutting stock problem number of available rolls is limited to previous stage production in intermediate stages. They state that the problem can be divided into different subproblems for each stage. In board industry achieving decent trim solutions in multi-stage cutting stock problems is highly dependent on width limitations of the machines, thus optimizing the trim solution requires the intermediate rolls to be suitable widths for the later phases of the machine chain.

2.5 Distribution and logistics process

Distribution management can be defined as planning, implementation, evaluation, and control of physical movement of goods from manufacturer to the customer. It is a strategic concept of series of activities and processes including packaging, transportation, tracking and return. In addition, set of distribution channels needs to be established. Packaging process and packaging system ensure avoiding shipping damage to the goods. In board industry rolls are packed in closed wrap packages and sometimes these wrap packages are packed on pallets. Sheets are packed on pallets. Transport process is needed to physically move the goods to customers. In board industry shipments to customers are done by ferries, by trucks, by rails and in rare cases by air freight. Tracking system is necessary for making sure the goods are delivered to the right place at the right time. Return system is utilized when quality issues are found, and products need to be returned to manufacturer. Distribution channels are used to deliver products from manufacturer to a third-party warehouse or directly to a customer. In board industry common distribution route is from mill to port by rails where rolls are loaded into shipping containers and shipped to the destination country. At the destination country rolls are loaded to trucks or trains and transported to the customer. Managing distribution also includes determining optimal quantities of products to specified warehouses or points-of-sale to achieve efficient, sustainable, transparent, and satisfactory delivery to customers. (Zijm et al. 2019 pp. 306-307)

Logistics process can be defined as having right quantity of the right products at the right place at the right time (Mallik 2010). According to Zijm et al. (2019 pp. 307-308) common objectives regarding distribution management and logistics process are quality, On Time and In Full (OTIF), transparency, flexibility, resilience, and cost-efficiency. Quality is important from customer perspective – the products should be damage-free and according to the customer specifications. OTIF is usually measured and it means having the delivery done by requested due date in required quantity. Customers prefer having their order produced to the exact ordered quantity but in board industry there usually is some tolerance in ordered amounts (Keskinocak 2002). Proper tracking system and helpful support helps in being transparent, which usually leads to customer satisfaction. Flexibility means that orders and distribution can be changed in volume, destination, and requirements whilst resilience means that the system can withstand long-term and short-term changes including market shifts, changes in distribution channels and even major disasters. Cost-efficiency in board industry is related to transportation payload optimization, which can be defined as maximizing carrying capacity usage. Logistics process cost-efficiency can also include holding costs from the inventory if the holding costs are caused for logistical reasons such as sparse shipments.

Time between placing an order and receiving the goods can be defined as lead time. Lead time can include order preparation time, queue time, production time, move or transportation time and receiving time (Fogarty, Blackstone & Hoffmann 1991, p. 826). In cyclic production environment lead time sets the time of production by counting backwards from requested arrival date and placing the order to the first available production cycle before latest production date. Example of this is illustrated in figure 6.

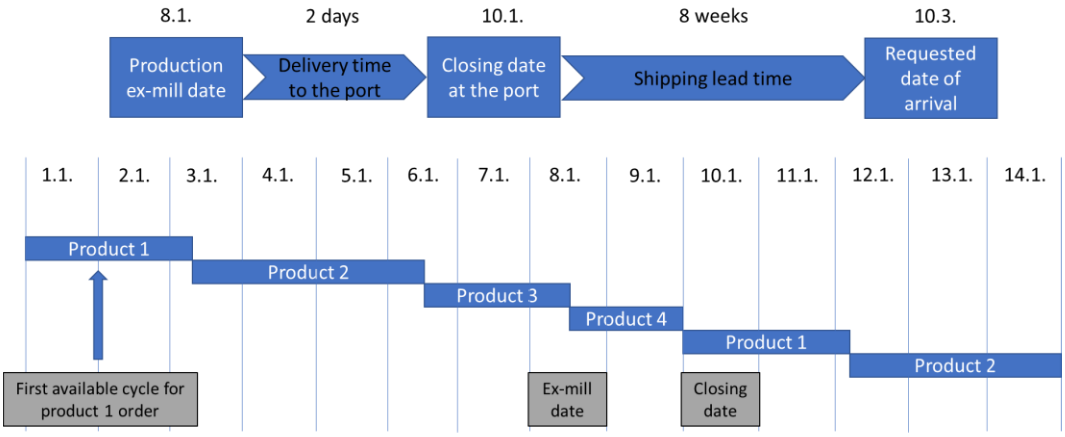

Figure 6. Setting order production date in cyclic production using lead time.

3 MEASURING PERFORMANCE FOR SALES AND OPERATIONS PLANNING PROCESS

In this chapter sales and operations planning process and its benefits and requirements are presented. Also, performance measurement systems and their usability as a part of sales and operations planning process is discussed. Reasoning behind performance management and criteria for developing performance measures are presented. The goal of this chapter is to increase understanding behind the motives of the research from operations management point of view and to clarify which factors are needed in comprehensive performance measure and how to develop performance measures.

3.1 Sales and operations planning process

Sales and operations planning (S&OP) process can be defined as a tool to integrate business plans such as customer, sales, marketing, research and development, manufacturing, sourcing, and financial plans, into one set of tactical plans. S&OP process has two main functions: to balance supply and demand, and to connect business plans, strategic plans, and operational plans together. S&OP process is cross-functional, it has a planning horizon from several months to up to two years, it connects strategy and operations together, and creates value while being linked with the company's performance. (Thomé et al. 2012a; Grimson & Pyke 2007)

S&OP process is usually a five-step process including creating demand forecast, drafting overall picture and rough-cut capacity plan of available supply, developing the final operating plan for the planning period, distributing and implementing the developed operational plan, and measuring the results and effectiveness of S&OP process (Grimson & Pyke 2007). The steps of S&OP process are illustrated in figure 7.

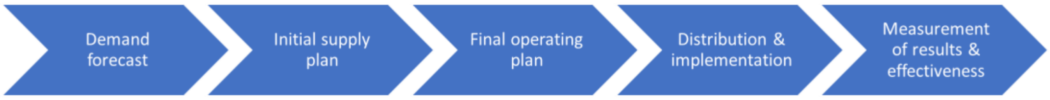

Figure 7. Steps of sales and operations planning process (Grimson & Pyke 2007)

First, the sales team forms consensus-based demand forecast that considers marketing plans, promotions, product introductions and obsolescence. In addition, planning horizon is decided – typically planning horizon is from several months to up to one and half years. In general, industries which have long production lead times like board industry lean towards longer planning horizons. Next, the operations team gathers information of supply chain capacity, internal capacity, and current inventory strategy to create overall picture of available supply and uses the demand forecast to create a rough-cut capacity plan which should meet the forecasted requirements. The third step is to create a final operating plan for the next planning horizon to balance forecasted demand with available capacity. S&OP team usually creates this operational plan in co-operation, and decision-making should include representatives from sales and marketing (demand management & forecasting), operations (inventory management, purchasing, supply chain, master production scheduling), and finance. In board industry capacity plan can include market curtailments, replanning maintenance stops, rerouting orders, rescheduling production, adding or removing quota restrictions, and activating sales fillers to reach balance between demand and supply. After creating operating plan for the planning horizon, it is time to implement and distribute the plan on operational level. Usually implementing the plan means that the operations team needs to meet required production targets, whilst sales team rarely needs to adjust sales plan. The final step of the S&OP process is to measure the results and effectiveness of it. Measuring performance is important for continuous improvement and it can include performance measures such as capacity utilization, quality, inventory on hand, stockouts, forecast accuracy and sales growth. (Grimson & Pyke 2007)

Vertical and horizontal integration is often discussed in studies regarding S&OP process (e.g. Thomé et al. 2012b; Hulthén, Näslund & Norrman 2016; Noroozi &

Wikner 2017). Vertical integration can be defined as linking strategic plan, business plan, financial plan, and long-term objectives to operational planning. Horizontal integration on the other hand can be defined as cross-functional integration with suppliers and customers. Noroozi & Wikner (2017) presents integrative framework for S&OP process in their study, shown in figure 8.

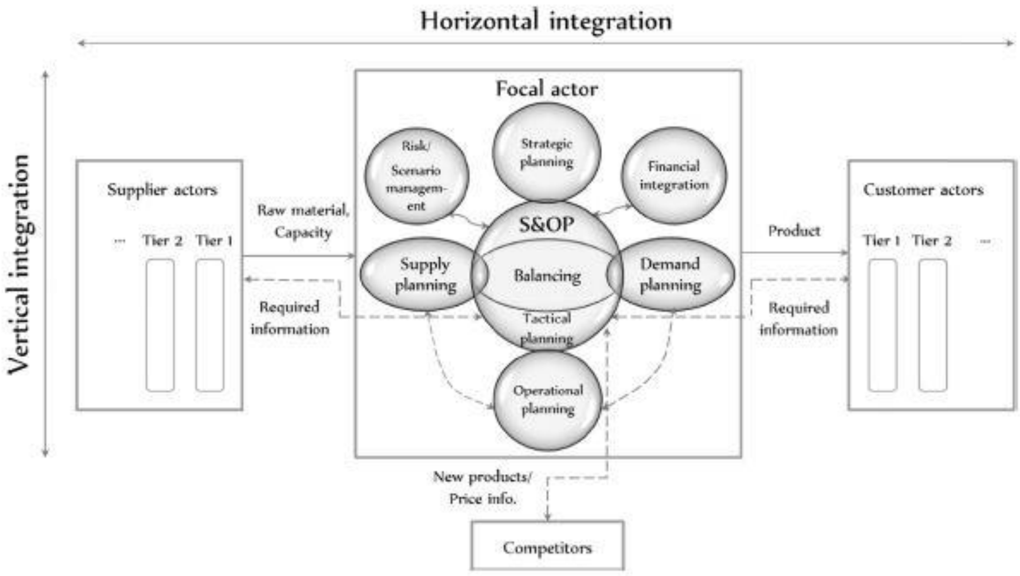

Figure 8. Integrative framework for S&OP process. (Noroozi & Wikner 2017)

3.2 Goals and requirements of S&OP process

According to Thomé et al. (2012b) goals of S&OP process are alignment and integration of demand and supply, business plans and company functions, operational improvement of forecasting, managing inventory, capacity resources, constraints, uncertainty, risk and resource allocations, as well as financial goals such as increased profits, increased revenue and cost minimization. In board industry balancing supply and demand is a constant effort: as a capital-intensive industry production machine utilization is important benchmark for profitability (Berends & Romme 2001), which leads to policy of trying to keep the machines running. However, common manufacturing strategy is make-to-order, so only customer lots are produced. In case of having too little demand, supply can be reduced by adding market curtailments to stop the production for determined periods of time. Demand can also be increased short-term by activating sales fillers or producing stock lots to free up capacity in the future. In case of excessive demand quota restrictions, customer allocations, and rerouting or resequencing orders can be used to balance the situation. In addition, excessive inventory can be sold either directly to customers or after customizing rolls on a rewinder.

According to Lapide (2004) there are multiple success factors for efficient S&OP process, such as preparing for the meetings with demand forecast and rough-cut demand and supply plans, measurement of the process, integrated supply-demand planning technology, and external inputs to the process. Overall, he lists twelve success factors for S&OP process, shown in figure 9.

SUCCESS FACTORS OF SALES & OPERATIONS PLANNING (S&OP) PROCESS

1. Ongoing, routine S&OP meetings
2. Structured meeting agendas
3. Pre-work to support meeting inputs
4. Cross-functional participation
5. Participants empowered to make decisions
6. An unbiased, responsible organization to run a disciplined process
7. Internal collaborative process leading to consensus and accountability
8. An unbiased baseline forecast to start the process
9. Joint supply and demand planning to ensure balance
10. Measurement of the process
11. Supported by integrated supply-demand planning technology
12. External inputs to the process

Figure 9. Success factors for S&OP process. (Lapide 2004)

The rough-cut demand and supply plans should include all known factors which could influence future demand or supply, including details of marketing and sales actions, supply capacities and limitations, inventory data, and planned plant shutdowns. Measurement of the process is crucial to allow continuous improvement of the process over time. To improve the process not only profitability and forecast accuracy should by measured, but also variance to baseline forecasts and adherence of sales, marketing and operations plans. Integrating supply and demand planning technology includes synchronization of supply and demand data and software which allows to combine views of both supply and demand. External inputs to the process are from customers and suppliers to improve forecasting accuracy for future supply and demand. (Lapide 2004)

3.3 Performance measuring and management

According to Pekkola and Rantanen (2014) the goal of performance management is to use data from internal and external performance measurement sources to achieve continuous improvements and to enable effective decision-making. Information gained from performance management systems is used for decision-making and allocating resources like money and workforce to the right places (Ukko, Tenhunen & Rantanen 2007). Amaratunga & Baldry (2002) define performance measurement as a process of quantifying the efficiency and effectiveness of an action. They also state that it is a tool for more effective management, and it indicates what happened – to effectively use performance measuring outcomes company must be able to transition from measurement to management.

Ukko, Tenhunen and Rantanen (2007) present in their study that performance measure systems have impact on leadership and management. According to them it is important for employees to understand why something is measured and how the measurement is tied to objectives and goals of the whole company. They also state that early information and marketing are crucial for implementing new performance measuring system. In addition, communication between management and employees about what is the purpose of the new system and what is being monitored is also vital to reduce resistance.

Choo (2002) presents a model for information management to support the intellectual growth of an organization. His model is continuous process of six activities: information needs, information acquisition, information organization and storage, information products and services, information distribution, and information use. The process begins when information is created by organization's adaptive behavior. Information needs are identified by members of the organization who recognize volatility of the environment and seek information about it to understand the situation. This information is needed to solve problems and to do decisions. Information acquisition is motivated by information needs and it addresses these needs. Existing sources of information must be constantly evaluated, new sources added, and relation between information sources and needs reviewed. Information organization and storage means creating repository of knowledge and expertise within organization. Integrated information management policies ensure that necessary data for organizational learning is available – information technology often increases effectiveness of information organization and storage. This stored information is then packed into information products and services, which add value and enhance the quality of information by presenting the data user preferred way and improving fit between raw information and user need. Next step is information distribution with a goal of widespread sharing of the information. End users should be given the best available information to perform their work. Information use is the last step in the process. Choo's information management model is presented in figure 10.

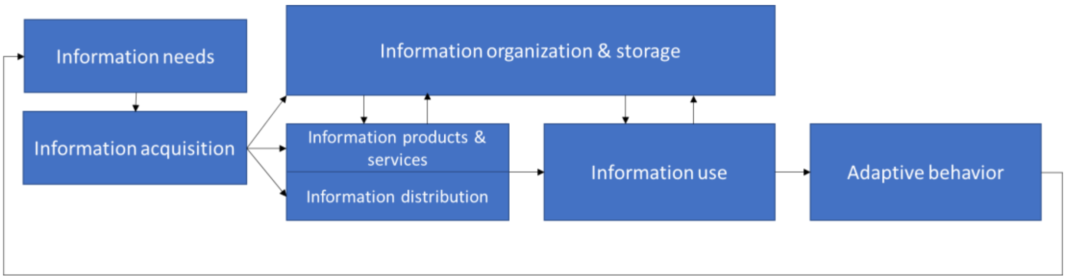

Figure 10. Information management model. (Choo 2002)

3.4 Developing performance measurement systems

Bourne et al. (2000) see development of performance measurement system as a three-phase process which includes designing of the performance measures, implementing them, and using the system for continuous improvements and decision-making. Designing phase requires identifying key objectives and designing the measures themselves. Implementing individual performance measures requires several steps including data collection, collation, sorting, and distribution. These steps can be done manually but in case of regular reporting needed it is best to automate the process. It can involve programming to capture data already available in the system or initiating new procedures to record data yet to be captured. The last phase of the process is to use the implemented system. The developed measures should be used to review how decisions made using the measured information effect the results. Process for developing performance measuring system is illustrated in figure 11.

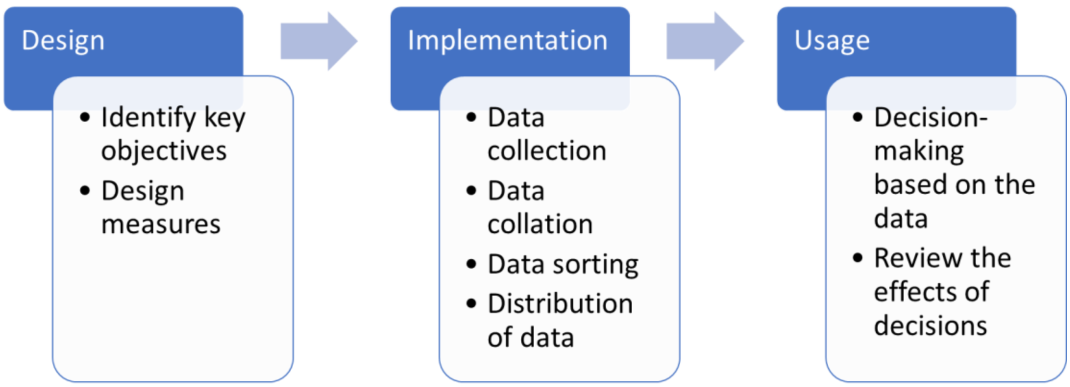

Figure 11. Process for developing performance measurement systems.

Lönnqvist (2004, pp. 85-96) summarizes several factors for comprehensive performance measure. According to him comprehensive performance measure is valid, reliable, practical, and relevant. In addition, measured data need to be relevant and measurable, and there need to be purpose and enough resources for using the performance measure. Emory (cited in Lönnqvist 2004) describes validity as how well the measure measures the objective it is intended to measure. According to him, reliable measure provides accurate and precise results consistently over time with little to no error. Emory also states that practicality refers to how cost effective the measure is – benefits should be greater than costs. In addition, practical measure is convenient to use and easy to understand. Relevancy of the measure indicates that the measure is useful and valuable for the users (Hannula, cited in Lönnqvist 2004). Factors of comprehensive performance measure are illustrated in figure 12.

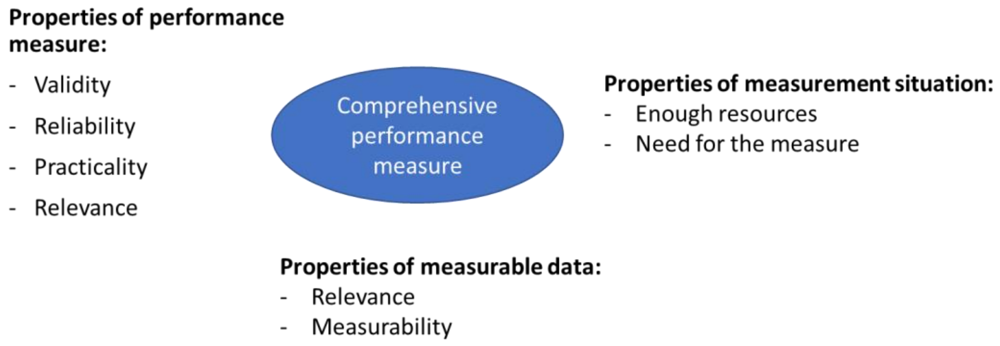

Figure 12. Factors of comprehensive performance measure. (Lönnqvist 2004)

According to Toni and Tonchia (2001) non-cost performance measurements include measuring time performance. Time performance can be divided into external and internal. Internal time performance includes run and set-up times as well as wait and move times. On the other hand, external time performance includes system times such as supply, manufacturing and distribution lead times, delivery speed and reliability, and time required to develop a new product. Measuring time between production and due dates in the scope of this research is measuring wait time of the order in inventory.

4 PRODUCTION AND INVENTORY MANAGEMENT AT STORA ENSO IMATRA MILLS

In this chapter production and inventory management principles as well as order handling process in the target company are presented. This chapter is based on data available in the mill and ERP systems, instructional material, and expert interviews. Interviewees and interview questionnaire are presented in appendix 1. Production and inventory management in the target company is described from Imatra Mills perspective but results of this study should be applicable to the other production mills as well.

4.1 Stora Enso Oyj

Stora Enso Oyj is a global pulp, paper, board, and other forest product manufacturer which employs over 25000 people all around the world. The company headquarters is in Finland and majority of production mills are in Finland or Sweden. In 2019 Stora Enso had total sales of 10.1 billion euros and operational profit of 1.0 billion euros. The company has annual production capacity of 5.9 million metric tons of chemical pulp, 5.4 million metric tons of paper, 4.7 million metric tons of board, 1.4 billion square meters of corrugated packaging, and 5.6 million cubic meters of sawn wood products. Europe is the biggest market segment with 73 % share of all sales in 2019. (Stora Enso 2020)

“Anything made from fossil-based materials today can be made from a tree tomorrow” is the business idea of Stora Enso. The company has a goal of doing good for people and the planet while replacing fossil-based materials with renewable solutions. Values Stora Enso follows are “lead” and “do what’s right”. The company aims to contribute for a better climate by managing sustainably their forests, absorbing CO_2 emissions from the atmosphere with substituting fossil-based products and promoting circular economy by reusing and recycling materials and resources. (Stora Enso 2020)

Stora Enso consists of six divisions: Packaging Materials, Packaging Solutions, Biomaterials, Wood Products, Forest, and Paper. This paper is focused on Packaging Materials division. Packaging Materials division has a goal of being global leader in high-quality renewable packaging materials based on fiber. The divisions strategy is to expand their relative market share in consumer board business and to increase growth on fluting and kraftliner market. Packaging Materials division helps customers to find better packaging solutions with low carbon footprint to replace fossil-based materials. (Stora Enso 2020)

Imatra Mills is one of the largest consumer packaging board production mills in the world with annual capacity of 1.2 million metric tons of consumer packaging board. Imatra Mills also produces 1.3 million metric tons of pulp and 0.4 million metric tons of polymer coating. The facility has around 1300 employees and it was founded in 1935. Currently Imatra Mills is the most complex and largest integrate of Stora Enso and it has two production units: Kaukopää and Tainionkoski. (Stora Enso 2020)

4.2 Board machine production planning

Board machine production planning is complicated task which is handled by production planners. At Imatra Mills production sequencing, cycle plans as well as trimming is done using Seitti mill system, which is production planners’ main tool. Seitti communicates with Fenix ERP system and the data is synchronized between the systems. Fenix ERP system is used for supply chain management.

Production planning at Imatra Mills consists of several steps. First, cycle sequencing and cycle lengths are decided based on S&OP forecast on monthly basis. Usually production cycles are created for the next few months and then updated later if demand does not match the forecast accurately. Cycle sequence and frequency depends on production machine, as each machine has different limitations and demands. Most optimal cycle sequence is commonly used, as grade change efficiency varies between different products. For example, grade change where only grams per square meter is changed produces less waste on average than grade change with greater product recipe changes, such as from uncoated to coated board. Creating production cycles is allocating overall capacity of the production machine to different products, and then linking the production of different products to certain periods of time. Example of cycle plan in Seitti is presented in figure 13.

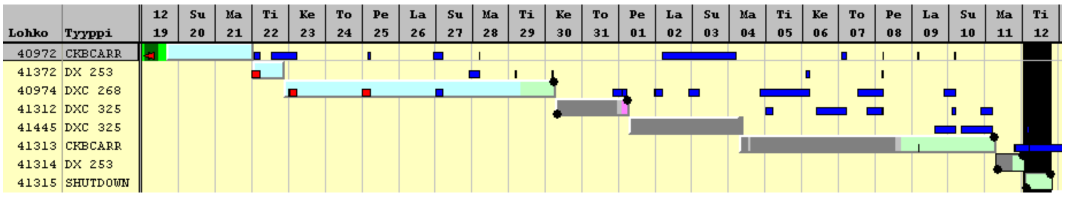

Figure 13. Cycle plan in Seitti.

Cycle plan determines cycle frequency, which has great impact on inventory levels caused by wait time of orders. High frequency of cycles allows producing certain products more often and closer to the due dates, which leads to overall smaller inventory levels. On the flipside, increasing cycle frequency requires more cycles, which results to lower production efficiency due to changing grades more often. Grade changes in board industry will always cause costs from waste and lost production time. Also, reaching good quality after grade change often takes some time and adjustments at the machine. Sometimes cycle plan needs to be changed short-term due production issues at the machine. In cases like this the original cycle plan is not followed, and most urgent orders are not produced. This will increase inventory levels temporarily until the situation is normalized. Effects of extending production cycles to inventory levels and time between production and due dates is further discussed in chapter 5.2.

After the cycle plan is created, orders can be taken in and placed in the correct production cycles. Order handling at Imatra Mills is further discussed in chapter 4.3. Production lots and orders have minimum lot sizing to increase cost-efficiency of production. The minimum required amount to have certain products to be produced varies between production machines and products. If the minimum amount is not met, production will be postponed until enough orders are in.

Next step is to trim the orders and release the trim patterns to the production. Trimming is done using AutoCut trimming software shown in figure 14. Goal of trimming is to create trim solutions with minimal trim loss, minimal overproduction, and minimal pattern changes while staying within the production machine limitations. Sometimes creating decent trim solution requires trim help, which can be a stock lot, a side run for clearance sales, or a customer lot which will be produced in advance. At Imatra Mills production is planned by tons, so order is considered fully produced when produced tons are equal to ordered tons or at least within the customer tolerance. Number of rolls can vary from estimated or ordered amount, as unit weight is not constant due to the nature of board production. After the orders are trimmed, the cycle can be frozen. Frozen production cycle means no orders can be taken in anymore unless the orders are bypassed in with the permission of the production planner.

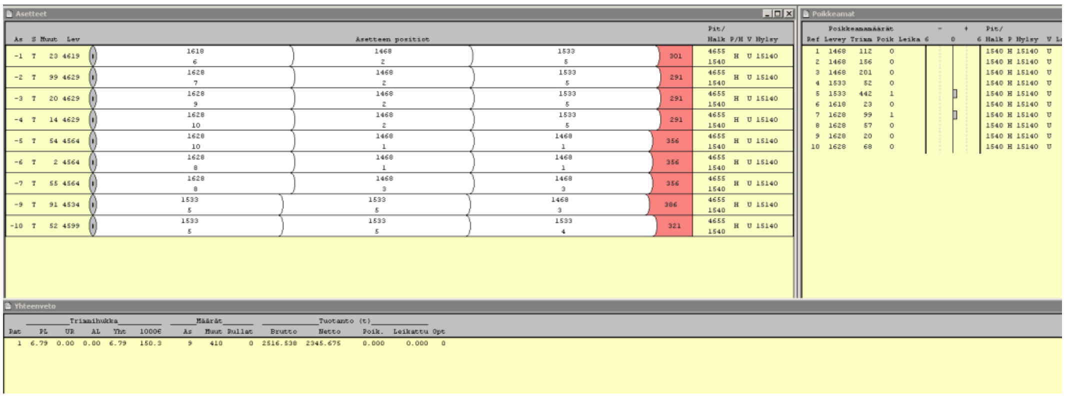

Figure 14. Trim patterns created in AutoCut software.

Each trim solution is considered as a separate production run. These production runs can then be sequenced based on due dates of the orders. If production run would last for several days and there are urgent orders, production planner can change the sequencing of trim patterns within one trim solution to advance production of urgent orders. Production runs can be seen in both Seitti mill system as well as in Fenix ERP.

Fenix Rough Production Planning (RPP) shows the current cycle plan and historical data. It is used mostly by Supply Chain organization to check available capacity and current production runs, to allocate capacity to customers with quota restrictions, and to determine when production for specific product is planned. Fenix RPP also has some useful settings for restrictions, such as quota restrictions for specific customers and ex-mill restrictions. Quota restriction means allocating certain amount of capacity for selected customer. The customer can only order up to their quota limit and orders over the quota limit will not be confirmed unless permission is given by the production planner. RPP quota restrictions can be determined for each product separately or for all products in certain period. Ex-mill restriction setting only allows setting the ex-mill after production cycle has ended. Ex-mill is defined as date when order should be ready for loading at the mill. This ensures the order will be produced in time if there are no major delays in production. On the other hand, it might cause inaccurate ex-mills if production cycles are long. Sometimes in cases like this, the order might have shipment booking before the ex-mill date. This effect can be reduced by splitting long production cycles into two shorter cycles. Then the system allows confirming earlier ex-mills for orders in the first cycle. View of Fenix RPP is presented in figure 15.

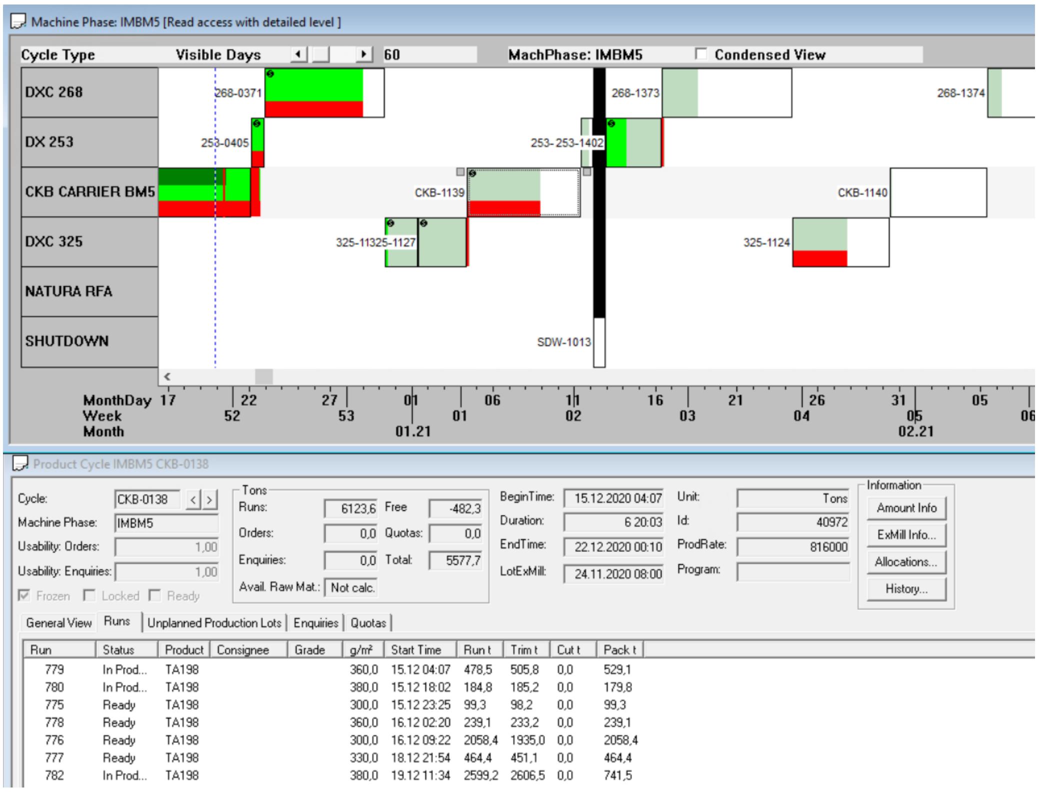

Figure 15. Fenix Rough Production Planning.

Each production machine has unique planning policies, limitations, and characteristics. At Imatra Mills there are four board machines: Board machine 1 (IMBM1), Board machine 2 (IMBM2), Board machine 4 (IMBM4) and Board machine 5 (IMBM5). IMBM1, IMBM2 and IMBM4 are located at Kaukopää production unit whilst IMBM5 is located at Tainionkoski production unit.

Board machine 1 is part of Liquid Packaging Fresh & FSB business line and it produces mostly liquid packaging board for fresh products including board for cups. IMBM1 average production volume is approximately 520 tons a day. Significant share of the rolls produced at the machine are raw materials for PE-coating machines, which dictates the production run specifications like diameter, core, and winding direction. IMBM1 production sequencing is quite flexible, as most of the products only vary by grams per square meter. Most of the products are produced twice a month, rest once a month or whenever needed. Machine specifications for IMBM1 are listed in table 1.

Board machine 2 is part of FBB & SBS business line and it produces folding boxboard (FBB) and solid bleached sulphate board (SBS) for end uses like cosmetics, chocolate, cigarette, pharmaceutical and food packaging, and laminated boxes for wine, spirits and graphical products. IMBM2 average production volume is approximately 655 tons a day. Production run specifications vary a lot depending on customer requirements and lots are produced directly for customers as well as for PE-coating raw material. IMBM2 production cycle sequencing is rarely changed, and it follows optimal rotation where Ensocoat L is produced twice a month, rest of the products once a month. IMBM2 machine specifications are listed in table 1.

Board machine 4 is part of Liquid Packaging Fresh & FSB business line like board machine 1 and it produces liquid packaging board for fresh products including board for cups. IMBM4 average production volume is approximately 1021 tons a day. Production run specifications are mostly standardized, including standard diameters 1500mm and 1600mm, standard core 306mm and standard winding direction top side in, excluding couple exceptions. IMBM4 produces lots directly for customers as well as for PE-coating raw material. IMBM4 production cycle sequencing follows three-week cycle with mostly fixed sequencing, but sometimes sequencing is changed due to production issues. Rarely ordered products are produced once every two cycles. IMBM4 machine specifications are listed in table 1.

Board machine 5 is part of Liquid Packaging Aseptic & CKB business line and it produces liquid packaging board for aseptic packaging outside of the cold chain and coated multilayer kraft back board (CKB). IMBM5 average production volume is 798 tons a day. Production run specifications are standardized as most of the orders are from strategic key accounts. IMBM5 does not produce raw materials for PE-coating at Imatra Mills: all the produced rolls are for customer lots or sheeting raw materials. IMBM5 production cycle sequencing is mostly fixed and follows optimal rotation, but it can be changed in cases it is necessary for customer needs. Every product is produced roughly once a month. IMBM5 machine specifications are listed in table 1.

Table 1. Imatra board machine specifications.

	IMBM1	IMBM2	IMBM4	IMBM5
Average production output	520 tons per day	655 tons per day	1021 tons per day	798 tons per day
Maximum trim width	4420 mm	5550 mm	6250 mm	4920 mm
Reel width range	400 mm - 2800 mm	500 mm - 2800 mm	549 mm - 3200 mm	500 mm - 3000 mm
Diameter range	1200 mm - 2100 mm	1200 mm - 1720 mm	1420 mm - 2100 mm	1200 mm - 1800 mm
Standard cores	151mm, 306 mm	151 mm, 306 mm	306 mm	151 mm, 306 mm
Standard diameters	1200 mm, 1470 mm	1490 mm, 1720 mm	1500 mm, 1600 mm	1450 mm, 1550 mm, 1500 mm , 1800 mm

Imatra Mills also has four PE-coating machines, IMPE2, IMPE3, IMPE5 and IMPE6. These machines produce PE-coated board from raw materials produced by board machines. When machine chain is longer than single machine, it can be considered multi-stage. When trimming orders for long machine chains production planner needs to consider multi-stage cutting stock problem presented in chapter 2.4. Usually multi-stage cutting stock problems are optimized for board machine trim loss and PE-machines set limitations to raw material specifications. As each PE-machine has specified maximum and minimum trim widths it is important to direct orders to correct machines to minimize trim loss. PE-machine scheduling and cycle sequencing are constantly updated depending on board machine cycle plans as production can only start when the raw materials are already produced. Also, certain products need to stay set amount of time in inventory before PE-coating to cool down for quality reasons.

4.3 Order handling in Fenix ERP

Order handling in the target company is done in Fenix ERP system. Orders are entered by sales offices all around the world. Supply chain coordinators are responsible for managing order specifications, stock allocations and overall handling of the orders. When entering an order to the system one need to specify ordered product and product attributes, width, diameter, quantity, ex-mill date, and production cycle. After inserting all the required information order can be confirmed and released for planning in the mill system. Basic UI of the Fenix Order Handling software is presented in figure 16.

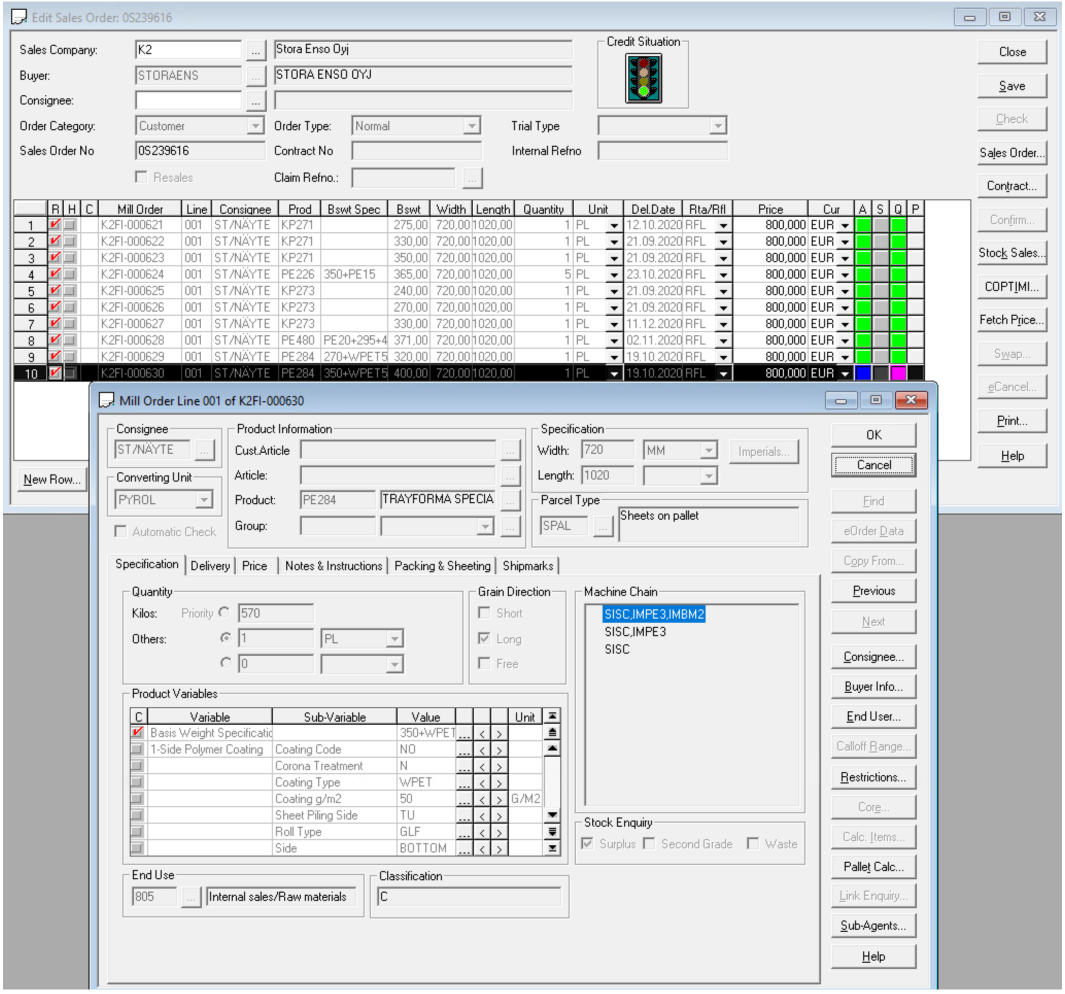

Figure 16. Fenix Order Handling software.

One important function in the order handling software is checking an order. When checking an order, the system will automatically put the order to the appropriate production cycles. Check-function starts determining production front-to-back. First it checks the last machine in the machine chain and searches for first open cycle with enough capacity before requested loading date and places the order there. Then the function will look up lead time for that machine which is specified in Fenix Basic Data System (BDS) for every product and machine chain. The function adds lead time for that machine and checks first open cycle with enough capacity for second-to-last machine in the chain and places the order there. This process is repeated until the order is placed in cycle for every machine in the machine chain. When check-function determines correct cycles, it uses lead time between machines, overall handling time and transport lead time defined in BDS-system.

If the checking fails, order can still be manually bypassed to the production using bypass-function. Bypass should not be used without caution, because with bypass-function the order can be put to frozen and planned production cycle which could already be released to production. Common practice regarding bypass at Imatra Mills is to always ask from production planner before bypassing an order into the system to avoid confusion and accidentally missing production of bypassed orders. Bypassing an order allows it to be set in any production cycle that is in the system before given ex-mill date. This includes already frozen cycles and cycles that are already in production. Also, in machine chains longer than one production machine all the production cycles before the ex-mill for all the machines are listed. In case like this the order could be accidentally put in a coating or sheeting production cycle that is before the board machine production cycle.

After the order is confirmed, it can still be edited. When editing an order, it needs to be unplanned in the mill system, otherwise it will be frozen, and changes cannot be made. Ex-mills are updated by supply chain coordinators in Fenix Order Handling software if customer requests delivery date change by searching for the order and then editing the ex-mill, production cycle and reconfirming the order. Ex-mills should also be updated if order routing is changed and shipping date or truck loading date changes. If the order has long machine chain and it already has work-in-progress inventory or some lots of the order are produced, then updating ex-mill might not be possible as removing freezing is tricky in the ERP system. Accurate ex-mills are important for validity of the data. Accurate ex-mills require valid data in the BDS-system for lead times, handling times and transport lead times as well as setting the ex-mills correctly and updating the ex-mills if requested to. According to interviews, most of the ex-mills should be up to date in the system and keeping the ex-mill dates accurate is desired.

It is a bit controversial in the target company should ex-mills be updated for production reasons. In cases when there are problems in production and orders will miss their original delivery dates, new bookings for transportation needs to be booked. If the ex-mill is updated after the booking, it will be accurate for the new delivery time. However, this will affect reporting of late orders, as the order is not shown as being late after the ex-mill is updated. Currently there are no common practices regarding updating ex-mills for orders that missed their original delivery for production reasons.

Order Handling can be restricted with settings in Fenix Rough Production Planning software. If quota limits are set, orders cannot be checked to production cycles if available quota for the customer is smaller than ordered amount. Ex-mill dates can be restricted with the setting that does not allow ex-mills to be within the selected production cycle. However, both quota and ex-mill restrictions can be bypassed with the bypass-function.

4.4 Inventory process and composition

Inventory serves a purpose of being buffer for production cyclicality and uncertainty and it is not desired to reduce inventory levels close to zero. Inventory is used to fill small orders, urgent orders, and underproduced orders. Risk of underproduction is higher on longer machine chains because there are more chances for something to go wrong in the production. The risk of underproduction is sometimes reduced by overproducing semi-finished products on purpose. This allows having extra raw materials for later phases of the machine chain if quality issues happen.

Imatra Mills inventory levels are measured weekly and updated in a dashboard file, which contains supply chain data for the whole facility. Inventory levels are measured in total stock, unnominated stock, nominated stock, prime surplus stock, over 180 days old stock and over 360 days old stock. These values are reported to administrative levels and used as a part of S&OP process. However, overall inventory levels do not always reflect the situation properly and better understanding of inventory composition allows for better decision-making process.

Inventory consists of customer lots (nominated stock), surplus stock (SP) which are usable leftovers from fully delivered customer lots or excessive raw materials, stock lots (unnominated stock) either as a raw material for upcoming orders or as trim help and side runs for clearance sales. In addition, second grade and waste are held in inventory until sold or used. Development of prime quality inventory composition during 2020 at Imatra Mills is presented in figure 17.

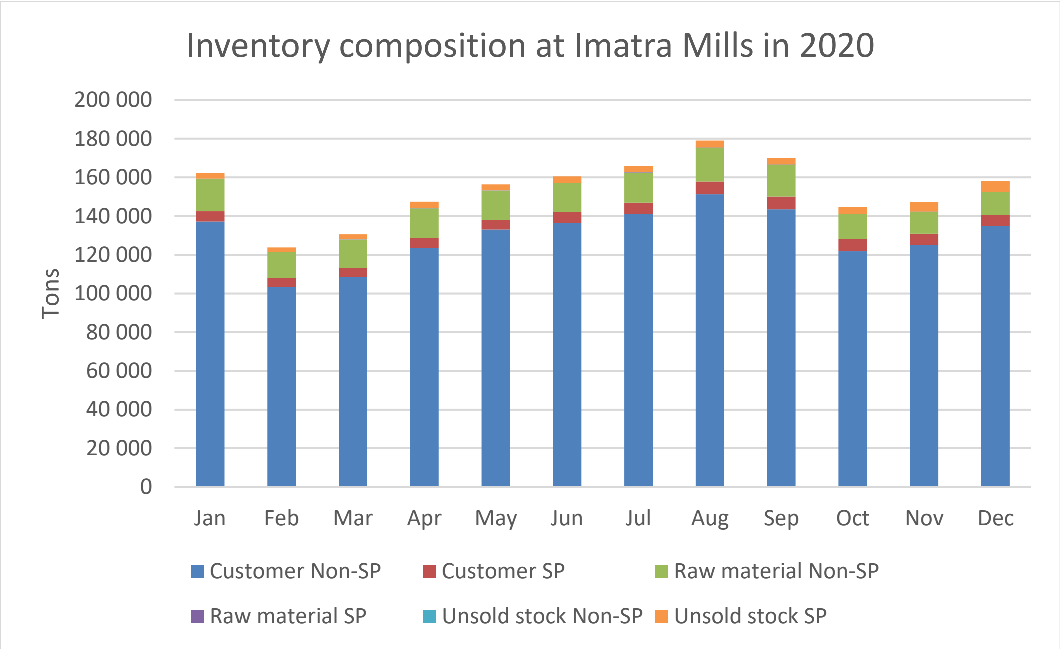

Figure 17. Development of inventory composition in 2020 at Imatra Mills.

As seen in figure 17, customer lots are by far the largest share of the inventory, thus their impact on overall inventory levels is highest. In the figure, SP stands for lots marked as surplus in the system. Raw materials are work-in-progress inventory and unsold stock is side runs and stock lots produced as trim help.

Inventory composition can also be presented by age of stock. Measuring age of stock is important as over 360 days old stock is considered second grade, because quality requirements might not be met anymore. Usually over 360 days old stock is mostly leftovers and stock lots which cannot be utilized for customer lots even using a rewinder. Age of stock is also useful for following development of over 30 days old stock: almost always orders that are over 30 days old and still in inventory are produced too early, as most production cycles have cycle frequency higher than once every 30 days. However, this does not apply to orders with longer machine chains because semi-finished products might have to stay in inventory while waiting for next phase of the machine chain. These lots that are produced too early have significant impact on inventory levels. Development of age of stock during 2020 at Imatra Mills is presented in figure 18.

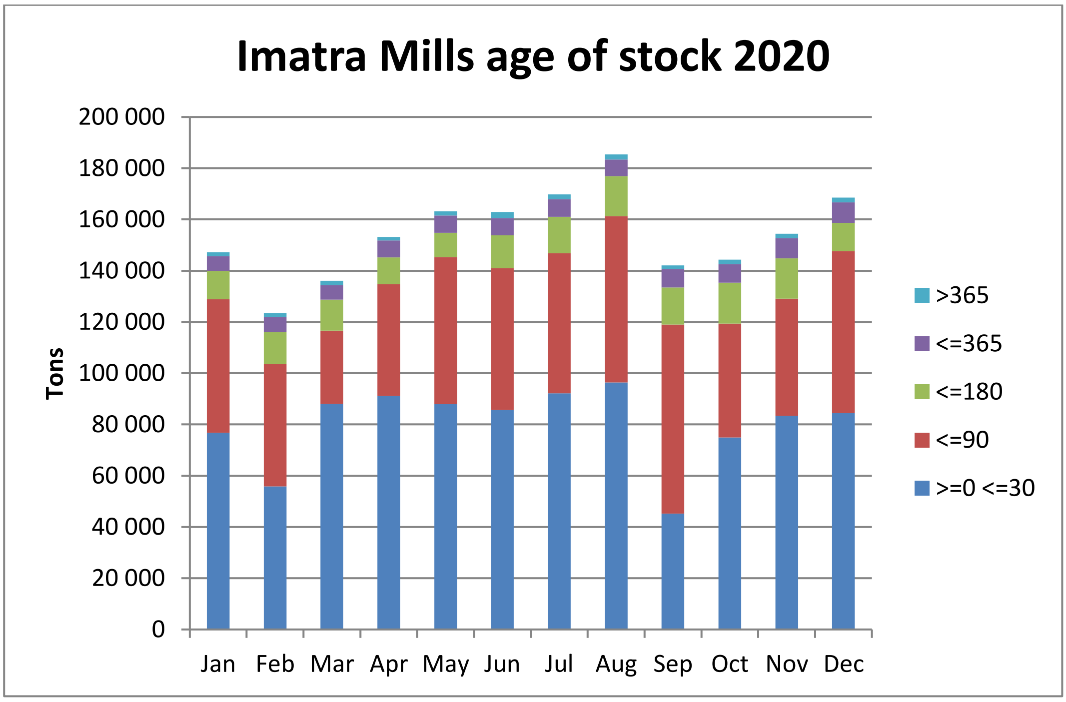

Figure 18. Development of age of stock in 2020 at Imatra Mills.

Inventory levels can be followed using reports from Fenix ERP. In this study development of volumes in stock before their ex-mill is used to solidify the causality of time between production and due dates to inventory levels. Stock trend report from Fenix allows to list every production lot in the stock for selected period and the data can be listed daily, on selected days, weeks, months, or quarters. Different variables can be included in the report, but in this study only volumes and ex-mill dates are used. The development of the stock levels is calculated for volumes, that are in the stock and their ex-mill is in the future during the considered day. Settings used in the stock trend report were one year as a date range, date as level, stock changes analyzed daily, single production machine orders including all prime orders and conditional stock. Ex-mill was selected as level to calculate is the ex-mill date in the future.

The stock volumes were modified to zero for all orders which have ex-mill date in the past on the analyzed day. For example, if order was in the stock between 1.1. and 10.1., but it has an ex-mill date of 8.1., the volume would be modified to zero on 9.1. and 10.1. After calculating all the volumes in the stock which have ex-mill in the future for every day for the selected period, a total sum of these volumes in the stock for every day was calculated using Pivot-tables sum function in Microsoft Excel. Example of development of volumes which have ex-mill in the future is presented in figure 19 for IMBM1.

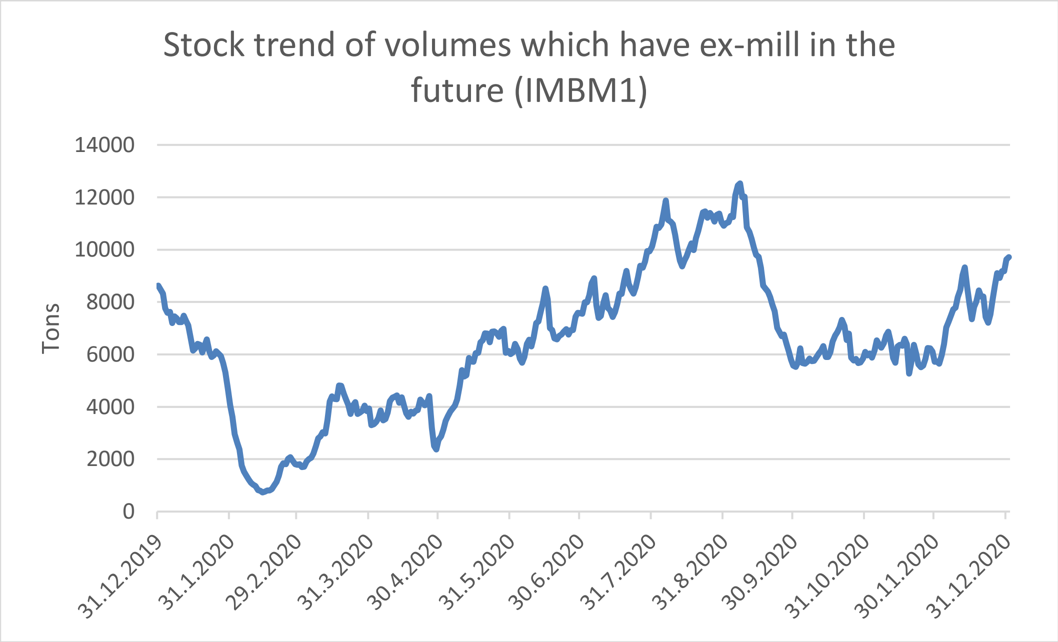

Figure 19. Development of volumes which have ex-mill date in the future for IMBM1.

4.5 Logistics process impact on inventory levels and ex-mill dates

Logistics process determines transportation dates to customers, so it has an impact on inventory levels. Transportation dates are determined by transportation lead time and customer requested date of arrival. Logistics department maintains a transportation schedule, which contains departure dates of each shipping line and transportation lead time to destinations. If shipping interval is sparse and produced orders wait in inventory for long periods of time before shipping, it has an effect of increasing inventory levels. Higher shipping frequency lowers overall inventory levels, but if the vessel's carrying capacity is not fully utilized it will increase unit costs for shipments. Maximizing transportation payload is important for cost-efficiency and the payload usage are followed in weekly team meetings.

Ex-mill dates tend to accumulate close to shipping dates, because ex-mill date is calculated automatically using transportation schedule when checking an order. If shipping line departures once a month, ex-mills for orders being shipped in that vessel are usually few days before the departure date. If the shipping interval would be less sparse, ex-mills could spread more widely closer to the actual customer need, reducing overall impact on inventory levels. Example of ex-mills accumulating close to the shipping dates is presented in figure 20.

Figure 20. Ex-mills accumulating close to the shipping dates.

In the example provided in figure 20 the customer needs the orders to arrive every other day. Calculating the orders' need for production from lead time alone would keep the due dates every other day. However, as the shipments are done weekly ex-mills of these orders are not every two days as the transportation schedule determines the ex-mill dates. In the example given orders 1-3 have same ex-mill dates, even though their actual customer need is not similar. The higher the shipping interval is, the bigger this effect will be.

Sometimes an order would make it in time from later shipping departure date, but the order will be shipped earlier. This allows balancing vessels’ carrying capacity by shipping orders earlier to fill the vessel and to utilize maximum carrying capacity. Balancing like this can result in cost savings if number of booked vessels can be reduced. In cases like this, ex-mill dates are usually not updated. By pushing the shipment earlier inventory space can be freed for future orders.

5 DEVELOPING PERFORMANCE MEASURE FOR TIME BETWEEN PRODUCTION AND DUE DATES

In this chapter causality of time between production and due dates to inventory levels is clarified, factors which effect on development of it is analyzed, and a performance measure for measuring time between production and due dates is developed. Also, reference values are determined for the performance measure, and benefits and problems regarding historical data analysis as well as future forecasting are presented.

5.1 Causality of time between production and due dates to inventory level development

Inventory effect (*IE*) can be defined as amount of increasement in inventory levels compared to optimal production timing where lots are not held in inventory for excess time. Optimal production timing is not possible for longer periods of time because of the cyclicality of the production. Inventory effect of producing orders earlier than the due date can be visualized with diagram which has time as x-axis and inventory level as y-axis. Orders stay in the inventory until shipped to the customer. Once the order is shipped, its effect to inventory levels is diminished instantly to zero. Diagram visualizing inventory effect is presented in figure 21.

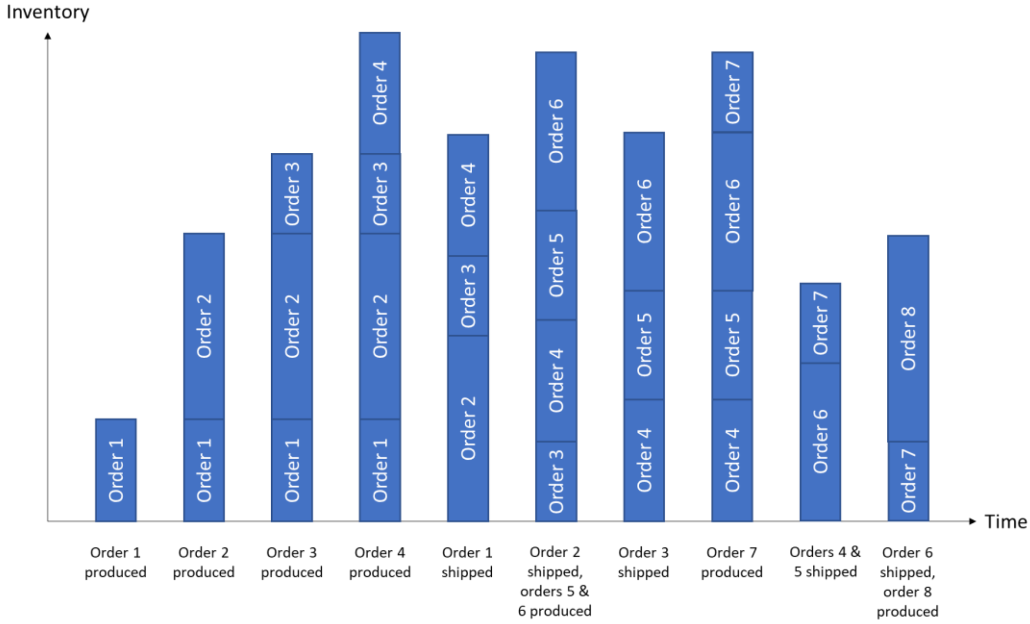

Figure 21. Inventory effect of orders produced early.

To visualize effect of time between production and due dates to inventory levels data presented in figure 21 is slightly modified. In figure 22 the production dates and production volumes are identical with figure 21, but due dates when the order is shipped are advanced by two days.

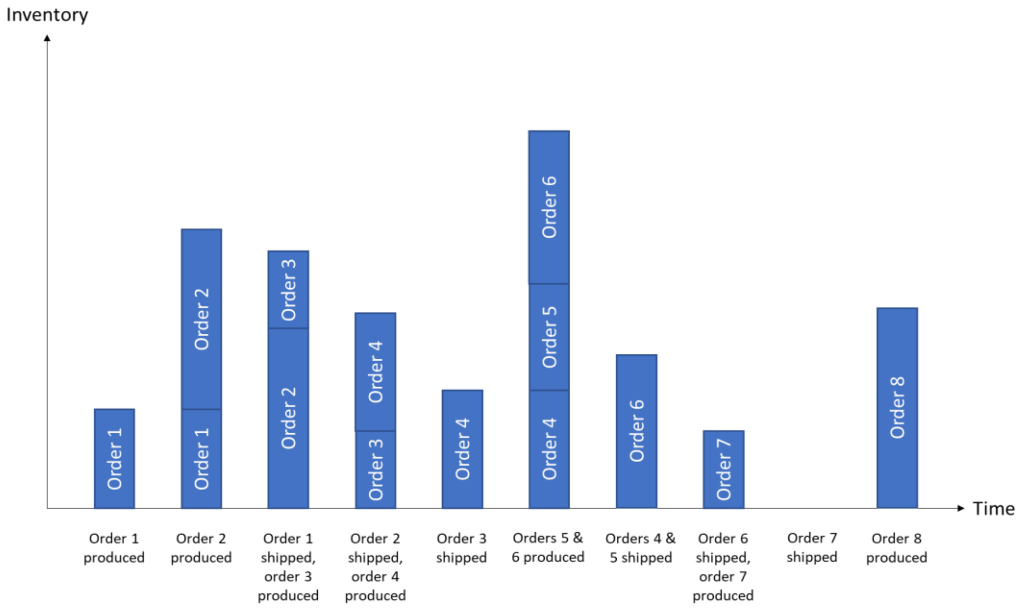

Figure 22. Change in inventory effect when time between production and due dates is reduced by 2 days.

As seen in the figures 21 and 22, the time between production and due dates has significant impact on the inventory levels, suggesting causal relation between them. This argument is further established in chapter 5.3.

To measure time between production and due dates and to estimate inventory effect caused by it several formulas needs to be defined. Interpretation of the values formulas provide is further discussed in chapter 5.4, where reference values are defined for the performance measure. Time between production and due dates (*TBPD*) for single order can be calculated with formula (1).

$$TBPD_x = DD_x - PD_x \tag{1}$$

$TBPD_x$	Time between production and due dates for order *x*
DD_x	Due date of order *x*
PD_x	Production date for order *x*

With formula (1) *TBPD* can be calculated for every order if due date and production date is known. However, to generalize it for selected period (e.g. single production cycle) is not as simple, as the orders have a varying range of *TBPD*. One way of estimating overall *TBPD* of selected period is to use average value of all orders within the selected period. Calculating average time between production and due dates (*aTBPD*) for selected period can be done with formula (2).

$$aTBPD_t = \frac{\sum_{x=1}^{a}(TBPD_x)}{a} \tag{2}$$

$aTBPD_t$	Average time between production and due dates for period *t*
$TBPD_x$	Time between production and due dates for order *x*
a	Amount of orders within the period t

Using average to estimate overall time between production and due dates in a performance measure has advantages and disadvantages. It is practical and reliable, because it is easy to use, understand and provides same results from the data set, but its validity is highly dependent on possible data errors in the data set. For example, orders with invalid ex-mill date might impact the average value significantly. Data errors and critical variables are further discussed in the chapters 6.2, 6.3 and 6.4. As a result of possible validity issues using median for set period might be better choice. Median time between production and due dates (*mTBPD*) for selected period can be calculated with formula (3), when data set is sorted ascending by *TBPD*. *TBPD* of order *m* is used as median value when order *m* is the order being produced when half of the total run tons have been produced.

$$mTBPD_t = TBPD_m \text{ when } \frac{\sum_{x=1}^{m}(R_x)}{\sum_{x=1}^{a}(R_x)} \geq 0.5 \qquad (3)$$

$mTBPD_t$	Median time between production and due dates for period *t*
$TBPD_m$	Time between production and due dates for order *m*
m	Running number of the order at the midpoint of the run tons
a	Amount of orders within period *t*
R_x	Run tons of order *x*

As seen in the figures 21 and 22, inventory effect of timing of the production for set period can be presented as inventory level over time. Inventory effect can be estimated using time between production and due dates and estimated daily production volume. As a *TBPD* either $aTBPD_t$ or $mTBPD_t$ presented in formulas (2) and (3) can be used. Estimated daily volume for each Imatra Mills production machine is presented in table 1. Inventory effect for period *t* can be estimated with formula (4).

$$IE_t = TBPD_t \times EDV \qquad (4)$$

IE_t	Inventory effect for period t
$TBPD_t$	Estimated time between production and due dates during period *t*
EDV	Estimated daily volume

5.2 Factors of development of time between production and due dates

Development of time between production and due dates is caused by several factors, such as imbalance of demand and supply, production planning policies, production efficiency, and transportation schedule. Imbalance of demand and supply is the most common reason for development of time between production and due dates: when order inflow is higher than available supply, not all orders can be produced in-time and overall time between production and due dates will decrease over time. On the flipside, when there is more available supply than demand, some orders will be produced in advance to keep production machine utilization high and overall time between production and due dates will increase over time.

Production planning policies can be described as rules, which dictate how production is sequenced and planned. These include how cycle plans are created, orders trimmed, and production runs sequenced. Production cycle length determines how much capacity is available for specific products. Production is sequenced by due dates, so increasing capacity in specific production cycle will increase the overall time between production and due dates of that production cycle, because more orders with due dates further in the future will be taken in. As a side effect, it also decreases the overall time between production and due dates of every following cycle, because those cycles will start later. In the figure 23, this effect of production cycle length on time between production and due dates is visualized. Grey rectangles represent production cycles and numbers inside the rectangles represent due dates of orders produced on that day. Below each production cycle average time between production and due dates is calculated. The two cycle plans presented in the figure are otherwise equal, but in the cycle plan below first production cycle for product 1 is extended by two days, resulting in removal of second production cycle of product 1, as all the orders in that cycle will be produced in the first one.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14
Product 1	4	5							13	14				
Product 2	3 days		5	7					4 days		14	15		
Product 3			2.5 days		8	9					3 days		18	18
Product 4					3 days		9	9					4.5 days	
							1.5 days							

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14
Product 1	4	5	13	14										
Product 2		6.5 days			5	7					14	15		
Product 3					0.5 days		8	9			3 days		18	18
Product 4							1 day		9	9			4.5 days	
									-0.5 days					

Figure 23. Effect of production cycle length on time between production and due dates.

Production cycles are sometimes lengthened for production reasons. For example, if coating unit is not functioning properly and coated products cannot be produced, it is more efficient to produce uncoated products until the coating unit is fixed than stop the production completely. In cases like this, daily production volumes can be normal, but overall time between production and due dates of the machine decreases every day because production is not following the original production schedule. At the same time, products which are being produced will stay in the inventory for extended period, which will result in increased inventory levels.

Production efficiency and trimming also influence development of time between production and due dates. If production is more efficient than estimated, more orders will be produced in same amount of time resulting in excessive supply and increasing overall time between production and due dates over time. On the other hand, if production issues occur and production is less efficient than estimated, there will be less available supply and overall time between production and due dates will decrease over time. Trimming influences development of time between production and due dates when trim help is needed: in cases like this, some orders will be produced in advance as trim help resulting in increased inventory levels until these trim help orders are shipped.

Cycle frequency effect on time between production and due dates as well. If the cycle frequency is high, then production can be done closer to the due date as there are more cycles available for each product. On the other hand, when cycle frequency is low the time between production and due dates will get higher by nature as orders placed in the cycle are more spread out to the future. Example of this is presented in figure 24.

Figure 24. Effect of cycle frequency on time between production and due dates.

Time between production and due dates describes how long the orders need to wait in the inventory for transportation. As transportation schedule determines how often orders can be shipped, it will directly influence the development of time between production and due dates. Higher shipping interval will allow shipping orders closer to their actual needs, which will lower the time orders have to wait in inventory. Also, if more shipments will be made, on average order ex-mills are split more evenly and overall time between production and due dates will decrease.

5.3 Performance measure for time between production and due dates

During development of the performance measure factors stated in chapter 3.4 regarding development of comprehensive performance measures are taken into consideration. One of the goals of this paper is to develop a performance measure for measuring time between production and due dates. Time between production and due dates is measured instead of inventory effect caused by it, because it is more practical and provides more valuable information. Measuring inventory effect instead would have several issues, like varying production speeds between different products, how average production speed tends to be higher for longer cycles, and how the wait time in inventory is reliant on next machine phases in longer machine chains. Also, measuring time between production and due dates can be used for several other purposes on top of estimating inventory buildup and composition, such as supply and demand balancing decisions, detecting possible issues in current production planning policies, estimating future development of time between production and due dates, and reacting to future development if production machine limitations and current order flow allows it. Detecting possible issues in production planning policies using historical data is further discussed in chapter 5.5 and reacting to future development of time between production and due dates is further discussed in chapter 5.6.

The performance measuring is done using data reports from Fenix ERP and making the calculations in Microsoft Excel with Visual Basic for Applications (VBA) macro. However, it is possible to add features in Fenix ERP and the calculations could be merged in the Fenix data report later. This merged data set could then be exported to Microsoft Azure and be visualized with Microsoft Power BI or other similar solutions, but in this research the measuring is only done with Microsoft Excel.

The required data for the performance measure already exists in Fenix Master Data, it just needs to be modified to provide needed information. The data report used as data set, “Prod. Lots by Product Cycle”, is taken from Fenix RPP reports. The report criteria specify machine phase, period, grouping, sorting level and report contents. The settings used in the study is using one-year time span with all report contents selected and grouping product cycles with runs. Settings used is presented in figure 25.

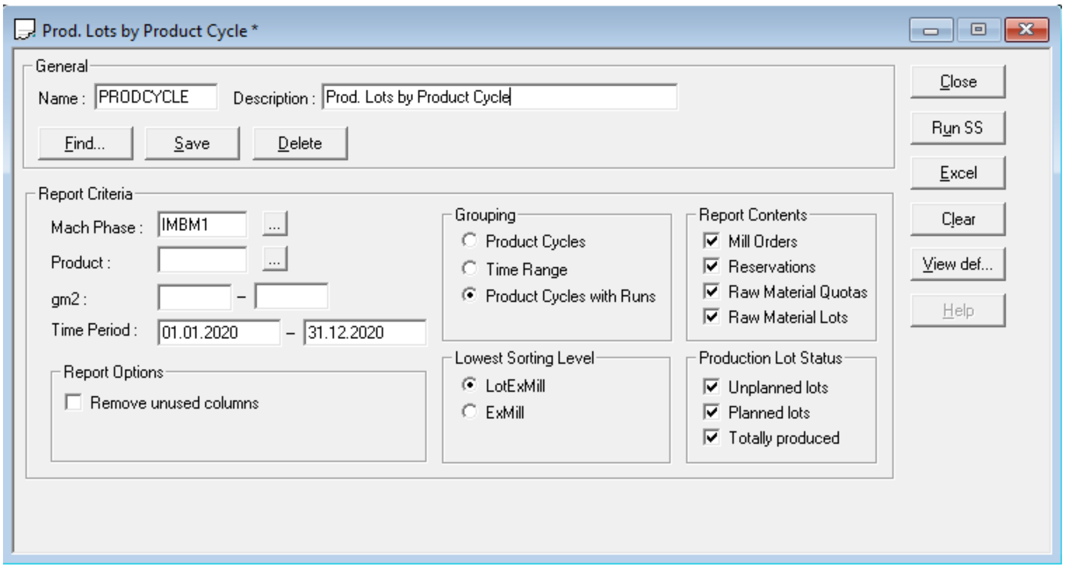

Figure 25. Settings used for obtaining data set.

Data presented in the report is defined in Fenix RPP basic data column definitions. Because the column definitions are part of Basic Data System, it means changing the settings will be universal for every user. Changing the settings could interfere with other users using the same report, thereby the column settings are left default and the data must be modified manually before running the Excel VBA-macro. The column definitions are different for each machine phase, so users must make sure to get the required data out. After running the report, columns need to be sorted in correct order to enable using the macro and excessive columns should be deleted. The required order is the same than the order columns are listed in figure 26, where data required in the data set is presented.

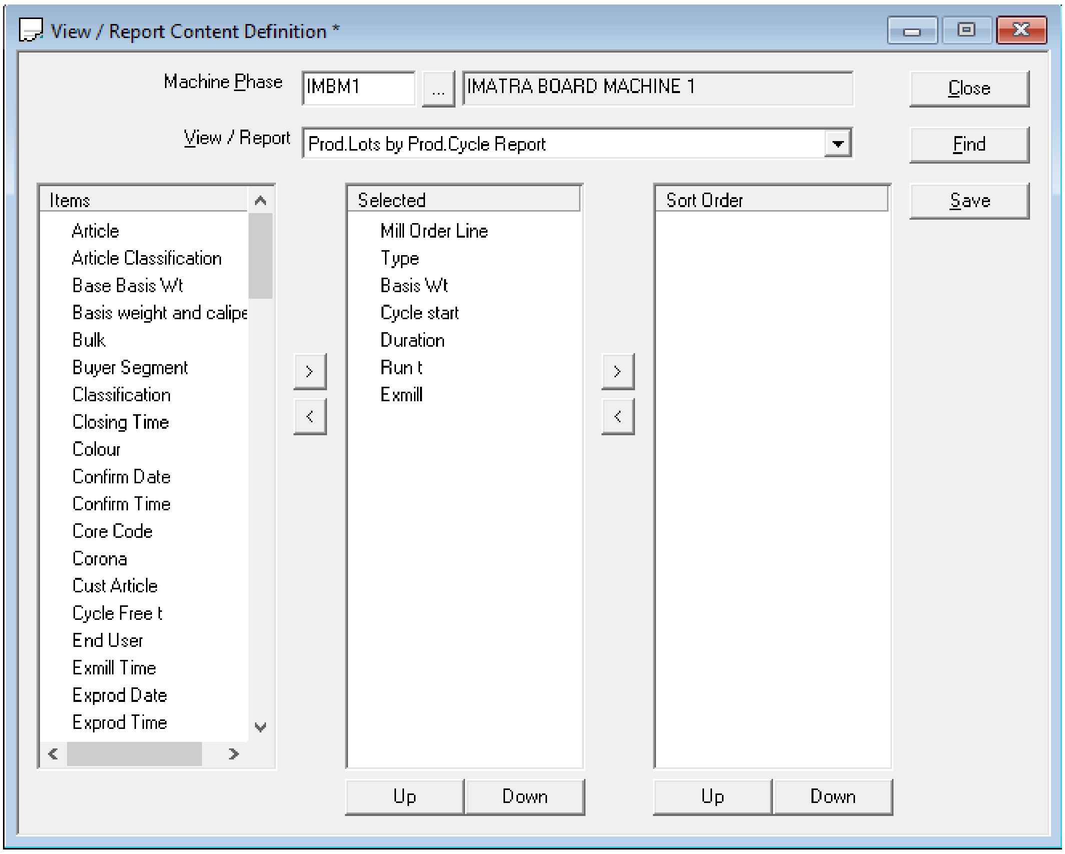

Figure 26. Data required for the performance measure.

In the performance measuring process several Excel-functions will be used to calculate necessary data. First, the data set needs to be sorted ascending by ex-mills, basis weight and cycle start dates. Then, cumulative run tons and cumulative run tons in percentage needs to be calculated to determine which orders' time between production and due dates represents the median value presented in formula (3). Cumulative run tons in percentage will also be used for estimating the production date. An estimate will be used for production date, because during the development process "ex prod" dates representing production date available in Fenix Master Data were observed more inaccurate than estimated production dates. Production related critical variables are further discussed in chapter 6.4. Production date can be approximated by calculating which orders can be produced during which day of the production cycle. The production cycle start date is used as a baseline and then the total tons produced in the cycle are split between each production day using rounded production cycle length. After the first split of the cumulative tons is full, a day is added to the estimated production date. This process is repeated until every order in the cycle has an estimated production date. After the production date is estimated, time between production and due dates can be calculated for every order in the data set by calculating days between ex-mill date and production date. Once these modifications are done, data set is ready to be analyzed and visualized. Before creating graphical presentation of the data set, simple error check is used to remove values above set threshold from the data set. This threshold was set to 100 days, as having median value of 100 days in advance should never happen. Functions used to modify the data set and logic behind calculations are presented in appendix 2.

In the developed performance measure median of time between production and due dates is used to counter possibility of inaccurate ex-mills of fill runs and stock lots. Other statistical methods are also considered in chapter 6.1, which presents different variations of the performance measure. Median values are calculated for each day. Finding median values for time between production and due dates is done using formula (3) by checking which order is in production at the midpoint of the day and then using the time between production and due dates of that order as median value. After the median values are calculated, graphical chart of development of time between production and due dates is created. In the chart daily median values are used as a data set and trend generalization for whole production machine is done using rolling average of 14 days. Graphical presentation of development of time between production and due dates is presented in figure 27. As seen in the figure 27, the calculations can be done for both historical data and future data, as the data set used also includes orders placed in the upcoming production cycles. Benefits and problems of using the performance measure for analyzing historical data is presented in chapter 5.5 and for future data in chapter 5.6.

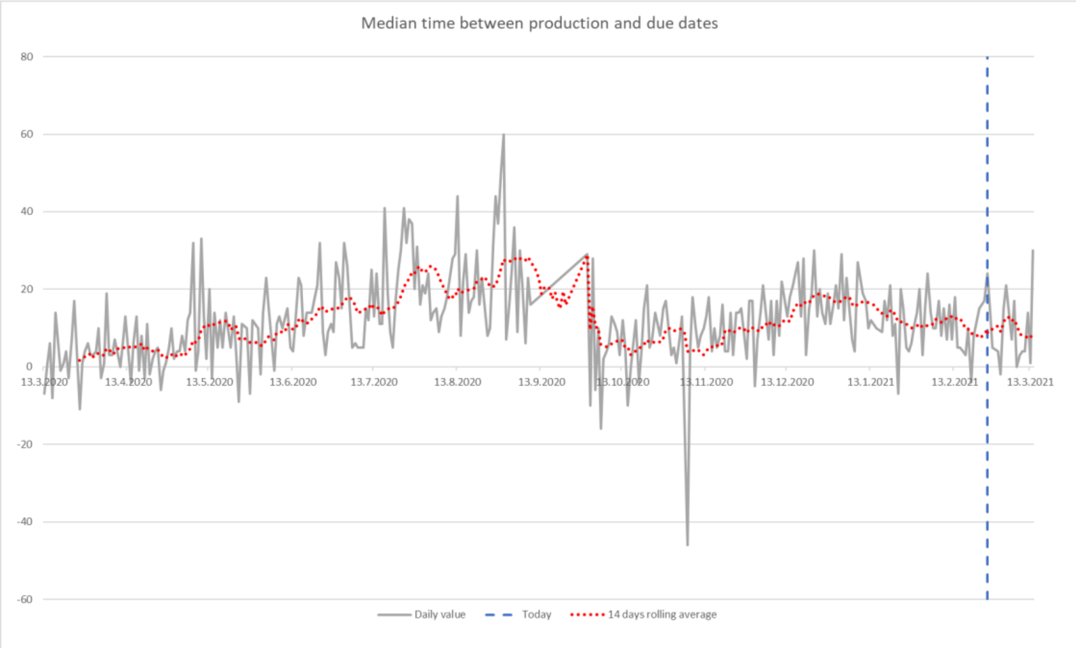

Figure 27. Development of median time between production and due dates for IMBM1.

To authenticate causality of time between production and due dates to inventory levels couple data points can be reviewed. Examples which are reviewed were decided based on observation of time between production and due dates during the past year. Different cases were chosen to analyze how the causality appears in different situations. First case is IMBM1 in August 2020. The order book has been diminishing during the summer and is around 16 to 17 days at the start of the month. A lot of free capacity is available for new orders and there is no urgency. Market curtailments are already planned to balance the situation. The development of volumes which have ex-mill date in the future have had ascending trend during the past few months as seen in figure 19. As seen in the figure 27, the time between production and due dates has also risen rapidly during the summer and is averaging between 20 and 25 days. Planned market curtailments temporarily decrease the overall time between production and due dates, seen in the figure 27 as small dips, but the overall trend is ascending.

Second case analyzed for IMBM1 is from November 2020. There is no urgency, but order book has developed to around 35 days at the start of the month and no market curtailments are required. Stock trend of volumes which have ex-mill date in the future has stabilized around 6000 tons after the rapid decrease during scheduled autumn maintenance stop. As seen in the figure 27, the time between production and due dates has also been quite stable between 8 to 10 days, which is within the normal reference values. Comparing development of time between production and due dates and stock trend for volumes which have ex-mill date in the future we can further solidify that causal relation exists between them.

5.4 Defining reference values for the performance measure

Reference values are used to interpret the data provided by the developed performance measure. Control policies can be developed based on reference values where these values are used as triggers for corrective actions. For example, if production is occurring too early and inventory levels rising rapidly, market curtailments can be planned to balance the situation if there is not sufficient demand. If demand is high but production is early due strong production volumes, extra volumes can be sold to customers to balance the situation. However, there are often multiple underlying causes behind the development of time between production and due dates, thus production planner should be consulted before using the data for corrective actions.

Production is late from the due dates when the performance measure provides negative values for the time between production and due dates. In cases like this, balancing actions should be taken immediately to prevent customer dissatisfaction. If customers are flexible regarding delivery dates, order rerouting might be enough to balance the situation. Stock allocations, moving orders to other production machines or production mills as well as cycle plan changes might be needed. As the performance measure is designed to reflect overall situation of the production machine, being late from most of the due dates is critical situation.

In optimal production situation the orders are shipped as soon as they are produced. However, it is not possible due production cyclicality and unreliability. Also, being ahead in production gives flexibility for short-term changes if issues arise at the production. If the performance measure is providing values close to zero overall production is in-time, but there might be some production lots that are late. Being close to zero also means that there is no room for major production issues or any flexibility. Having at least one to two days leeway should be pursued. Thus, minimum reference value should be set at least around two.

Setting maximum reference value depends on the cycle frequency. From Imatra Mills point of view, most products are produced at least once a month. If cycles exist once a month and order due dates spread evenly between the cycles, then on average produced orders are around 15 days ahead of schedule. However, the transportation schedule might clump up the ex-mills around shipping dates as stated in chapter 4.5. If the time between production and due dates is higher than average cycle frequency, the orders are already being produced too early.

5.5 Historical data of time between production and due dates

As stated in chapter 5.3, historical data of time between production and due dates is presented in the performance measure. Historical data can be used to determine how accurately the measure was representing the overall situation of the production machine and to detect possible issues in production planning policies.

Using the historical data for reflecting how accurate the forecast provided by the performance measure helps with improving it and increasing its forecasting accuracy. After the performance measure is used for forecasting, the forecasted data is available to use in the future and comparing it to the knowledge of what happened allows estimating the effectiveness of the forecast. Also, actively reflecting the performance of the measure increases the understanding of which variables has an effect to the time between production and due dates. This understanding can then be used to pointing out possible issues in production planning policies, which effect the development of the time between production and due dates under certain circumstances. For example, if the time between production and due dates increases significantly once a month, there might be a production cycle that has too low cycle frequency. By producing that cycle twice per month, the overall level of time between production and due dates could be decreased.

The performance measure can point out mismatch between development of time between production and due dates and overall situation of the machine including order book, order flow and production efficiency. For example, time between production and due dates might be increasing at the same time order inflow is strong and order book is increasing. There can be multiple reasons behind the mismatch, such as orders being in the wrong production cycles, having too much flexibility and leeway, production efficiency not matching estimated values, trimming reasons and problematic unit widths as well as production cycle sequencing compatibility with other machine phases in the machine chains such as PE-coating production machines, rewinders and sheeting machines. There is no definitive answer for what reason the mismatch occurred, but it can be resolved with input from production planner of the machine as well as checking the orders, cycle sequencing and comparing actual production speed with estimated values. For example, if all production cycles are full and order flow is strong, but production efficiency has been above the target, the time between production and due dates might have an ascending trend even with full production cycles.

When using historical data of time between production and due dates, the potential problems with data inaccuracies noted in chapters 6.2, 6.3 and 6.4 should be considered. The communication issues between the Seitti mill system and Fenix ERP system happen when production does not follow original production plan or production speed does not match the Fenix RPP estimates. This can invalidate the data such as ex prod dates, available capacity in the production cycle, production cycle duration and production cycle start dates. For example, an order which was produced in 12th of August in 2020 at IMBM5 due to coating issues at the machine has ex prod date of 8th of August 2020. During the coating issues at the machines uncoated products were produced. These orders that were produced show ex prod dates up to one month later compared to actual production dates. Also, their production cycle start date is invalid, as the cycle was started when production issues occurred on 8th of August, but in Fenix RPP the production cycle start is shown at 6th of September. The view of Fenix RPP in problematic situations like this is shown in figure 28.

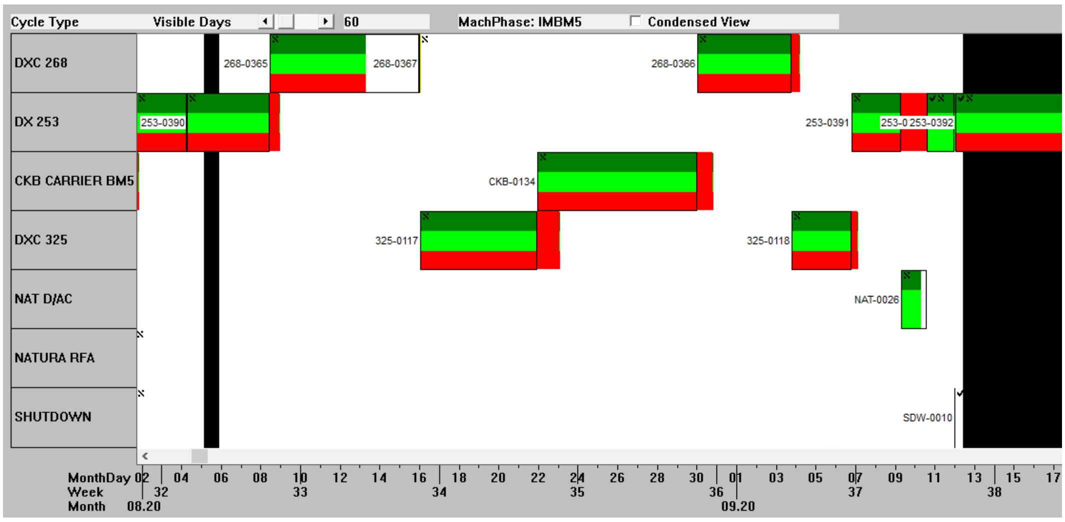

Figure 28. Fenix Rough Production Planning view where production issues happened.

The developed performance measure uses production cycle start dates for estimating actual production date. As seen in the example given above, this data can be invalid if major production issues happened, so consulting production planner should be standard procedure when analyzing historical data of unusual development of time between production and due dates. Also, historical Fenix RPP data at some production mills within Packaging Materials division is completely unreliable due to communication issues between various systems, thus the developed measure cannot be utilized in historical data analysis at production mills where this is the case. The only factual production date available in Fenix Master Data is date when unit was added to the system. However, this data is not available in the data set used for the performance measure and using it for calculating time between production and due dates requires changes to the data system.

5.6 Future forecasting with developed performance measure

Future forecasting with the developed performance measure is possible if orders are confirmed in the cycles for the forecasting period. Usually the orders should be confirmed couple weeks before production, but it varies depending on production machine and customer. Forecasting is easily added to the performance measure by simply lengthening data set taken from the Fenix RPP to the future. The performance measure works as intended even with including the future data. Forecasting the time between production and due dates with the performance measure provides information to which direction the timing of production is developing and is there room to make short-term changes in order routing, cycle length or cycle sequencing. The information provided by the performance measure can help recognizing upcoming problems as well as it can provide solutions to known problems like overbooking situations. If there is some room for changes in cycle sequencing and one cycle stands out with higher time between production and due dates, then sequencing can be changed, or cycle lengths tweaked to balance the production better. However, when planning short-term changes production planner should be consulted as planning limitations are production machine specific. Also, production planner has the latest information regarding the production machine situation. At Imatra Mills PE-coating sequencing usually dictates board machine planning, as the raw materials need to be produced before coating cycles start. To improve cycle plan synchronization of board machine and PE-machines based on forecasting not only volumes, but also other order specifications such as widths should be known. The order routing to different PE-machines is highly dependent on roll widths to achieve decent trim solutions and minimize trim loss at board machines. Also, certain changes in production cycle sequencing are not possible or cost-efficient as stated in chapter 4.2 due to increased grade change costs or lost production time.

The longer the forecasting period is, the higher margin of error raises. The margin of error is a result of using an estimated value for production speed, possibility of production issues and cycle plan or order changes. Also, if all orders are not in for the forecasting period, the performance measure will not provide accurate results. The biggest problem with forecasting is the fact that it is mostly accurate for up to two weeks in advance, but cycle plan changes at short notice are not desirable as raw materials such as pulp and chemicals for the production runs might already be prepared and transportation planned for upcoming orders. However, when using forecasting for medium- or long-term changes the forecast might not be very accurate. Thus, the time between production and due dates forecast should be used together with other forecast methods such as sales forecast to develop more accurate forecasts of the future development at the production machines.

6 CRITICAL VARIABLES IN MEASURING TIME BETWEEN PRODUCTION AND DUE DATES

In this chapter critical variables which have an impact on results provided by the developed performance measure are discussed. Factors impacting the performance measure are invalid data in the system, order handling related factors such as due dates, as well as production related factors such as production dates and cycle frequency. Also, different variations of the performance measure are presented.

6.1 Variations of the developed performance measure

The performance measure presented in chapter 5.3 assumes using ex-mill date as due date, median as statistical method for estimating time between production and due dates for selected period and estimating production dates using production cycle start dates and production volumes. However, there are multiple possible variations of the developed performance measure. Comprehensive list of possible variations of the developed performance measure is presented in table 2.

Table 2. Variations of the developed performance measure.

Production date	Estimation from cycle start date	Ex-prod date	Totally produced date	Date when unit was added
Due date	Ex-mill	Closing	Combination	
Statistical method	Daily median	Daily average	Cycle median	Cycle average
Overall approximation	Rolling average	Rolling median	No approximation	

Few possible variations for production date can be determined. “Ex prod” date is the easiest to use and available in the data set, but during the research process “ex prod” date was found not to be accurate, as stated in chapter 6.4. Totally produced date could also be used as production date, but it is reliant on production planner checking the order as produced, so it is not very reliable. The most accurate production date would be when the units were added to the system, but currently it is not available in the data set and it would require changes to the system. However, if the performance measure is found successful, the unit date could be used as a variant in the future if changes to the system are made.

Using closing date as a due date instead of ex-mill could eliminate effects of invalid production lots and false lot ex-mill dates presented in chapters 6.2 and 6.3. Using closing date as a due date comes with drawbacks as well – it does not consider orders that will be delivered by trucks, or raw material orders which are due to the next stage of the machine chain. For simplicity, the developed performance measure uses ex-mill dates only as due dates, even though closing dates could be integrated to the performance measure by using closing date as due date if available, else use the ex-mill date. This solution could be the most accurate representation of time between production and due dates for the production machine, but the reliability and reproducibility might suffer as bookings are not always done at the time of confirming the order.

Multiple different statistical methods can be used in analyzing the data set taken from the Fenix ERP system. Using average is very common in estimates, but median was chosen method for the performance measure to lessen the effects of invalid production lots presented in chapter 6.2 and false lot ex-mill dates which might not represent the actual due date. Also, minimum quintile or maximum quintile could be used to present situation of urgent orders or non-urgent orders. Data for any quantile is easily added to the performance measure by simply replacing the 50 % breakpoint value used for finding the median. For example, for presenting the minimum quintile the breakpoint would be set at 20 %. The Excel-function used for finding the median value is presented in appendix 2. The values were also calculated on daily basis instead of cycle basis, because cycle lengths vary a lot and using daily values allows for more accurate graphical presentation of the time between production and due dates.

Overall approximation for the machine can be done with rolling average or rolling median. Rolling average is used in the developed performance measure for practicality reasons: it is easy to implement and understand. Testing the performance measure with rolling medians provided very similar results to rolling average. This happens because most of the invalid lots are already diminished from the data set with daily medians and the error check implemented to the graphical presentation removes biggest false data points from the chart. Also, one option would be removing overall approximation completely.

6.2 Invalid production lots

Invalid production lots in the system may have an impact on the results provided by the performance measure and they might make the measurement unreliable and thus not usable. Invalid production lots in the context of this research are lots which do not represent the overall situation of the production machine. These lots might be fill runs to fill underproduced orders, side runs as trim help, or stock lots. Removing invalid production lots completely and the effects of it is not possible, but the effect on overall results the performance measure provides can be diminished. In addition, understanding why the measure might provide certain numbers in certain cases helps to interpret the reasons behind the values provided by the performance measure. To diminish effects of fill runs, median values can be used.

When stock lots are created in the systems, the ex-mill dates are automatically set couple days from the estimated production. This does not reflect the actual need, as these lots are usually only produced as trim help or as raw material for PE-coating or sheeting. Stock lots might also have ex-mill dates set to last day of the year, which was noticed observing the data set for different production machines. When there are lots of stock lots in the production run with ex-mills in next few days, it will decrease the overall time between production and due dates, even though the production is not necessarily urgent. The effect can be diminished by using median as estimate, but it doesn’t remove the effect completely. The effect can be removed completely by manually removing all stock lots from the data set before using the developed VBA-macro.

6.3 Order handling related critical variables

Order handling is one major process effecting the results of the developed performance measure. Ex-mill dates have great impact on the results of the measurement, as it sets due dates for orders. False ex-mill dates which do not represent the actual need of the orders invalidates the data. Ex-mill dates should be determined by customer requested date of arrival, lead time, and shipping line schedules to represent the actual date by when the order should be produced. If customer requests change in date of arrival and the shipping line booking of the order is changed, then the ex-mill date should be updated as well.

Mismatch of ex-mill dates happen when setting ex-mill date is dictated by production dates. In cases like this, ex-mill date is usually set right after the production cycle end time, even if the actual due date would be later. This might happen in cases when the booking for shipment is done later, and some ex-mill date is just given for the order to confirm it in the production. However, the ex-mill date should be updated to meet the actual need when the transportation is booked for the order. Also, if production cycle is long and the setting which does not allow confirming orders with ex-mill during the production cycle is on, then the ex-mill dates might be a bit inaccurate and some orders could be shipped even during the production run. This inaccuracy can be reduced by splitting long production cycles into two shorter ones in the system allowing to confirm urgent orders in the first part of the cycle.

Product lead time influences ex-mill dates on longer machine chains. Product lead time in this context means time required between different machine phases on longer machine chains, first introduced in chapter 4.3. It is defined in Fenix BDS for each product and used when determining ex-mills of raw material production lots. When checking an order into the system Fenix Order Handling determines the ex-mill of raw material lots based on product lead time. The importance of product lead time on the results provided by the performance measure depends how significant share of the orders have multi-phase production. The product lead time should be determined for each product as accurately as possible by analyzing how much time is required between different machines.

6.4 Production related critical variables

Production related factors, such as production dates, cycle frequency and cycle length as well estimated daily volumes are all important variables for the performance measure. Production lot sequencing should mainly follow due dates to allow the values provided by the performance measure represent overall production situation accurately. Also, communication accuracy between various systems like the mill system and Fenix ERP system must be taken in consideration, as there are certain inconsistencies existing between the systems.

Production dates might be a bit inconsistent if using Fenix “ex prod” date or “totally produced” date as production date. Ex prod date is determined from Fenix RPP cycles and how the order is positioned within the cycle, but these RPP cycles might not be completely accurate if production does not follow predetermined production sequencing or if the actual production speed varies from daily estimate. This mismatch between Seitti mill system production cycles and Fenix RPP production cycles is quite common occurrence. Totally produced date is set for an order when the order is flagged as totally produced by production planner. If the order was produced on weekend, most of the time it will be flagged earliest by Monday when the production planner is back at work. In the performance measure production date is estimated using production cycle start date. However, the production cycle start date can also be misleading if some cycles are skipped in production due to production issues and cycle plan is not updated. In cases like this, the cycle start date is when it was originally planned, even if the cycle was taken in production before that date. Also, when production cycle is over maintenance stop, the cycle length is abnormal and production date estimates are inaccurate. This is not an issue with one-day standstills but during longer standstills the production date estimates are invalidated, and the graph produced by the performance measure might look weird. To counter this, Fenix “shutdown”-cycle or empty frozen cycle could be used during maintenance stops and standstills. However, this only works for future data, as empty cycle length is set to zero in the historical data. The only accurate production date available in the system is unit date, which represents when the unit was added to the system. However, it is not available in the data set used currently and cannot be utilized in the performance measure.

Cycle lengths and cycle frequency both effect the time between production and due dates directly and cycle frequency also determines reference values for the performance measure. When creating cycle plans, cycle lengths are decided based on demand forecast to allocate enough capacity for each product. Cycle plan is usually created for several months at a time, so the cycle lengths are subject to change if demand does not match the forecast. Cycles might also move for production reasons if there are issues in production or production speed does not match the estimates. For this reason, forecast data of the performance measure might change if the cycles are changed.

Cycle frequency does not vary as much as cycle plan and cycle lengths, because most of the production cycles have certain frequency based on demand and optimal cycle rotation. Cycle frequency effects the reference values of the performance measure as it determines how often certain products can be produced. Also, increasing cycle frequency reduces overall time between production and due dates as orders can be produced closer to the due dates. However, increasing cycle frequency also increases grade change costs and can influence overall utilization of the production machine, as issues at production most often happen at grade changes.

Estimated daily volumes are used to estimate the inventory effect caused by the time between production and due dates, and Fenix RPP uses estimated volumes for calculating available capacity and production times for cycles and orders. Actual daily production volume is highly dependent on which product is being produced, as with certain products production speed is significantly higher. Because estimated daily volumes effect the data in the data set such as cycle start dates and duration, it influences the values provided by the developed performance measure.

7 SUMMARY & CONCLUSIONS

In this chapter the results of the study are summarized, and areas for further actions and research discussed. This chapter also answers the research questions presented in the introduction.

7.1 Summary of the results & answering research questions

Three research questions were set for this research:

1. *How does the time between production and due dates effect on inventory levels in board industry?*

The causality of time between production and due dates to inventory levels can be presented using formula, where inventory effect caused by timing of the production is calculated by multiplying time between production and due dates with estimated daily volume. This formula is approximation of the inventory effect, as it is based on estimated daily volumes and the value used for time between production and due dates is approximation for the production machine. Time between production and due dates is approximated for single production machine using daily median values as data points and 14 days rolling average as generalization of the trend.

Inventory effect can be visualized with area of inventory-time chart, where single rectangles present order volumes. These rectangles are added to the chart on the day they are produced and removed when they are shipped. Area of the chart presents the overall inventory effect caused by timing of the production. Example of this is presented in figures 21 and 22. Causality of time between production and due dates to inventory level development can also be observed and solidified by comparing graphs of development of volumes produced in advance and development of time between production and due dates, presented in figures 19 and 26.

2. *Which factors influence the development of time between production and due dates?*

There are multiple factors influencing the development of time between production and due dates, including imbalance of demand and supply, production planning policies, production efficiency, and transportation schedule. Imbalance of demand and supply will rapidly influence the development of time between production and due dates: if order inflow is higher than available supply, not all orders will be produced in time and the time between production and due dates will start decreasing. On the other hand, if order inflow weakens, orders will be produced in advance to keep the machine utilization high. This will result in increase of time between production and due dates.

Production planning policies effect the development of time between production and due dates as changes in the cycle plan directly effects the timing of the production. Increasing cycle frequency will lower the overall time between production and due dates, as orders can be produced closer to their due dates. Extending production in a single production cycle will cause increase in time between production and due dates for orders in that cycle, but overall situation of timing of production for the production machine will decrease, as all other production cycles will be started later than planned in the original cycle plan. The effect is nullified over time as the orders that were produced in advance are shipped. Also, other changes in the cycle plan will affect the time between production and due dates, as the cycle plan determines production dates for all orders.

Production efficiency directly effects on the development of time between production and due dates as being more efficient in production allows extra orders to be produced in the same time frame, which increases overall time between production and due dates. On the flipside, production issues or slower than estimated production speed will result in decrease of time between production and due dates.

Transportation schedule effects the development of time between production and due dates, as it determines how often orders can be shipped: order due dates tend to accumulate before the shipping date. If shipping intervals are sparse, orders will have to wait for transportation in the inventory for excessive amount of time. Increasing shipping interval allows shipments closer to the actual customer need, thus reducing the time orders need to wait for transportation in the inventory.

3. *How to measure the time between production and due dates and which variables are critical for measuring it?*

Time between production and due dates can be measured using data report available in the target company's ERP system. The data report can be modified in Microsoft Excel to estimate production dates and to calculate *TBPD* for each order. Daily values for *TBPD* are estimated using medians and overall development for whole production machine is approximated using 14 days rolling average of daily values.

Critical variables for measuring time between production and due dates are order handling and production related variables as well as invalid production lots. Order handling sets due dates for orders. If the order due dates are invalid or not updated when changes in customer need or shipment dates happens, the performance measure will provide inaccurate results. Also determining ex-mill dates for raw material lots based on product lead time defined in Fenix BDS should be accurate. As a variation of the performance measure closing date can be used as due date or a combination of ex-mill and closing date.

Production related factors such as production dates, cycle lengths and cycle frequency as well as daily production volumes are critical variables for the performance measure. Production dates are used in calculating *TBPD*, cycle lengths and cycle frequency both effect the development of time between production and due dates, and daily production volumes is used to estimate inventory effect caused by time between production and due dates. As production date there are multiple possible choices, such as ex prod date, totally produced date, unit date and estimation of production date based on cycle start date. In the developed performance measure estimation of production date is used, as it was observed to be the most accurate way of presenting production date. Unit date would be more accurate, but it is not available in the data report used. Ex prod dates are based on Fenix RPP data, which might not be accurate because of communication issues between the Seitti mill system and Fenix ERP system. Totally produced date is marked when production planner checks the order as produced, thus it is not reliable way of presenting production date.

Invalid production lots in the context of this research are production lots which do not represent overall situation of the machine, such as fill runs, side runs as trim help and stock lots. These lots effect the performance measure values, but their effect can be diminished by using median values or by removing the lots from the data set before running the macro.

7.2 Further actions & discussion of the results

Further actions regarding results of this research are implementing and using the developed performance measure in the target company. If the performance measure is found successful, the measuring process can be implemented in the ERP system, combined with other relevant data in cloud services and visualized automatically using services like Microsoft Power BI. Also, the performance measure can be enhanced to be more accurate if changes in the data system are made and unit date can be used in the calculations. This also allows implementation of the performance measure to production mills, where Fenix RPP data is not accurate and does not provide reliable information. In addition, multiple variations were discovered during the performance measure development process and presented as a part of this research. Analyzing the most accurate and practical variation of the performance measure is suggested as a subject of further development.

This research contributed to the existing research of production and inventory management and performance measuring systems and provided new insights in the perspective of board industry. Production and inventory management as well as performance measuring systems are widely researched topics, but in the scope of board industry and its industry-specific problems not as much research has been done. The results suggest causal relation of time between production and due dates to inventory levels, but further research regarding the topic is needed to solidify the findings. This causal relation is significant finding for board industry management, as most of the working capital in the board industry is tied to inventory. Understanding the reasons behind inventory development and actively measuring development of production timing allows supply and demand balancing process to be more accurate. Balancing process in board industry is crucial, as mismatch of demand and supply can lead to lost sales, obsolete inventory and holding costs caused by inventory buildup, resulting to lower profits.

REFERENCES

Amaratunga, D. & Baldry, D. 2002. Moving from performance measurement to performance management. *Facilities.* Vol. 20, Issue 5/6, pp. 217-223.

Beemsterboer, B., Land, M. & Teunter, R. 2017. Flexible lot sizing in hybrid make-to-order/make-to-stock production planning. *European Journal of Operational Research.* Vol. 260, Issue 3, pp. 1014-1023.

Berends, P.A.J. & Romme, A.G.L. 2001. Cyclicality of capital-intensive industries: a system dynamics simulation study of the paper industry. *Omega (Oxford).* Vol. 29, Issue 6, pp. 543-552.

Berk, J. & DeMarzo, P. 2014. *Corporate finance.* 3rd edition. Harlow: Pearson. 1104 pages.

Bourne, M., Mills, J., Wilcox, M., Neely, A. & Platts, K. 2000. Designing, implementing and updating performance measurement systems. *International Journal of Operations & Production Management.* Vol. 20, Issue 7, pp. 754-771.

Briskorn, D., Zeise, P. & Packowski, J. 2016. Quasi-fixed cyclic production schemes for multiple products with stochastic demand. *European Journal of Operational Research.* Vol. 252, Issue 1, pp. 156-169.

Chauan, S.S., Martel, A. & D’Amour, S. 2006. Roll assortment optimization in a paper mill: An integer programming approach. *Computers & Operations Research.* Vol. 35, Issue 2, pp. 614-627.

Cherri, A.C., Arenales, M.N., Yanasse, H.H., Poldi, K.C. & Vianna, A.C.G. 2014. The one-dimensional cutting stock problem with usable leftovers – A survey. *European Journal of Operational Research.* Vol. 236, Issue 2, pp. 395-402.

Choo, C.W. 2002. *Information Management for the Intelligent Organization: The Art of Scanning the Environment*. 3rd edition. Medford, New Jersey: Information Today, Inc. 325 pages.

Fogarty, D., Blackstone J., & Hoffmann, T. 1991. *Production & Inventory Management*. 2nd edition. Cincinnati: South-Western Publishing. 870 pages.

Grimson, J.A. & Pyke, D.F. 2007. Sales and operations planning: an exploratory study and framework. *The International Journal of Logistics Management.* Vol. 18, Issue 3, pp. 322-346.

Hulthén, H, Näslund, D. & Norrman, A. 2016. Framework for measuring performance of the sales and operations planning process. *International Journal of Physical Distribution & Logistics Management.* Vol. 46, Issue 9, pp. 809-835.

Muter, İ & Sezer, Z. 2018. Algorithms for the one-dimensional two-stage cutting stock problem. *European Journal of Operational Research.* Vol. 271, Issue 1, pp. 20-32.

Noroozi, S. & Wikner, J. 2017. Sales and operations planning in the process industry: A literature review. *International Journal of Production Economics.* Vol. 188, Issue 1, pp. 139-155.

Keskinocak, P., Wu, F., Goodwin, R., Murthy, S., Akkiraju, R., Kumaran, S. & Derebail, A. 2002. Scheduling Solutions for the Paper Industry. *Operations Research.* Vol. 50, Issue 2, pp. 249-259.

Lapide, L. 2004. Sales and Operations Planning Part I: The Process. *The Journal of Business Forecasting Methods & Systems.* Vol 23, Issue 3, pp. 17-19.

Lehtonen, J-M. & Holmström, J. 1998. Is just-in-time applicable in paper industry logistics? *Supply Chain Management: An International Journal*. Vol. 3, Issue 1, pp. 21-32.

Lönnqvist, A. 2004. *Measurement of Intangible Success Factors: Case Studies on the Design, Implementation and Use of Measures.* Department of Industrial Engineering and Management. Tampere University of Technology, Tampere, Finland.

Mallik, S. 2010. Customer Service in Supply Chain Management. In: B. Hossein ed., *The Handbook of Technology Management: Supply Chain Management, Marketing and Advertising, and Global Management. Volume 2*. 1st edition. Hoboken, New Jersey: John Wiley & Sons.

Olhager, J. 2003. Strategic positioning of the order penetration point. *International Journal of Production Economics.* Vol. 85, Issue 3, pp. 319-329.

Pekkola, S. & Rantanen, H. 2014. Utilization of performance measurement information in management: top manager perspective. *International Journal of Business Performance Management.* Vol. 15, Issue 1, pp. 23-34.

Sox, C.R., Jackson, P.L., Bowman, A. & Muckstadt, J.A. 1999. A review of the stochastic lot scheduling problem. *International Journal of Production Economics.* Vol. 62, Issue 3, pp. 181-200.

Stora Enso. 2020. *Stora Enso official webpage*. [online] Available at: https://www.storaenso.com/ [Accessed 20 Dec 2020]

Thomé, A.M.T., Scavarda, L.F., Fernandez, N.S. & Scavarda, A.J. 2012a. Sales and operations planning: A research synthesis. *International Journal of Production Economics.* Vol. 138, Issue 1, pp. 1-13.

Thomé, A.M.T., Scavarda, L.F., Fernandez, N.S. & Scavarda, A.J. 2012b. Sales and operations planning and the firm performance. *International Journal of Productivity and Performance Management.* Vol. 61, Issue 4, pp. 359-381.

Tomat, L. & Gradišar, M. 2017. One-dimensional stock cutting: optimization of usable leftovers in consecutive orders. *Central European Journal of Operations Research.* Vol. 25, Issue 25, pp. 473-489.

Toni, A.D. & Tonchia, S. 2001. Performance measurement systems – Models, characteristics and measures. *International Journal of Operations and Production Management.* Vol. 21, Issue 1, pp. 46-70.

Ukko, J., Tenhunen, J. & Rantanen, H. 2007. Performance measurement impacts on management and leadership: Perspectives of management and employees. *International Journal of Production Economics.* Vol. 110, Issues 1-2, pp. 39-51.

Winands, E.M.M., Adan, I.J.B.F. & van Houtum, G.J. 2011. The stochastic economic lot scheduling problem: A survey. *European Journal of Operational Research.* Vol. 210, Issue 1, pp. 1-9.

Zijm, H., Klumpp, M., Regattieri, A. & Heragu, S. 2019. *Operations, Logistics and Supply Chain Management.* 1st edition. Cham: Springer International Publishing. 734 pages.

Appendix 1. Interview questionnaire.

Interviewees:

Head of Master Planning (Packaging Materials)

Operational Planning Manager (Packaging Materials)

Demand and Operations Planning Manager (Supply Chain Imatra)

Production Planners (Supply Chain Imatra)

Supply Chain Coordinator Team Leaders (Supply Chain Imatra)

Key Accounts Team Leader (Supply Chain Imatra)

Master Planning / Operations Planning questionnaire:

How the measured data of time between production and due dates will be used? Who will be end users for the data?

Which corrective actions can be done when production is too early and inventory levels are increasing rapidly?

Can the measurement results cause questions about development of time between production and due dates?

How demand forecasts are utilized in operations planning? How often forecast is updated and does updated forecast effect cycle plans?

How are changes in inventory levels measured? What is included in the weekly reporting?

How are new features added to Fenix?

Order handling questionnaire:

Are ex-mill dates mostly accurate in the system? How often there are cases when ex-mill dates are inaccurate?

Are ex-mill dates updated if customer requests different delivery date? How are the updates done?

Are customers flexible regarding delivery dates? How is the customer ordering behavior?

How does Fenix Order Handling check-function work? How are ex-mills determined on longer machine phases?

Production planning questionnaire:

How far forward production cycles are usually determined and how often the original plan is changed? Is the production schedule flexible?

Which settings there are in Fenix Rough Production Planning?

Does the production reliability and production rates vary a lot between different products?

How are average daily production volumes determined?

Appendix 2. Logic for Excel functions used in data analysis

Calculating cumulative production tons per production cycle:

=IF(AND(R2=R1;U2=U1);W2+Y1;W2)

If “Type” and “Cycle start” are equal than cell above, sum cell above with “Run t”, else the amount is only “Run t”.

Calculating cumulative production tons in % per production cycle:

=Y2/SUMIFS($W$2:$W$7132;$R$2:$R$7132;R2;$U$2:$U$7132;U2)

Divide “Cumulative production tons” with sum of all production lots run tons within the cycle. Checks if “Type” and “Cycle start” are equal.

Rounding production cycle length to full days:

=LEFT(V2;FIND(" ";V2;1))+IF(TIME(LEFT(RIGHT(V2;FIND(" ";V2;1)+3);2);RIGHT(RIGHT(V2;FIND(" ";V2;1)+3);2);0)>=TIME(12;0;0);1;0)

Manipulates the “Duration” into days and rounds it to closest full day.

Calculating estimated production date within the cycle d:

=IFS(AA2=0;0;AA2=1;0;22/AA2<Z2;22;21/AA2<Z2;21;20/AA2<Z2;20;19/AA2<Z2;19;18/AA2<Z2;18;17/AA2<Z2;17;16/AA2<Z2;16;15/AA2<Z2;15;14/AA2<Z2;14;13/AA2<Z2;13;12/AA2<Z2;12;11/AA2<Z2;11;10/AA2<Z2;10;9/AA2<Z2;9;8/AA2<Z2;8;7/AA2<Z2;7;6/AA2<Z2;6;5/AA2<Z2;5;4/AA2<Z2;4;3/AA2<Z2;3;2/AA2<Z2;2;1/AA2<Z2;1;1/AA2>=Z2;0)

Estimates production date within the cycle in days based on cumulative run tons for up to 22 days. Divides the orders produced in the cycle for each day equally, adding gradually one day as certain threshold in “Cumulative run tons in %” is reached.

Estimated production date:

=INT(U2)+AB2

Takes date of “Cycle start” date and adds the “estimated production date within the cycle d” in it to estimate production date.

Calculating time between production and due dates for each order:

=DAYS(X2;AC2)

Calculates days between “estimated production date” and “ex-mill” date.

Calculating daily median time between production and due date:

=IF(AND(SUMIF($AC$2:AC2;AC2;$W$2:W2)/SUMIF($AC$2:$AC$7203;AC2;$W$2:$W$7203)>=0,5;SUMIF($AC1:AC$2;AC1;$W1:W$2)/SUMIF($AC$2:$AC$7203;AC2;$W$2:$W$7203)<0,5);AD2;"")

Finds median of “time between production and due date” for each “estimated production date” using cumulative “Run t”. Median value is the value of order, that was in the production when 50 % of the days production volume was produced.

Date for Vlookup:

=IF(AF2="";"";AC2)

Shows “estimated production date” next to the daily median value for Vlookup-function search.

Searching median values for each day in the dataset to present the data in a chart:

=@IF(VLOOKUP(AH2;$AE$2:$AF$7203;2;FALSE)<100;VLOOKUP(AH2;$AE$2:$AF$7203;2;FALSE);NA)

Does a lookup from the large data table to collect daily median value for every “estimated production date” for a year for graphical presentation of development of “time between production and due dates”. Also, an error check is included, which removes values over 100 from the graphical presentation. This threshold was chosen, as median should never be over 100 for time between production and due dates.