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DEVELOPMENT OF THE PRODUCTION PLANNING PROCESS OF A MACHINE SHOP WITH STANDARDIZATION

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TIIVISTELMÄ

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Konepajan tuotannonsuunnitteluprosessin kehittäminen ja epävarmuustekijöiden kartoitus Lean-viitekehyksessä

Diplomityö

2020

80 sivua, 28 kuvaa, 1 taulukko ja 0 liitettä

Tarkastajat: Professori Juha Varis
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Hakusanat: Tuotannon suunnittelu, Lean, tuotannonohjaus, konepaja, riskien kartoitus, kysynnän ennustaminen

Tämän tutkimuksen tavoite oli luoda standardoitu prosessi keskipitkän aikavälin tuotannon suunnittelu prosessille Konecranes Hyvinkään vaihdetehtaan osavalmistus linjalle. Standardoinnin lisäksi tutkimuksen tavoitteena oli kartoittaa riskejä, jotka vaikuttavat tuotannonsuunnittelun onnistumiseen osavalmistus tuotantolinjalla. Lisäksi tutkimuksen tavoitteena oli kartoittaa ja selventää vaihdetehtaalle sitä, kuinka Supply and Operations Planning osasto tekee kysynnän ennustamista Hyvinkään vaihdetehtaalle.

Osavalmistus linjan tuotannonsuunnitteluprosessi on suuresti riippuvainen Hyvinkään vaihdetehtaan kokoonpanolinjan tuotannonsuunnittelusta, sillä yli 95% kysynnästä osavalmistuslinjalla tulee kokoonpanolinjan tarpeista. Tuotannonsuunnitteluprosessin riskien kartoitus sisälsi riskejä tuotannonsuunnittelusta, tuotanto henkilökunnasta, käytettävästä konekannasta, käytettyjen materiaalien laadusta sekä tuotettujen tuotteiden laadusta. Hyvinkään vaihdetehtaan kysynnän ennustaminen toteutetaan arvioimalla yksittäisten nosturi- sekä vaunukauppojen todennäköisyyttä.

Tuotannonsuunnitteluprosessiin kehitetyt työkalut sisälsivät kapasiteetti kalenterin, joka jaettiin sidosryhmille, jotta kapasiteetin ylityksiltä vältyttäisiin. Lisäksi myös graafi jossa kaikki vaihteet olivat saman yksikköisiä kehitettiin, jotta tuotannonsuunnittelija saisi helpommin kokonaisvaltaisen kuvan tulevaisuuden tilausmääristä. Riskien kartoituksen seurauksena vaihdetehtaalle luotiin konerikkojen seuranta prosessi, jotta tehtaan johdolla olisi selkeämpi kuva tehtaan konekannan nykytilasta sekä luotettavuudesta.

ABSTRACT

LUT Univeristy
LUT School of Energy Systems
LUT Mechanical Engneering

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Development of the production planning process of a machine shop with standardization

Master’s thesis

2020

80 pages, 28 figures, 1 table and 0 appendices

Examiners: Prof. Juha Varis
M. Sc. (Tech.) Juho Syrjänen

Keywords: Production planning, Lean manufacturing, production scheduling, machine shop, risk assessment, demand forecasting

The goal of this thesis was to standardize the existing process of production planning in the Konecranes Hyvinkää gear factory component manufacturing line. Within the standardization of the intermediate production planning process mapping of risks effecting the successfulness of the production planning in the component manufacturing line. Also, the study included a view to the demand forecasting done for the gear factory by the Supply and Operations Planning division of the Hyvinkää Konecranes.

Production planning process of the component manufacturing line is highly dependent on the demand of the assembly line of the Hyvinkää Konecranes gear factory as it provides over 95% of the demand of the component manufacturing line. The risks mapped included risks in production planning, production personnel, machinery and quality of products and material. The demand forecasting of Hyvinkää gear factory is done by approximating the individual propabilites of individual sales of cranes.

Some tools developed for the production planning process included a capacity calendar of the gear assembly line to be shared with interest groups and a measuring graph which measures the demand and capacity of the gear factory in universal gear assemblies. A tool for measuring the amount machinery breakdowns was also developed to the component manufacturing to provide the factory management data about the reliability of machinery used in the component manufacturing line.

ACKNOWLEDGEMENTS

I would like to thank Prof. Juha Varis, from LUT University, for guidance and for examining my thesis. From Konecranes I would like to thank Jussi Haatainen and Tuomas Patanen for giving me the opportunity and support to write this thesis for Konecranes. Also, I would like to thank Juho Syrjänen for sparring and guiding my thesis along. Compliments must be extended also to the whole office of the Konecranes Hyvinkää Gear factory for helping me with every step of the way – this thesis would not have been possible without the input they provided.

Writing of this thesis has been a difficult process which has resulted into countless messages and rants to my friends and family. My family has always been there for me and provided me with endless amount of lessons and support during my whole education. This thesis would have been quitted a long time ago without them. This thesis hopefully signals the end of my academic career and my time in the LUT University. I have no ill words about the people in the University and I have had the time of my life in the University, surrounded by most amazing people. It has took a while, but after six years the end of my University life is coming to an end. It was amazing, but now it is time for something new. Lastly, I want to thank my future wife for the patience and support she has had for me and provided me the confidence I needed to have, to complete this milestone and my whole education.

Tuomas Pouta
Hyvinkää 16.3.2020

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LIST OF SYMBOLS AND ABBREVIATIONS

5S	A tool for visual management
JIT	Just-In-Time
MTO	Make-to-order
MTS	Make-to-stock
PDCA	Plan, Do, Check, Act
SMED	Single-Minute-Die-Exchange
TPS	Toyota Production System
WIP	Work in progress

Andon	A method to visualize the deviations in a production process
Heijunka	A method for levelling production amounts
Jidoka	A production system that reacts automatically to deviations
Kaizen	Continuous improvement
Kanban	Production scheduling system that is based on pull production
Poka-yoke	A mechanism in a process that corrects or highlights deviations
Takt	The time needed for manufacturing products to fulfil the demand

1 INTRODUCTION

We live in a society that creates a hyper-competitive environment for the manufacturing industry (Cole 2002). In this kind of hyper-competitive environment, the development of the production process in a company is essential for the survival of the business (Cole 2002). Production planning is an integral part of the daily and monthly activity of a production facility. With effective production planning, one tries to maximize the production effectiveness of a factory or a production facility (Hopp and Spearman 2008, p. 434).

1.1 The goals of the research and the limitations of the research

The goal of the research is to clarify the production planning procedure used now and to make clearer to the production planning personnel the way demand is predicted in the Sales and Operations planning-department. The study of the production planning procedure is aimed to improve the quality of the production planning done in the gear factory component manufacturing- and in the assembly-line and to improve the punctuality of the whole factory. This study will also consider and comment on the insecurities coming from the production side of the gear factory and how the insecurities affect the punctuality of the production planning process.

The thesis will not consider insecurities coming outside of the factory's production process. As the production planning procedure is researched and analyzed, the goal is to form a standardized procedure and clear roles for the intermediate (6-10 weeks) production planning to minimize the possible confusion inhouse in the production planning process. The production planning in the Konecranes company varies according to the factories in question (Haatainen et al. 2019). In this study the production planning procedure of the Konecranes Oyj's Hyvinkää Gear Factory is only considered. (Haatainen et al. 2019)

The research does not consider the functionality of the process of demand prediction, but only explains roughly how the demand prediction is done as a part of the production planning process in the Konecranes Hyvinkää gear factory. The assembly lines production planning process is considered because the component manufacturing lines production planning relies heavily in the production planning of the assembly line. The study also concentrates on the process as whole and does not analyse the manufacturing process of any single product. Also, the study explains only some of the Lean concepts in the literature review part. This is because in Lean the concepts are various and numerous, so to view all the concepts would take too much time. The selection of viewed Lean concepts is done by choosing the already used ones in the factory and the most relevant ones. (Haatainen et al. 2019)

1.2 Research problem and the research questions

The main problem of the research is that the production planning procedure is not standardized and risk mapping considering the production planning has not been carried out. The intermediate production planning is done in the gear factory now according to rough data from the demand forecasting, but there is confusion how to make use of that data.

The main research question of the thesis is:

- What is the most optimal way to carry out the intermediate production planning of the gear factory's component manufacturing line?

Additional research questions for the thesis are:

- How the demand prediction and the production planning for the gear factory is done?
- What kind of insecurities must be considered when intermediate production planning is considered and how are the insecurities measured?
- What are the optimal parameters for intermediate production planning measurement?

In a previous study, done by the development engineer of the Hyvinkää gear factory, a correlation between the amount of hoisting gears completed on time and late and the backlog of component manufacturing was found. Also, a correlation was found between the backlog of component manufacturing and the amount of gear reducers manufactured on time and late. With both correlations there was a clear relation that when the backlog of component manufacturing line has risen, the amount of gears manufactured late has risen in relation to gears manufactured on time. Relation can be considered significant, when the relation value p is lower than 0.05.

1.3 Research methods

In this study the research is done by consulting professionals inside the company in question and with a literature review. The notes and recordings of the meetings and interviews are kept by the person conducting the research. The tools to assemble a working production planning process and the tools for measuring the insecurities effecting the production planning are taken from previous studies, interviews, meetings and literature. In the literature review part of the study, production planning processes, Lean philosophy and some key parameters are reviewed and researched. Databases that are used in the literature review include library of LUT University, Finna, the library of Aalto University and other digital e-book and e-magazine databases.

1.4 Introduction to the presented company

Konecranes Oyj has long traditions on manufacturing lifting solutions. The Konecranes history goes back to 1910 when KONE Corporation was founded in Hyvinkää, Finland. In 1994 KCI Konecranes was founded, when KONE corporation was listed on the Helsinki Stock exchange, as part of a structural changes in the KONE Corporation. (Konecranes 2019b) After the separation Konecranes has solidified its position as one of the biggest manufacturers of industrial cranes (Konecranes 2019a). Konecranes has service locations in 50 countries and the product range includes small lifting solutions for process industry to ship hull assembly cranes for shipyard handling (Konecranes 2019a). The service solutions are the biggest employer in the Konecranes company as 48 % of the employees work for service segment (Konecranes, 2018. p.2). This is partly because Konecranes does not only offer service to Konecranes cranes, but it offers service solutions to all brands of cranes. This is also one of the biggest reasons for the big product-mix of the gear-segment of the Hyvinkää factory (Konecranes 2018).

2 PRODUCTION IN GENERAL

Production process is defined as a “sequence of activities used to manage one or more functions of the organization” (Chiarini 2013, p. 16). Activity is a single operation which is done inside the process and the activity can be considered as an activity with added-value, when the activity possesses more value coming out of the process than when the activity is inputted into the process. (Chiarini 2013, p. 16)

2.1 Production process

There are several production processes in a manufacturing facility. Production process is the combination of actions that are needed to achieve a product or a service for a customer that marketing has acquired (Uusi-Rauva et al. 1993, p. 326). Production includes every action that is linked directly for achieving a product or a batch of products. Company’s different main functions take part in different ways in the production process. Uusi-Rauva et al. (1993, p. 326) define the different roles for company’s main functions as follows:

- Manufacturing is a part of production process in its entirety.
- From marketing, the specification of the product and making an order are defined to be a part of production process.
- The customer specific designs that are done according to the order are a part of production process from the design section of the company.
- From the procurement division of the company, the material procurement is considered to be a part of production process.

Production processes can be divided in many ways to ensure the controllability of the process. One of the ways is to divide production processes by its design and layout. The production process design usually starts by choosing a layout for the facility. Layout types differ on the positions of the manufacturing equipment and the direction of the workflow (Uusi-Rauva et al. 1993, p. 345). The layout types according to Uusi-Rauva et al. (1993, p. 345) are production line layout, functional layout and a production cell-layout. Also, in addition to these layout types, production can be based on manufacturing in different locations. With the production cell-layout the production process is divided into workstations or cells. The workstation layout can be classified into two categories according to Hopp and Spearman (2008, p. 215), which are a process-oriented layout or a product-oriented layout.

2.1.1 Push and pull systems

Push system is a production system where a manufacturing facility manufactures the products and sells them to the distributors, regardless of if the distributor or customer really has a need (Liker 2010, p. 110). In a pull system, the impulse to manufacture a product or a service comes from the customer demand (Liker 2010, p. 110). Hopp and Spearman (2004, p. 142) define the difference between push- and pull systems to be the fact that in a pull system the amount of WIP (work-in-progress) is limited and in a push system there are no limitations for work in progress. According to Uusi-Rauva (2003, p. 365) push production systems are still the most common production system, but in the recent years, pull production systems have become more common. Push systems work the best when there is a short lead-time and the demand of the product is very constant (Liker 2010, pp. 110–111). Push systems are problematic if the production process is complex and wide. The problems manifests in contradictions between the production and the production plan, because in a lengthy production process, the process cannot always function according to the production plan. Deficits in the production plan and problems in the production process are usually tackled with creating inventories between manufacturing phases. These in-between inventories cause that production planning and management is even more difficult, because the number of controlled products grow exponentially, and the lead-times of the products grow longer. Examples of a push production system include MRP and MRP II. (Liker 2010, pp. 110–111)

In a pull production system, the products are made only when there is a real demand. The demand information sequence of a pull production system goes from the last production phase to the first one. In action, the material flow is implemented with small buffer storages between production phases. When a product is taken from the buffer storage, it creates an order impulse to the previous production phase. Pull production enables short lead times and high quality for the products, but because a problem in one production phase can stop the entire process as the in-between storages run out, it also needs high quality to work. There are a lot of versions of traditional pull production process and its widely used in the companies that have own component manufacturing facilities. The difference between traditional pull- and push production systems is depicted in the Figure 1. (Uusi-Rauva 2003, p. 365; Liker 2010, pp. 110–111)

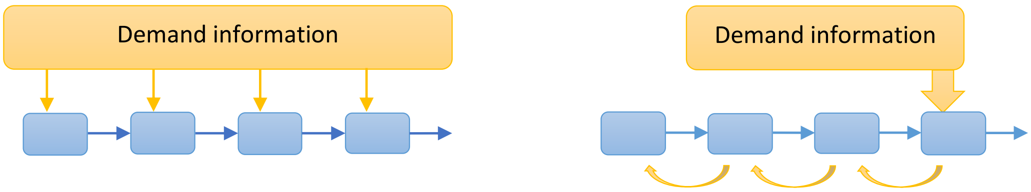

Figure 1. Basic push (left) and pull (right) production systems. Demand information sequence (orange), production sequence (blue). (Uusi-Rauva 2003, p. 365)

Pull systems are generally more efficient, easier to control, more flexible and supports improvement in quality easier than push production systems. Because of these advantages incorporating pull into production systems is becoming more and more common, but still pull systems are inherently rate-driven and dependable on the consumer demand. This means that for the demand prediction and production planning to succeed, one must achieve a stable demand. To achieve stable demand, JIT (Just-In-Time) and Lean-literature place a heavy emphasis in production levelling. A rate-driven system is logistically appealing, but it creates some difficulties in production planning. This is why push systems are inherently more suitable for production planning because the demand is stable and there is clear link between the customer due dates and production release dates. (Hopp and Spearman 2008, p. 430).

In real life, there are usually no production systems that are purely push- or pull systems, but some sort of hybrids of both. For example in a pure MRP system, the amount of WIP is not constricted but in a real situation the amount of WIP is most certainly monitored and there is some kind of limit for WIP for the management to recognize it and prioritize it over planned orders. (Hopp and Spearman 2004, p. 143)

One of these hybrid production systems is CONWIP, which stands for constant work in progress, which is based on nearly constant amount of WIP. In a CONWIP production system the demand impulse to the start of the process comes from the end of the process. For example, when a product is manufactured the process end sends an impulse to the start of the process that manufacturing of a new product can be started. CONWIP production system assumes that the production process has only one routing, through which all parts flow and that all the jobs are identical. If all the jobs in the process are identical, the WIP can be measured in universal units in the process, for example in operations or parts in the manufacturing line. If the manufacturing facility has multiple routings that have same workstations, or products demand different manufacturing times, the usage of CONWIP gets substantially harder. This is because if the manufacturing time differs in the product mix, there is constantly unbalance between workcenters. The basic principle of CONWIP is depicted in the Figure 2. (Hopp and Spearman 2008, p. 346)

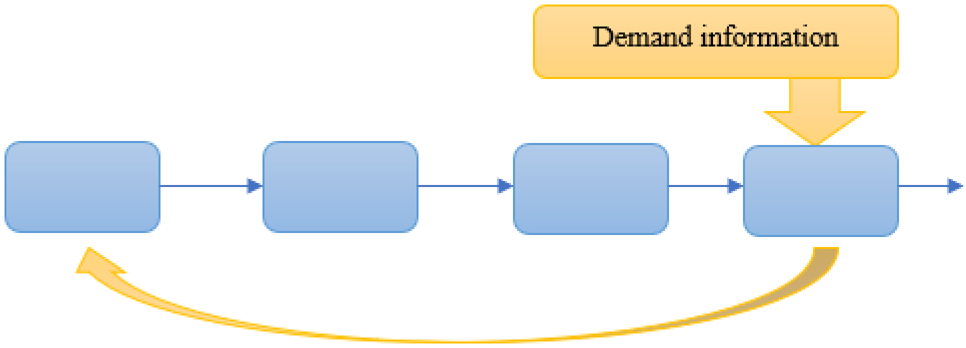

Figure 2. Basic principle of a simple CONWIP production system. Production sequence (blue), demand information sequence (yellow). (Hopp and Spearman 2008, p.346)

2.1.2 Capacity and lead-time

Capacity is variable that describes the maximum performance capability of a production unit in a unit of time, for example units per day (Hopp and Spearman 2008, p. 216). If different products need a different amount of capacity between them, capacity can be defined as a usage time of production resource, for example 160 hours per week (Spearman 2008, p. 216). If capacity is overloaded it can make the production process unstable and build WIP without bound (Hopp and Spearman 2008, p. 216). A load group is a group which capacity and load are observed as a group. These load groups are formed according to production scheduling needs. In the fine production planning, one can use cell, machine- or personnel-group specified load groups. Capacity management relies on the workstation capacity and on the load of the planned production. Load is defined as a capacity that is required to do a certain action. Capacity and load should be indicated in the same unit to simplify the process. (Uusi-Rauva 2003, p. 344)

Lead time is the time allocated for the manufacturing of a product and it consists of time that product is in the supply chain (Uusi-Rauva 2003, p. 345). Most commonly when lead time is measured, the purpose is to measure the entire process lead time or the manufacturing lead time of a individual product (Uusi-Rauva 2003, p. 345). Manufacturing lead time consists of time that is consumed from the starting point of manufacturing to the finished product (Uusi-Rauva 2003, p. 345). Lead time for a specific product should be constant, if the lead time is not constant for the product, there is a problem within the production process. With short lead times there are many advantages for the company's operations and competitiveness, for example more flexibility in the production planning process, better punctuality and smaller amount of tied-up capital in the inventories. (Uusi-Rauva 2003, p. 345)

2.1.3 Delivery reliability and punctuality

Punctuality is defined by Filippini (1998) as the ability to deliver products within a specified timeframe, and it can be calculated with the percentage of the orders delivered in time, over the total orders received. Punctuality can be compared to delivery reliability, which is defined according to Sarmiento et al. (2007, p. 369) as an ability to meet exactly the anticipated and quoted quantities and delivery dates. In a make-to-order environment the delivery reliability is defined as meeting the quoted dates and quantities and in a make-to-stock environment as an ability to meet the anticipated dates and quantities (Sarmiento et al. 2007, p. 369). Delivery reliability can be considered as a competitive advantage as customers are valuing the suppliers reliability more and more (Sarmiento et al. 2007, p. 370). Delivery punctuality is strongly linked with quality consistency and delivery time, because with quality issues the delivery times of products will be delayed (Sarmiento et al. 2007, p. 374). Also, the insecurities linked to a manufacturing process can affect greatly company's deliver reliability. These insecurities include machinery reliability and material quality. Because of the effect these uncertainties have, the company might be inclined to answer the uncertainties with costly extra resources, like increased inventory with safety stock or safety capacity (Sarmiento et al. 2007, p. 374). If the uncertainties are identified and reduced, company has better chances to meet its delivery commitments without using costly extra resources (Sarmiento et al. 2007, p. 374).

2.2 Production planning and demand forecasting

Demand forecasting is one of the foundation pieces of successful production management. Forecasts are needed, because the response time of the production process is usually longer than the time of demand change. With demand forecasts, production facility can react to the anticipated changes in demand beforehand with capacity and inventory level changes. The global economy has made demand forecasting increasingly difficult and mistakes in the demand forecast can be troublesome for the production facility (Hopp and Spearman 2008, p. 416). Wrong timed capacity changes or changes in the personnel can cause major economical and mental losses, therefore companies are pursuing more flexible and reactive production processes. The demand forecasting can be done, for example, with regression analysis or analysing the previous demand. With the previous demand analysis, the global market changes affect analysis negatively making it more unreliable, but the analysis can also consider trend changes and seasonal variation. The food product industry is one of the biggest utilizers of the previous demand analysis. Regression analysis can be used in a situation where there is a relation between determining value and product demand. For example, the demand for faucets can be predicted from the amount of building permits granted, because it has been analysed how many faucets are consumed per building square meter. These kind of methods for demand forecasting are suited for products which have large volumes. In a production facility with a large quantity of small volume products, one must rely on subjective estimates of personnel about consumption. To improve the demand estimate, the subject analysed can be divided into smaller sections. For example, the sections can be sales regions, product groups or customer groups. Suppliers with products that are big systems and the quantity sold annually is small, the supplier usually must estimate the probability of a single sale when forecasting the demand of the product. (Uusi-Rauva 2003, pp. 357–358)

Production planning is a part of production management and it usually relies heavily on the demand forecasting done in the company (Hopp and Spearman 2008, p. 414). Hopp and Spearman (2008, p. 414) state that the basic starting point of all production planning is demand forecasting. This is because the successfulness of production planning depends always on the future demand. According to Hopp and Spearman (2008, p.488) basic principle of manufacturing is that the manufacturers aim at on-time delivery with minimal work-in-progress (WIP), with maximum utilization of resources and short lead times to customer. The goal of production planning is to achieve all these goals, without expanding the inventory massively or without using too lenient delivery times (Hopp and Spearman 2008, p. 488). Uusi-Rauva et al. (1993, p. 362) adds to these goals the constant development of planning process and the high utilization percent of the facility's capacity. In a Lean production environment the productivity of a manufacturing process is not considered to be an important factor, but the punctuality is highly weighted in the JIT production philosophy. Uusi-Rauva et al. (1993 p. 364) recognizes that there is also a contradiction in the goals of the production, because high productivity needs big batch sizes and big batch sizes needs big inventory, but the goal to minimize floating assets is to minimize the inventory and WIP (Uusi-Rauva et al. 1993, p. 364). This is where production planning sets its importance. One should use multiple planning horizons to ensure that the production planning process can be flexible and can react to sudden changes to the demand without going through the whole production planning process (Hopp and Spearman 2008, p. 413). The planning horizon timeframes of production planning process differ a lot with different industries and these planning horizons also represent different regeneration frequencies (Hopp and Spearman 2008, p. 413-414). For example, with long range decisions with information that extend years into the future does not need to be reconsidered frequently. Usually these kind of decisions are considered quarterly to annual basis (Hopp and Spearman 2008, p. 414). Also, with the different planning horizons timeframes, the amount of details differs as well within the planning horizons (Hopp and Spearman 2008, p. 414). Generally, the shorter the time period considered in the planning horizon, the more details it consists (Hopp and Spearman 2008, p. 414). A traditional production management process is depicted in the Figure 3.

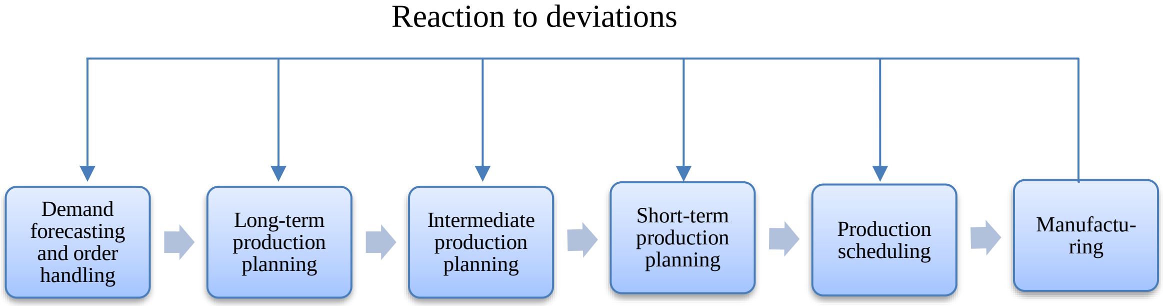

Figure 3. A traditional production management process (Uusi-Rauva 2003, p. 353)

In a make-to-order (MTO) environment, the customer demand dictates the due date for the product. Vice-versa in a make-to-stock (MTS) environment the demand is not dictating due dates, this is because it is presumed that the demand will be filled instantly from the inventories. The production is dictated with reorder points calculated to the products. With the MTS system the inventories of the manufacturing company must be vast to answer the customer demand immediately. These different production philosophies each demand a different production planning method, as do any production philosophy. Also, one must remember that production planning processes vary a lot, and one that have worked somewhere else, might not be successful in the environment considered. (Hopp and Spearman 2008, p. 489)

2.2.1 Long-term production planning

Long-term production planning means upper level production planning, where the decisions about the factory's total volume and financial decisions are made (Hopp and Spearman 2008, p. 413). Hopp and Spearman (2008, p. 413) define the timeframe of long-term production planning to be from one year to five years. Long-term production planning includes: facility location decisions, supplier contracts, personnel development programs, quality assurance policies, marketing strategies, volume definitions, definition of inventory levels and definitions of the needed resources and capacity (Hopp and Spearman 2008, p. 413). The basis of long-term production planning lies in order volume, demand forecasts and inventory situation. With these, more precise production planning can be done and changes in the capacity, personnel, suppliers and subcontractor amounts. One of the biggest objectives of long-term production planning is to manage the changes in demand, because usually the flexibility of the production capacity is not as high as the changes in the demand (Hopp and Spearman 2008, p. 413). The means to managing changes in demand are according to Uusi-Rauva (2003, p. 358) storage of products, capacity changes, changes in the date of delivery or loss of orders and managing the demand. For managing changes in demand, storage of products can be used if the products are easily stored. Inventories can be increased when there is less orders in the production and consumed when the production cannot answer the grown demand. In this situation the products can be delivered from the inventory quickly, but the costs of the inventory are increased. Capacity can be changed to answer changes in demand by investing in new machinery and thus growing the production capacity. Other solutions to change capacity are working overtime, increase or decrease in production shifts, increase or decrease in personnel or using subcontractors. All the actions lead to different additional costs. Also, increased capacity that is not used in its entirety will increase additional costs. The difficulty of managing production capacity or the demand, has resulted into that production facilities are trying to improve the flexibility of the production. The changes in date of delivery is usually used when capacity flexibility is poor. In crane manufacturing, where projects are large, the failure of achieving the delivery date, because of component manufacturing, is not usually tolerated. Usually when the delivery dates must be moved far into the future, this results in a loss order or penalties. Also, poor punctuality and long lead times can affect negatively the company's reputation. Selection of operating model with demand management, is usually based on the cost estimation of different options. In addition to costs, matters that should be taken into account include: personnel satisfaction, company's reputation and risk factors that affect the options. (Uusi-Rauva 2003, p. 356-358)

2.2.2 Intermediate production planning

Intermediate production planning concentrates on tactics, for example, by determining what to work on, who will do it, what must be done in equipment maintenance and what products must be prioritized. Intermediate production planning does include some rough production scheduling, but main attention is at adjusting resources to the amount of consumption (Uusi-Rauva 2003, p. 359). This includes planning the usage of resources, factory's deliverability, work scheduling, staffing assignments, maintenance planning and purchasing decisions (Uusi-Rauva 2003, p. 359; Hopp and Spearman 2008, p. 413). Capacity is also defined on a general level and the decisions about increasing or decreasing capacity is made (Uusi-Rauva 2003, p. 359). Also the time of delivery that is promised to the customer is premised on the intermediate planning (Uusi-Rauva 2003, p. 359). When making these decisions, one must take into account the previous decisions made about the company's strategic long-range production planning. Intermediate production planning timeframe is considered to be from one week to a year (Hopp and Spearman 2008, p. 414). In an inventory orientated production, intermediate production planning examines inventory levels and volume of orders and the production planning is done by planning the replenishment batches. When rough production scheduling is done in the intermediate production planning phase, it includes information about the needed capacity of production batches and about needed capacity for different orders (Uusi-Rauva 2003, p. 359). With rough scheduling, the production planner can get updated information about the sufficiency of the capacity in use and if the capacity is insufficient, production planner can make changes to the capacity or level the planned orders to a different slot in the schedule. Scheduling can be done, for example, with a load graph (Uusi-Rauva 2003, p. 360). A load graph measures the production load in the facility in a period of time. Usually rough scheduling concentrates in key production load groups, key bottleneck groups or rough scheduling can also concentrate on the biggest customer groups (Uusi-Rauva 2003, p. 359).

2.2.3 Short-term production planning

The goal of short-term production planning is to build a detailed production plan, or work schedule, which is used when products are manufactured. The work schedule is composed in a way that fulfils the goals of the production process in a best possible way. Usually these goals are delivery reliability and high productivity. The basis for the work schedule is in the rough scheduling made in the intermediate production planning phase (Uusi-Rauva 2003, p. 360). For the work schedule, sufficient production batches are designed, production order of the batches is planned and a detailed plan for usage of production capacity is made (Uusi-Rauva 2003, p. 361). This requires detailed knowledge about the individual manufacturing times and time consumption of production phases (Uusi-Rauva 2003, p. 361). The detail level of this information depends on the accuracy requirements of work schedule. Previously the mindset throughout in the industry was to come up with detailed work schedules, where the capacity was planned carefully, but the trend in the modern industry is to plan the production more roughly to ensure the flexibility and to increase the self-controllability of the production process (Uusi-Rauva 2003, p. 361). When preparing a work schedule, the actual situation in the production process must be known and taken into account. For example, the amount of backlog and WIP and the amount of disturbances in the production flow (Uusi-Rauva 2003, p. 361). The main problems in the short-term production planning are the changes in the order pool and sudden changes in the production capacity, for example machinery breakdowns. Because of these factors, short-term production planning is usually pushed to the last moment, making the timeframe in which short-term production planning is done from day to a week (Hopp and Spearman 2008, p. 413).

When there is a production process where setup costs are large, short-term production planning must minimize the setup times and costs. This can be done with linking production orders or optimizing batch sizes. Batch size optimization is an important part of the production scheduling. With batch size optimization, one can minimize the amount of time wasted with setup times when the product is changed, but with growing batch sizes there is a danger that there is no demand for the batch manufactured products and the products that are not manufactured for the demand, end up to grow the inventory value of the manufacturing facility. Also, the cycle time of the products is rising when batch size of grown to a certain point. This is because if the batches are large, the time to start the next product also rises, and the cycle time of the production schedule grows longer and longer by the product. The relation between lot size and cycle time is depicted in the Figure 4. (Hopp and Spearman 2008, p. 307)

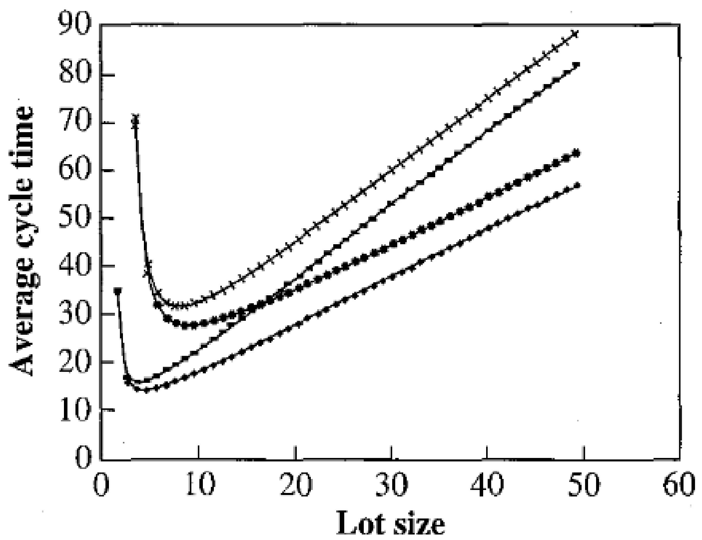

Figure 4. The relation between batch size and average cycle time (Hopp and Spearman 2008, p. 307)

In the bottleneck phases of the production process, it is important to assemble the production schedule carefully. This is because if the bottlenecks of the production process do not supply the other phases of the process with products, the bottlenecks hold back the capacity of the whole process. When doing production schedule, a high production rate usually leads to longer lead times as the batch sizes grow, in these situations the short-term production planning has to be based on the decisions made in the long-term- and intermediate production planning phases. Also, the goals set in the previous phases has to be known and the decisions has to be based on them, for example if productivity is a priority or if shorter lead times are the priority. This ensures that everybody is on the same page what is prioritized in the production output and confusion is evaded. (Uusi-Rauva 2003, p. 362)

The timing of the production can be done with two ways, forward- or backward scheduling. With the forward scheduling the first thing to do is to define the starting point of production. From the starting point of the production the production time of first phase is added and after that all of the other production phase durations are added until all of the phases have been put into the schedule and the process is scheduled. With the backward scheduling, the products finish date is defined and from there the production phases are scheduled back to the starting point of production.

In a production process, when a decision must be made within the production plan what to manufacture first, prioritization rules are used. Prioritization rules are usually used when the planning situation is simple, but also prioritization can be used in a complex situation where no other rules are defined (Uusi-Rauva 2003, p. 363). When the product must be hurried, prioritization can be also used. According to Uusi-Rauva (2003, p. 363) some prioritization tools include:

- Order of arrival (First-In-First-Out, Last-In-First-Out)
- Smallest amount of margin in the delivery time and manufacturing time
- Largest amount of overdue
- Quickest phase first
- Slowest phase first
- The most expensive phase first
- Quickest to manufacture first
- Earliest start date first
- Smallest or largest amount of manufacturing phases first

(Uusi-Rauva 2003, p. 362-364)

3 LEAN MANUFACTURING-IDEOLOGY

Lean is a production philosophy which has the basic idea of a continuous improvement of the production process with elimination of waste (Chiarini 2013, p. 15). The philosophy concentrates on production process viewed as a flow, with a viewpoint that everything that is not value-added activity is waste or non-value-adding activities. (Liker, 2010, p. 28; Chiarini, 2013, p. 6).

The history of Lean stems from the 1940s Japan when Toyota started to develop their production system TPS (Toyota Production System), to answer the challenge of mass production of the United States (Holweg 2007, p. 421). This was a challenging task because Japan was suffering from higher raw material costs, rigid salary ranges and smaller internal demand compared to western countries, resulting from the World War II, which had just ended (Chiarini 2013, p. 3). Contrary to the common belief that TPS was invented in a short amount of time, TPS was developed by continuously iterating and developing the production process from the 1940s. According to Holweg (2007. p.422) the basic reason for the success of TPS was the dynamic learning ability it has. Amazingly TPS was not documented before the 1970s. Later the TPS was developed even further named Lean production system by international researchers. (Uusi-Rauva 2003, p. 311; Holweg, 2007, pp. 421–429)

3.1 Basic concepts of Lean

The process in Lean philosophy is viewed as a flow, and Uusi-Rauva (2003, p. 311) describes Lean as a “Japanese leadership philosophy” which relies on efficient JIT-production. Smith and Tan (2013, p. 115) state that good results in Lean Systems can be attributed to three factors:

- That there is good leadership in place and target setting is realistic
- Responsibilities are decentralized and problem solving is active
- Properties of the typical system design and its components in a stochastic environment are known and recognized

According to Liker (2010, p. 7) for a manufacturer to be Lean, one has to adopt a way of thinking which concentrates on value-added production flow without stoppages and a culture of a continuous improvement. Liker (2010, p. 37) also identifies 14 Lean principles which, when utilized decrease the amount of waste in the production process. These principles are:

- Decisions should be made according to long-term philosophy, even at the expense of short-term financial goals
- Create a continuous flow in the process to bring out the possible problems
- Use pull production to evade over production
- Balance the amount of work (Heijunka)
- Create a culture where working is stopped to correct a problem to ensure that quality is achieved with the first try
- Standardized work is the basis of continuous improvement and workforce commitment
- Use visualization to ensure that problems are brought to light
- Use only reliable and thoroughly tested technology which serve personnel and process
- Groom leaders that understand the process thoroughly and who follow philosophy and teach it to others
- Develop exceptional people and groups who follow the company philosophy
- Respect the supplier and associate networks and help them to develop
- Go to the source, to understand the problem (Genchi genbutsu)
- Make decisions slow and with consensus, considering all options and execute them swiftly
- Establish you company to be a learning organization through continuous development (kaizen) and tireless evaluation (hansei)

3.1.1 Waste

In Lean waste can be classified in different ways, but one of the most used definition is the seven relevant wastes according to the TPS. As in previously was stated, the basic principle of Lean manufacturing is to avoid waste in all its forms. The seven wastes in production process consists of:

- Overproduction
- Inventory
- Motion, as in unproductive movement of products or personnel
- Defectiveness
- Transportation
- Over processing
- Waiting

(Chiarini 2013, p. 19)

Overproducing as a waste is defined by Chiarini (2013, p. 19) as producing when there is no customer demand in place. The possibility is that the products produced and stored are going to be bought when the orders arrive, but there are no guarantees that the orders in fact will be made. Also, the inventory for the products will tie up money and resources. Overproducing will also lead to many negative consequences including increase in inventory, slowing down the production process, reduction in planning flexibility and increase in indirect costs. Overproduction can be evaded with balancing the workload and capacity of the production facility. Some of the Lean tools can be used for the workload and capacity balancing, for example, Single Minute Exchange of Die (SMED), production levelling and one-piece flow cells. Overproduction can be considered as the worst of wastes because when overproduction is done, it enhances all the other wastes. Also, the developer of the TPS, Taiichi Ohno, considered this to be the most crucial type of waste (Liker 2010, p. 29). (Bhasin, 2015, p. 4; Chiarini, 2013, pp. 19–21)

The second waste is defined as **inventory**. Inventory can be defined as products that are not used in the production process or products that are not capitalized. These stored products take valuable space and the production capacity used to make the products into storage is wasted. Inventory can be viewed as a typical by-product of the waste of overproducing. Inventory or stock can also be WIP if the products are waiting to be processed. The best way to identify where waste is forming is to find the process step where WIP usually stacks up and to ask why the flow is not working there. The most usual reasons include:

- Long changeover times
- Big production batches or early production
- Production or service bottlenecks in the production flow
- Ineffective or defective parts of process
- Quicker processes in the beginning than nearer to the end
- Acceptance of the fact that inventory cannot be avoided, because it effects the delivery punctuality

(Chiarini 2013, p. 22; Bhasin 2015, p. 4)

Especially the last reason is very important, when one is attempting to change the production culture in a production facility and realizing that all excessive inventory can be eliminated (Chiarini 2013, p. 23). According to Chiarini (2013, p. 23) excessive inventory does not solve the problems in the production, but in fact hides them. Traditional Lean methods for removing inventory include: improvement of production balancing, better layout planning, faster setup and change time and implementation of pull production using a Kanban production system (Chiarini 2013, p. 23). Although Lean targets removing all inventories in its purest form, it recognises some situations where a process without inventories is not possible (Liker, 2010, pp. 105-108). For these kinds of situations, the pull system is made for. Usually these inventories consists of buffer inventories between processes to ensure a constant flow in the process (Liker, 2010, pp. 105-108). If in the process there are no inventories, the process is called a 0-inventory system (Liker 2010, p. 105). The basic relationship of Lean and inventories could be summed with a phrase: ensure the flow everywhere and use pull when you have to (Liker 2010, p. 109).

The **motion** waste is unproductive movement of products inside the production facility or between production processes. Also, the waste can refer to unnecessary movement or activity of personnel, especially operators. These include, for example, locating tools, movement to load data onto software and worker movement from department to another that results from lack of staff. The causes for these include poor layout design, insufficient training or skills of personnel, poor cleanliness or lack of staff. These problems can be tackled with, for example, better production flow, improvement in workers’ skills and training, increase in awareness of movement waste, design of work cells and review of instructions and procedures. (Chiarini 2013, p. 23; Bhasin 2015, p. 4)

Defectiveness as a waste is one the most commonly known waste of the seven wastes. The defectiveness of a product results in scrap or reworking, which both are costly parts of the process. Usually defects are results of poor manufacturing process, which is caused by breakdown of equipment, human error or both. These defects must be repaired by reworking the product or scrapping it, which leads to more additional costs and the profitability of a product deteriorates. When identifying defectiveness reasons, it is important to find the root cause of the defectiveness because it is important to treat the problem and not the symptoms of defectiveness, this ensures that the problem does not reoccur in the future. (Chiarini, 2013, p. 24; Bhasin, 2015, p. 4)

When considering **transportation** as a waste, it is important to remember that larger than needed inventories lead unavoidably to increase in transportation operations. Usually in process environment the waste of transportation is connected to unnecessary transportations between warehouses and production facilities. According to Chiarini (2013, p. 25) the usual reasons for waste of transportation are caused by poor layout design, too large lots, personnel with inadequate or limited skills or acceptance that transportation is inevitable part of the process. One of the most common ways to decrease the amount of transportation operations is redesign of the layout within the process. Lean tools to make the redesigning more effective include flow analysis using Value Stream Mapping (VSM) and spaghetti-chart, use of U-cells in the process and the use of multi-skilled workers. (Chiarini, 2013, pp. 24-25; Bhasin, 2015, p. 4)

Over-processing as waste stands for unnecessary steps taken in the manufacturing process. Also, over-processing includes when higher quality products than required are made. According to Bhasin (2015, p. 5) usually the reason behind over-processing is malfunctioning equipment, reworking errors, process ineffectiveness, lack of communication or ineffective benchmarking, including customers' requirements. With accurate process and product design this kind of waste can be minimized or even eliminated. When a process is designed or altered and standardized it is important that all of staff have been informed and trained sufficiently to execute the plan, otherwise the work will produce only limited results. (Chiarini 2013, pp. 27–29; Bhasin 2015, p. 4)

When considering a manufacturing process, every single task is dependent on the tasks before and after it. **Waiting** as a waste happens when the production process is delayed because of operators, equipment, information or materials. This causes time to be wasted and the cost of production to increase, which effects the profitability of a production process. According to Chiarini (2013, p. 29) usually waste of waiting accrues when in the process there is lack of balance between tasks, ineffective preventive maintenance, big lot production, lack of order and cleanliness and the lack of procedures and instructions. Some tools for reducing the amount of waiting as a waste include: levelling, layout improvements, preventive and predictive maintenance, order and cleanliness, quick changeover and mistake proofing systems. (Chiarini 2013, pp. 27–29; Bhasin 2015, p. 4)

Some literature recognises an eight waste, **waste of employee creativity** (Liker 2010, p. 29). In a Lean environment creativity is encouraged and every wasted employee time, idea, skill, development or learning experience is a wasted opportunity. (Bhasin 2015, p. 4)

3.1.2 Just-In-Time

Just-In-Time (JIT) is a pull production operating model where the right number of the exact products are made right at the time when they are needed (Toyota Production System 2019). This way the amount of inventory is minimized. Also, JIT enables the production process to be flexible and it can answer to the changing demand of the customer quickly. In JIT manufacturing the next process phase is perceived to be the next customer, so the earlier phase must fulfil the demand of the next process in products and in quality. According to Uusi-Rauva (2003, p. 369) characteristics of a JIT production system are: high productivity, small amount of tied-up capital, high quality and short lead times. The basis of JIT operating model is a distinct production where material flow and production management have been organised to be as productive and clear as possible. (Uusi-Rauva 2003, p. 369; Liker 2010, p. 106)

The basis of the development of JIT operating model is to minimize the amount of time used for setup in the production. This is done by improving setup technique and methods. Short setup times make possible to use small batch sizes and small batch sizes enable short lead times for the products. The short lead time for products enable the size reduction of stored products and stored semi-finished product. JIT operating model requires a high quality-level in the production, because defects in quality can quickly halt the whole production line. On the other hand, because of swiftness and clearness of JIT production, quality problems and causes for these problems can be easily detected. (Uusi-Rauva 2003, p. 370)

The goals of JIT operating model according to Hopp and Spearman (2008, p. 153) are "the seven zeros" and they are as follows:

- Zero defects. Quality must occur at the source, because if there are defects, with small inventories, the consequences are enhanced.
- Zero (excess) lot size. Maximum responsiveness is maintained if each workstation can replace products one at a time.
- Zero setups. Small lot sizes require the tool setups to be frequent and cause great capacity deficit, so one must minimize setup times as much as possible.
- Zero breakdowns. Without excess WIP, breakdowns will quickly stop the production.
- Zero handling. No extra moves of material from and to storage can be tolerated. Ideal is to feed the material straight from workstation to workstation.
- Zero lead time. When JIT parts flow is executed to the perfection, request of parts from a downstream workstation is fulfilled immediately.
- Zero surging. A level production plan and clear product mix are important inputs to a JIT system.

These are the goals of a JIT system, but reaching these goals is not realistic, according to Hopp and Spearman (2008, p. 153). The purpose of goals that are not possible to meet, is to inspire an environment of continuous improvement to the workplace. (Hopp and Spearman 2008, p. 153)

For example, the Toyota car factory uses JIT as follows: First when the order is received, the production instructions are issued to the beginning of the production process as soon as possible. Secondly the assembly line must have enough required parts for any kind of vehicle that can be assembled on the line. Thirdly the assembly line must replace the used parts from the parts-producing process. Fourthly the process phase has to be stocked with small amounts of needed parts for the desired product and the operator must produce only the amount of parts the next operator is requesting. (Toyota Production System 2019)

One of the basic Lean tools for using JIT as a production system is Kanban, which means “a signal to manufacture” (Liker 2010, p. 23). Kanban is a production scheduling and production management tool, which helps the production manage the WIP internally (Chiarini 2013, p. 38). For example, a factory has a small end inventory for the finished product, and the customer orders the product from the inventory (Liker 2010, p. 106). The emptied container of the product is transferred to the production facility and it works as an indicator to the process that this product has to be manufactured (Liker 2010, p. 106).

3.2 Lean in a production environment

As the TPS was developed within the production environment, Lean also considers widely the production process and the development of the production process. Lean is a complete organizational philosophy, but its roots are heavily in the production environment. (Bhasin 2015, pp. 2-3)

3.2.1 Jidoka

Jidoka can be translated as “automation with human touch” or in-built quality control, and the idea behind it is that when a problem occurs, the equipment or personnel stop immediately to prevent the defective products from moving on in the production process (Toyota Production System, 2019; Liker, 2010, p. 129). After the process equipment stops, production foreman is notified, problem is solved, and the solution standardized (Toyota Production System 2019). Also, Jidoka forces the production personnel to rectify the recognized problem to ensure that the equipment do not stop again for the same reason (Toyota Production System 2019). With repetition of this, the problems of the manufacturing will be repaired, and the quality of the manufactured products will improve. In-built quality control will also become more profitable in the long run, because the amount of reworking and scrapping is dropping (Liker, 2010, pp. 129-132). Also, eventually the added value of a singular production worker will diminish and the largely standardized job can be performed up to par by any operator (Toyota Production System 2019).

Jidoka is a crucial part of the Lean manufacturing process, because when the buffers are eliminated from the inventories, and when quality problems appear there is no buffers to use (Liker 2010, p. 130). In Jidoka if the quality problem is challenging, the operator can use a sound or visual signal to signal to a co-worker that the operator needs help to solve the quality problem (Liker 2010, p. 130). These signals are called Andons. The correction of quality problems might seem as a logical thing to do, but in the mass production system, the production process should never be stopped, so usually the errors in quality are just marked and moved aside, leaving the root cause unsolved (Liker 2010, p. 131). It should be noted that Andon does not mean a button in the process phase that stops the entire production facility from working, but a signal that stops the work-cell in question. In one-piece-flow this will eventually cause the entire process to stop if the problem is not fixed fast enough. As the Andon is used, the cell leader will come and inspect the situation and decide if the problem is solvable when the line is moving or if it needs stoppage of the line to be repaired. When Jidoka is implemented to the production line, the production line should be monitored with poka-yoke sensors, which notify the operator if abnormalities occur in process and stops the cell or corrects the deviations. (Liker 2010, pp. 131–133)

3.2.2 Kaizen

Kaizen is an integral part of the Lean philosophy and the basic principal is to pursue continuous improvement in the production environment, no matter how small the development is (Liker 2010, p. 23). Kaizen is an entire state of mind and it pursues perfection and maintains the production system in place (Liker 2010, p. 23). Continuous development starts from standardizing the existent process. The existing process has to be standardized, because no development can be done if the process is not standardized and the baseline is not set. In Lean the process standardization is done with the process operator and the operator is a part of the development process. This is how the operator is committed to the development process and motivated to follow the standard guidelines. (Liker 2010, pp. 142–143)

3.2.3 PDCA – Plan, Do, Check, Act

One of the ways to use Lean philosophy in a development environment is based on the PDCA-cycle. PDCA-cycle is an integral part of Kaizen culture in a Lean environment and it aims at deletion of waste through improvement initiatives. PDCA-cycle, or Deming-cycle, was developed in 1930 in the United States and further developed in 1950s by William Edward Deming and it was first developed for ensuring quality of products, but quickly enlarged into including developing improvements at organizational level. The cycle is demonstrated in the **Figure 5** (Realyvásquez-Vargas et al. 2018, p. 2).

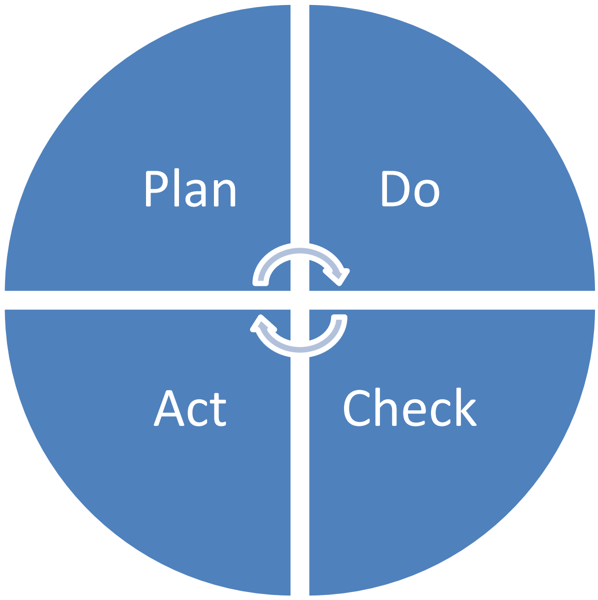

Figure 5. PDCA-Cycle (Sehested and Sonnenberg 2011, p.56)

The plan-phase in the PDCA-cycle includes the identification of opportunities and priority assignment of these opportunities. Also, in the plan-phase one must analyse the current situation of the process in question with consistent data provided, causes of the problem are defined and hypothesis or possible solutions for these problems are planned. A common tool which is used in the plan phase is the Ishikawa diagram. In the do-phase, the action plan is put into use and the important information is selected and documented. The check-phase includes analysis of steps taken in the do-phase. This includes comparison of before-and-after situations and analysis if any improvement was made, if the goals defined in the plan-phase were fulfilled and if the root cause identified in the plan phase has been erased. The check phase also usually includes visual tools to demonstrate the results, including for example Pareto chart from the data gathered. In the act-phase, which is the last step of PDCA-cycle, the process developed is standardized and re-tested to ensure that the decisions made are correct. If the developed process has not improved the previous process, the developed solution is scrapped and a new project is initiated. (Realyvásquez-Vargas et al. 2018, p. 4)

Fishbone diagram, or Ishikawa's cause-and-effect diagram, is one of the most commonly used tools for depicting the cause and effect relation between effects and process outcome. Kaosu Ishikawa designed the diagram in 1943 to explain to Kawasaki Steel Works engineers how interrelated manufacturing factors are and how to sort them. The fishbone diagram is drawn primarily for bringing light to possible causes for a specific problem by using classification schema to sort them and to organize them in relation to each other. Each of the causes or reasons for imperfection that are put to the diagram are a source of variation. When the Ishikawa diagram is drawn, to ensure the most realistic assessment, there should be representatives present from all the departments which are observed. (Kuster et al. 2015, p. 399; Van Aartsengel and Kurtoglu 2013, pp. 455–456)

The diagram is built from right to left, because the Japanese language is written from right to left. The main causes are drawn as arrows pointing to the middle, to the main axis. The arrows can be categorized initially with main process inputs categories, which are : man, method, machine, material, environment, metrics and management. The basic principle of the Ishikawa's cause-and-effect matrix is depicted in the **Figure 6**. (Kuster et al. 2015, p. 399; Van Aartsengel and Kurtoglu 2013, pp. 455–456)

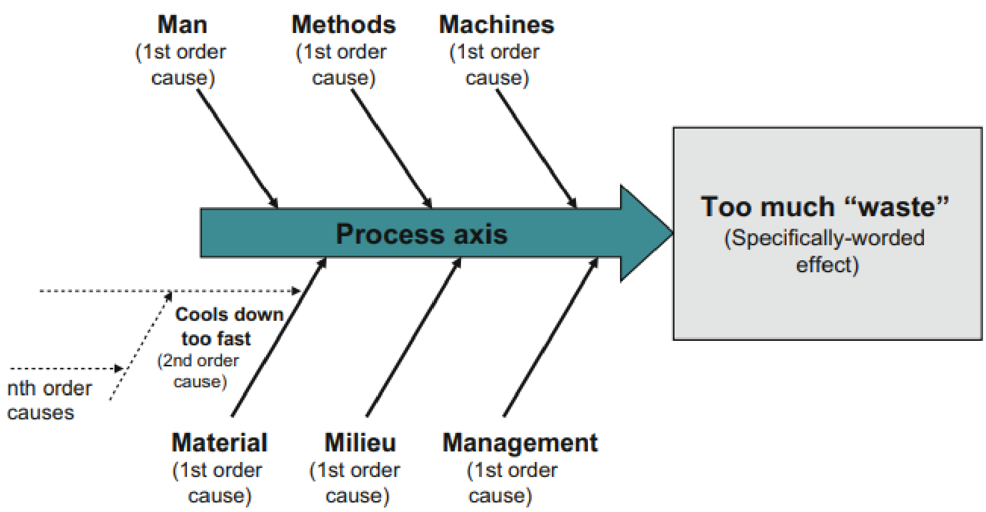

Figure 6. Example of the Ishikawa's cause-and-effect matrix. (Kuster et al. 2015, p.399)

3.2.4 5S

5S is a Lean tool which aims at recognizing and removing waste from the process under survey. 5S consists of five actions to eliminate waste, which causes mistakes, mishaps and accidents in the workstation. These five actions consist of: Sort, Set in order, Shine, Standardize and Sustain. The five actions are depicted and explained in the Figure 7 (Liker 2010, p. 150)

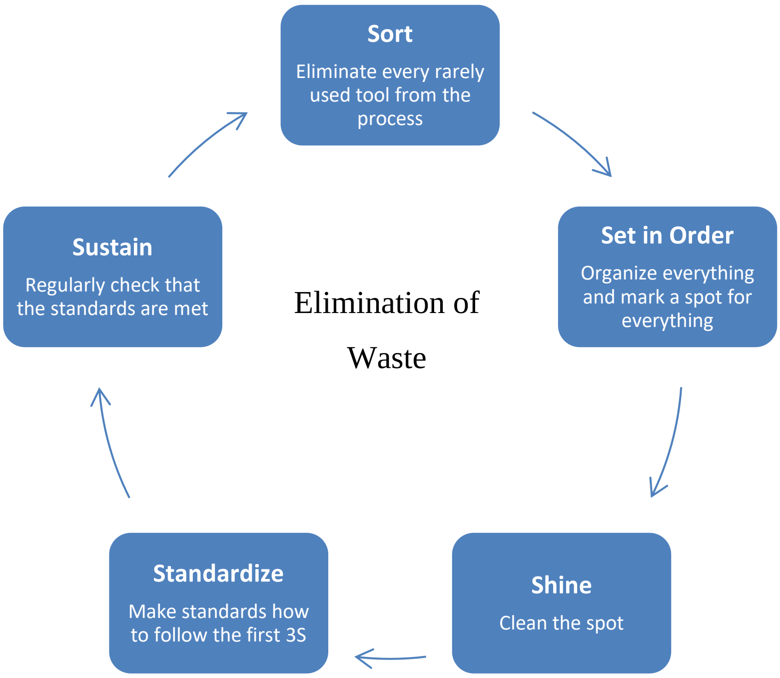

Figure 7. The basic actions of 5S explained. (Liker 2010, p. 151)

In a production environment the elimination of five wastes is usually the first thing that is considered when implementing Lean production philosophy (Liker 2010, p. 115). This is usually done by standardizing the workstation with using the 5S-approach and adding visual elements to the management of production personnel. This includes elimination of tools that are rarely used so that they are not in the way and organizing the tools used often and defining a place of storage for every tool. When the place of storage is defined, the place is usually somewhere that is easily seen and there is visual outline of the tool drawn to the place to ensure that the place of storage is quickly found. After these are defined, the workstation is cleaned, and the workstation is standardized. The process is sustained with regular checks, or “waste walks”, to ensure that the standard process is used and the workstation is as defined. (Liker 2010, p. 151)

3.2.5 Visual management

Every process possesses three kinds of flows: information, material and flow of cash (Torghabehi et al. 2016, p. 204). With visual management one can effectively regulate the flow of information (Torghabehi et al. 2016, p. 204). Visual management is one of the basic principles of Lean manufacturing and the tools were developed while the TPS was evolving (Torkkola 2015, p. 49; Torghabehi et al. 2016, p. 188). Torghabehi et al. (2016, p. 188) define the core values of TPS to be flow, value, harmony, perfection and scientific mindset. Visual management can support all these values (Torghabehi et al. 2016, p. 188). The goal of visual management is to create a working environment, where the worker does not need to perform additional tasks to get the information needed to fulfil his or her job description (Torkkola 2015, p. 49). In a traditional management environment the team leader has the best understanding of the big picture because the leader gets information from various processes and can build the understanding from there and relays the information to team (Torkkola 2015, p. 49). With visual management in Lean, the goal is to improve the viewpoint of a member of the team and to improve the transparency of the whole process (Torkkola 2015, p. 49).

Torghabehi et al. (2016, p. 191) state that visual management can be used in two ways: as an informative tool or as a directive tool. As an informative tool, the core idea behind visual management is to relay and visualize information. This category includes many Lean tools such as value stream mapping and flow chart. The second category, usage as a directive tool, the main point is to display requirements, set directions and guide actions. In the sense of usage as a directive tool, visual management has a strong performance management idea linked to it. Torghabehi et al. (2016, p. 195) list the benefits of visual management as follows: information simplification, information is provided at the point of use, employee empowerment, improves continuous feedback and communication, increased transparency, improved discipline, creation of shared ownership, management by facts is at the centre, morale boost and that visual management supports continuous improvement. (Torghabehi et al. 2016, p. 188-204)

The tools of visual management do not have to be technical and it can be done effectively by just using post-its, markers and a whiteboard (Sehested and Sonnenberg 2011, p. 63). A plan made to a board in a place everyone can see, can spark more conversations and ideas than a presentation. Sehested and Sonnenberg (2011, p. 63) state that in fact, low-tech tools can improve the two-way communication in a working environment. Also, usage of these kinds of low-tech materials can increase the flexibility and the swiftness of meetings. An example of a simple visual management board is depicted in the **Figure 8**. (Sehested and Sonnenberg 2011, p. 61-63)

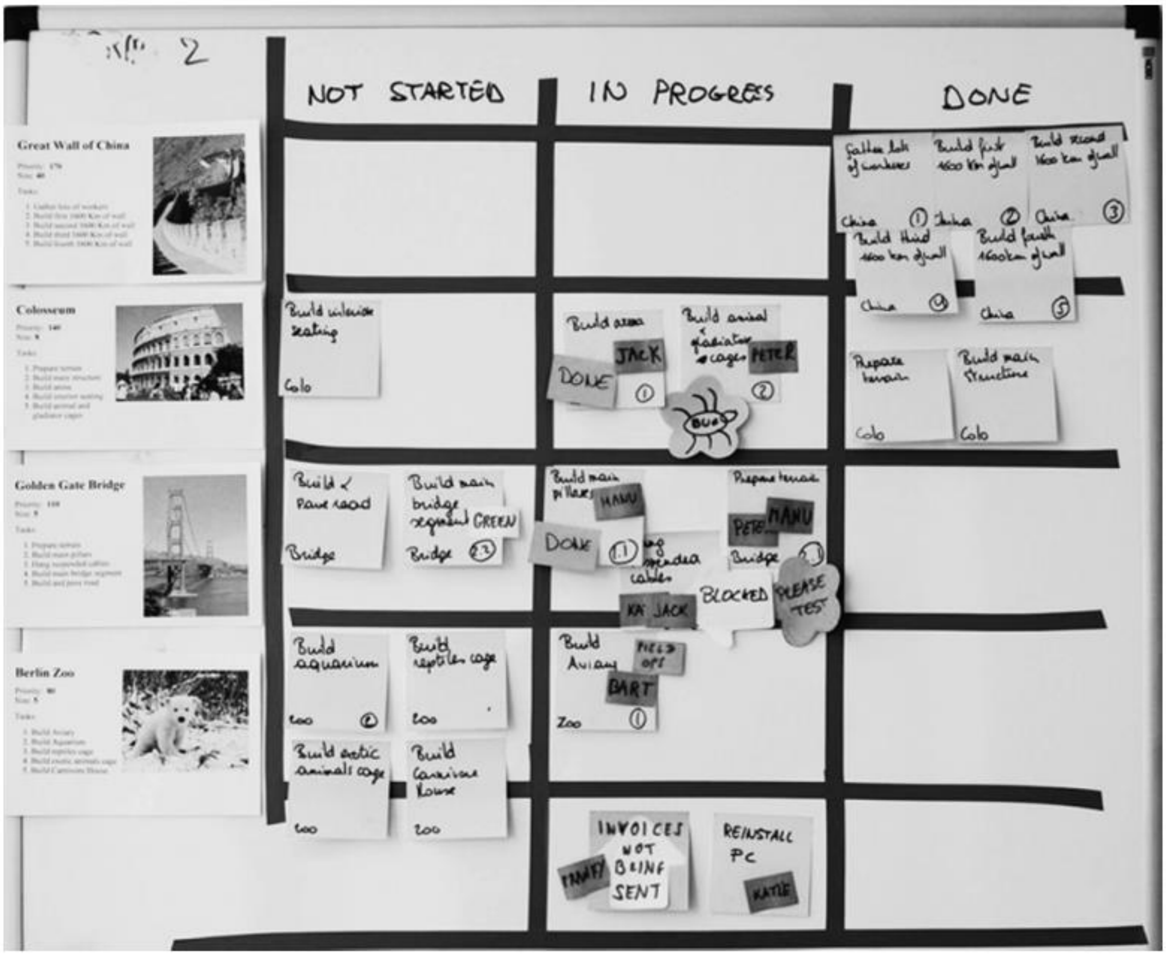

Figure 8. A simple visual management board (Sehested and Sonnenberg 2010. p.63)

Visual management as an autonomous process can render itself ineffective. To ensure that visual management is used to its full potential, according to Torghabehi et al. (2016, p. 191), it requires some supportive tools added to it. These supportive tools include continuous improvement initiatives and corrective action programs (Torghabehi et al. 2016, p. 191).

Also, as with any management program, the leadership and managerial support is crucial in the visual management (Torghabehi et al. 2016, p. 204).

3.3 Production planning and Lean

One of the things that Lean philosophy tries to avoid is “mura”, or imbalance (Liker 2010, p. 89). The imbalance develops from the waste within the process and from overloaded workforce and machinery (Liker 2010, p. 114). The imbalance within the production process can be tackled with effective production planning and standardization of the processes. In a Lean environment, exhausting the workforce with a unrealistic production amount is not acceptable (Liker 2010, p. 114).

3.3.1 Levelling - Heijunka

Heijunka is a specific methodology in Lean manufacturing which links the production planning to delivery to the customer. Heijunka can be described to be a simple method for balancing the make-to-order or make-to-stock production schedule. Heijunka aims at balancing the production through volume and product selection. In Heijunka, the production planning takes all the orders from a specified period and levels them to everyday production. The goal is that every day a same amount and selection of products is manufactured in the process. Also, the production schedule of the products is scrambled, for example product A and product B are not manufactured in the order AAABBB but ABABAB to balance the production time. With Heijunka, the demand of the manufacturing facility is also standardized to the subcontractors who deliver some products to the facility. This helps the subcontractor’s production planning, because with balanced production in the process also the demand to the subcontractors is balanced. Because Heijunka tries to balance the number of different products manufactured day-by-day it needs a small inventory of finished products, so the facility can respond to rapid spikes in the customers demand. For the levelling to be successful, the accurate manufacturing times are crucial to make sure that right amount of work is planned for the day. (Liker 2010, pp. 116–122)

To achieve successfulness in Heijunka, the production facility must minimize the setup times of production phases with SMED (Single-Minute-Die-Exchange) (Hopp and Spearman 2008, p. 157). Hopp and Spearman (2008, p. 158) identifies four basic concepts for reducing setup time:

- Separation of internal and external setup operations. Critical analysis if the steps that have the machine stopped in the current process, are necessary to stop the machine.
- Internal setup operations should be converted to external setup operations as much as possible. For example, component preassembly before shutting down the machine.
- Minimizing the adjustment process. According to Hopp and Spearman (2008, p. 159) this frequently counts for 50-70 percent of the setup time.
- Erasing the setup phase. This can be done with unifying the product design or by using parallel machines for different products.

The first step of SMED is to recognize which setup steps are internal and what steps are external setup. Internal setup operations include the steps that are performed when the machine is stopped, and external setup operations are setup steps that can be performed when the machine is running. For example, the change of picot is an internal setup operation, but the collection of tools to perform the change of picot is an external setup operation. The techniques for implementing SMED are various, ranging from quick-release bolts to standardized tools and procedures and to colour coding schemes. (Hopp and Spearman 2008, p. 158-160).

3.3.2 Kanban and takt time

Hopp and Spearman (2004, p. 137) characterise the main benefits of Kanban to be reduced WIP and cycle time, smoother production flow, improved quality and reduced costs. WIP and cycle time is reduced because the Kanban regulates amount of WIP and releases to the production, and because the WIP is reduced, according to Little’s Law, the cycle time is also reduced (Hopp and Spearman 2008, p. 243). With regulated WIP, the fluctuations in WIP levels are smoothed, the production flow also is more predictable and steadier. With the reduced WIP, the quality of the production line has to also improve. This is because with short production queues, the production flow cannot tolerate high yield losses and rework. Also, with short cycle times, the time between manufacturing error and detection of that error is shorter. The costs are also reduced with the improved quality and lower level of manufacturing errors. (Hopp and Spearman 2008, p. 137-139)

Krajewski et al. (1987, p. 57) concluded in a simulation study that benefits of Kanban are more due from improvement in the production culture than improvements in the logistics of the production process. However Hopp and Spearman (2004, p. 138) state that contributing the benefits of Kanban for cultural improvements, does not explain what exactly is the reason behind Kanban's improvements. While cultural improvements are integral for process improvement Hopp and Spearman (2004, p. 138) state that there are three primary logistical reasons for the performance improvement of pull systems:

- Less logjams in the process
- The process is easier to control
- Process has a WIP cap

In a Lean manufacturing environment, prioritization is not recommended but a Lean manufacturing environment makes possible product prioritizations easier as the production process is more flexible. The flexibility enables that manufacturing can be started as soon as possible as there is limited WIP and not long production waiting list, but because every production order comes from a customer demand, single product prioritization and hurrying through the process can lead to delay of delivery of many products. Lean manufacturing stresses that if prioritization within the production orders is done, then the prioritization has to be made with standardized process and according to a plan (Torkkola 2015, p. 57). Prioritization done wrong can be accumulate to overproduction waste. (Torkkola 2015, p. 27; Bhasin 2015, p. 78)

Takt time is a parameter used in Lean manufacturing when capacity is considered and takt time can be calculated by dividing the available hours of production with customer demand (Womack and Jones 2003, p. 55). When the production volume is changed, also the takt time has to be recalculated (Womack and Jones 2003, p. 56). The main principle of takt time is to always precisely and accurately define the process takt time in relation to demand and to plan the production sequence according to it (Womack and Jones 2003, p. 56). In a Lean company, the production slots are created according to the takt time calculations (Womack and Jones 2003, p. 56). Because the takt time is defined by the customer demand, customer demand should be balanced and predictable (Van Aartsengel and Kurtoglu 2013, p. 491). If the necessary takt time in relation to demand cannot be met, the whole team has to consider how to erase waste to ensure that the takt time is met (Womack and Jones 2003, p. 56). If the process cycle time is less than the takt time, then the process moves faster than the customer demand and building inventory. This also needs to be addressed when takt time is used so that no excess inventory is built (Van Aartsengel and Kurtoglu 2013, p. 492). This also drives the process to continuous improvement (Van Aartsengel and Kurtoglu 2013, p. 492).

3.4 Mass production vs. Lean production philosophy

According to Chiarini (2013, p. 3) mass production follows a very simple equation: quality equal to costs. This means that the basic principle of mass production is that employees and machinery is used to the highest possible capacity with the lowest possible cost. Usually in a mass production system in a manufacturing environment, employees are divided into department (e.g. welding, machining, assembly) and materials are moved between the departments. With movement of materials between the departments, the most profitable way to move the material is to move them when the batch size is big, for example in two weeks or even once a month. Usually the production planning in a mass production system is done by designing production for each department separately to maximize the output of each department. For example, if the production plans are done weekly, every department head can plan the department production cycle for every day to optimize the usage of machinery and personnel. This also enables some flexibility day-by-day if there is absences in the department personnel, but still if some day lacks production, it has to be supplemented by manufacturing more on another day. (Liker, 2010, pp. 91-92)

Mass production is problematic when it is considered in a Lean environment, because mass production produces a lot of intermediate storage between process phases. Also, if there are differences in the manufacturing speeds, the fastest process will produce a lot of intermediate storage. This is overproduction and is considered in a Lean environment to be wasted production facility space and waste of materials and resources. In a Lean manufacturing system, optimal batch size is always one. The other problem in a mass production system when studied with Lean is that when products are moved between the departments it causes delays in the lead-time of product. The biggest difference between a Lean manufacturing system and mass production system is that in a Lean system, one does not try to optimize the utilization of machinery and personnel for maximal capacity. Lean system optimizes the material flow to be fast and punctual and to fulfil the demand. This enables the manufacturing process to be flexible and to rapidly react to changing demand or to recognize defects and problems in the process. (Liker 2010, pp. 91–92)

One of the biggest advantages of Lean manufacturing is the one-piece-flow which enables for example, in-built quality control (jidoka), flexibility, improved productivity, freed factory floor space, enhanced safety, improved moral in the personnel and smaller storage expenses. In Lean manufacturing the in-built quality control is more efficient than in more traditional manufacturing systems. This is because every employee works as an inspector and works for repairing the defects of the manufacturing system. Also, the defects are quickly noticed and rectified, because there is not so much time between the manufacturing phases. The flexibility in the one-piece-flow system is a result of the short lead-time it provides so process can react quickly to the customers desires. Productivity improvement is a result of elimination of wasted time by the production personnel. When there is no unproductive moving of products the time is saved to be used in manufacturing or assembly. When the intermediate storages within the process are minimized it also frees up floor space. Also, usually when the machinery is separated into departments there is much wasted floor space and usually reorganizing the factory floor to Lean principles the space is used more efficiently. This also negates the need to do more investments in to the factory infrastructure. The decreased amount of unproductive movement also increases the safety of a manufacturing facility. With Lean manufacturing it has been noticed that employee motivation also rises. This is probably because the employee has realistic goals, employee can affect their own position process and an employee can also see the immediate effects of their work. (Liker 2010, pp. 105–112)

3.5 Previous Lean projects in the gear factory

There have been many different Lean implementations in the Hyvinkää gear factory, and many projects are ongoing to develop the Lean philosophy even further in the gear factory. During the year 2017 there was a master thesis carried out in the Hyvinkää Gear factory which considered the assembly lines acclimation to Lean manufacturing principles. The study constructed an example Lean-workstation for the assembly line and some developmental procedures were made to the production scheduling and measuring of the gear factory paint shop. Also, the study mapped the need for other development projects for the gear factory assembly line. The study observed the impact of Lean philosophy by comparing numbers in throughput and work-in-progress by recording them before and after the implementation. The observations from the production line were made by using workshops, daily leadership and using databases. As a result of this study the number of WIP was reduced by 11 % and the lead time of traveling machineries was reduced by 24 %.

During the year 2018 there was Lean Six Sigma-project where the current short-term production planning method was developed and launched. The starting situation of the project was that the component manufacturing lines poor part production amount was causing poor punctuality on gear deliveries. It was found that before the start of the project 80 % of the late gear deliveries was caused by lack of parts manufactured by the component manufacturing line. During the project, a slot model for the trolley line was developed and the data from the trolley line could be reduced to gears and drums for gear factory's production planning to use. The project clarified the role of daily management and the role of everybody in the chain of command of the daily operations.

In the year 2018 a Lean Six Sigma Black Belt training study was conducted in the gear factory. The main objectives of the training study were to stabilize production in the gear factory, ensuring that manufacturing is started on time, and to ensure that the parts that are hardened, are hardened in the right order. Also, one of the goals of the study were to guide the daily management of the manufacturing line and to ensure that the key performance indicators (KPI) are relevant. The study was conducted in the first phase of component manufacturing, and it included the turning, hobbing, deburring and keyway cutting manufacturing steps. The main tool for the study was a waste walk type of monitoring and visual observation in the manufacturing facility. The positive observations made from the training study were visualized priority items, new machine investments, clean working environment and lack of safety issues. The development suggestions that stemmed from the study were that transformation from push to pull should be driven forward and there should be visual KPI's in the daily management.

4 DEFINING THE PRESENT STATE OF THE PRODUCTION PLANNING PROCESS OF THE GEAR FACTORY AND COMPONENT MANUFACTURING LINE

The gear factory in Hyvinkää is in the middle of a development process which is leading from mass production process to a more order-based production process. The mass production history of the factory still is recognizable from different parts of the factory, for example, in the fact that there still are safety stocks on some products. The Konecranes strategy includes more and more Lean philosophy implementation, and it has already started in the gear factory. Gear factory's production goals are tied to higher punctuality and shorter lead time, and some changes to the manufacturing philosophy have been presented, for example the assembly line layout has been developed according to Lean philosophy and there is a project for increasing multiple know-how in the component manufacturing line. The biggest customer of the component manufacturing line is the gear factory assembly line. There are a few individual components that are manufactured on the component line individually and sent to the customer, but these are rare occasions. More common situations are when a customer orders a spare part package, for example ten shafts. These spare part orders are 2.42 % of the whole production amount of the whole component production amount. The core business of the component manufacturing line is to supply the gear assembly line with parts, so the assembly can function. The customer distribution is depicted in the **Figure 9**.

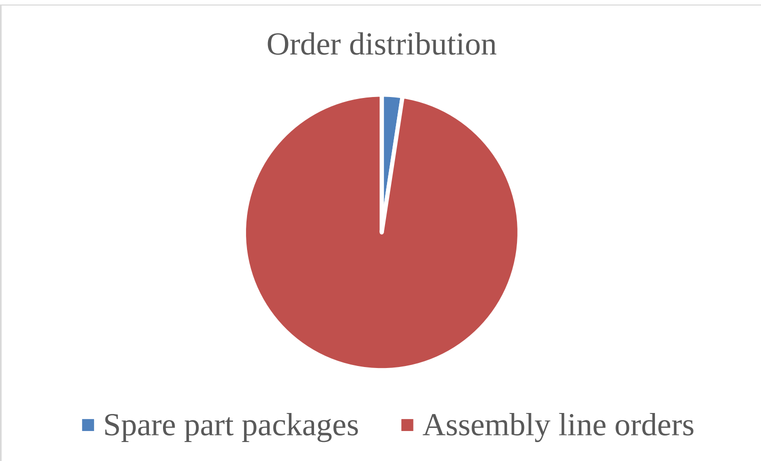

Figure 9. Order distribution of the component manufacturing line.

4.1 Factory setting of the component manufacturing-line and the production methods used

The Konecranes Hyvinkää gear factory component manufacturing line is a typical machine shop. The layout of the process is U-shaped and partly built according to the Lean philosophy. The workstations are positioned within the load groups they represent and according to the process the machines are manufactured for, so the layout is process oriented. The component manufacturing line has a one-shift cycle and the workday consists of eight hours, if something else is not decided. Factory is supplied with billets, and the billets are machined, hardened, grinded and tested. Details and the size of the products vary a lot, but the basic principles of the products are the same. The component manufacturing line manufactures shafts, gearwheels and other components. After the components are manufactured, the products are moved to the assembly line where the components are assembled to a gear or shipped as spare parts. The gear housings are painted and manufactured in other parts of the factory. When the billets are brought to the factory site, every billet have been already allocated to be a certain component. The supplier has also already cut the billets into specific sizes, so only one product comes from the billet. The gear factory gets all the billets from the same supplier. The most usual production routing of the billets is: turning, milling, deburring, hardening, cylindrical-, internal- and profile grinding. The usual production routing is depicted in the Figure 10. (Haatainen et al. 2019)

Figure 10. The usual production routing.

Cylindrical-, internal- and profile grinding are divided into two workstations. This results into that the most common routing amount is six. The distribution of routing amounts is depicted in the Figure 11.

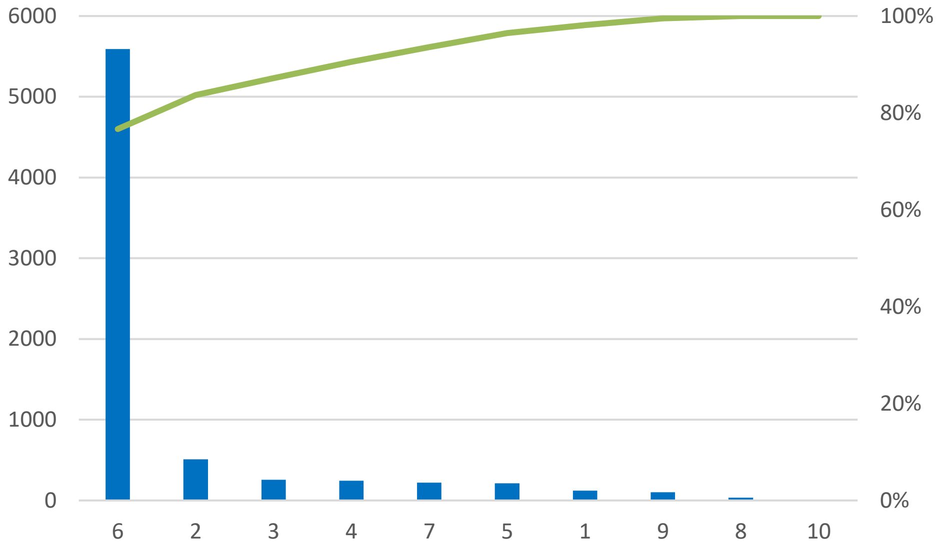

Figure 11. Number of routing phases in production orders for products.

From the **Figure 11** it can be seen that the most usual number of routing phases is six as it forms 77 % of the whole routing amount. The timeframe that was studied was from January 2018 to December 2019 and the data gathered was from all the products manufactured in the component manufacturing line. The graph does not consider what kind of work phases the routing consists of but only the amount of work phases on a production order. The variation of the number of routing phases results from the various product mix the gear factory manufactures. There are some products that are not hardened at all and there are some products that are hardened before the turning process. The component lines manufacturing cells are depicted in the Table 1.

Table 1. Manufacturing phases, number of cells in those phases and number of machines in cells.

Manufacturing phase	**Number of cells**	**Number of machines**
Turning	**4**	**7**
Milling	**2**	**3**
Deburring	**1**	**6**
Hardening	**1**	**3+1 in reserve**
Cylindrical grinding	**1**	**2**
Internal grinding	**1**	**2**
Profile grinding	**1**	**4**

The lead time of the products is generally distributed as follows: one week in the processes before hardening, week in the hardening process and a week in the finishing process. This equals to 21 days in the production process. There are some exceptions to this, for example the products that are not hardened and some products that are hurried through the process. The products that are hurried take usually a week, but these hurried products are rare. The usual time consumption is depicted in the Figure 12.

Figure 12. Normal time consumption in the production cycle.

The daily performance of different sections of the component manufacturing line is monitored in daily pulse-meetings, where possible abnormalities in the performance are identified. With the decisions of changes made in the pulse-meeting, the production foreman carries them out on to the factory ground. The product mix of the component manufacturing line of gear factory is various but the product mix can be divided in to five different categories: gear wheels, intermediate-, primary-, output-shafts. The number of gearwheels manufactured in the component manufacturing line forms 46 % of the entire products manufactured. Shafts form 54 % of the entire product mix. The distribution curve of the product mix in 2019 is depicted in the Figure 13.

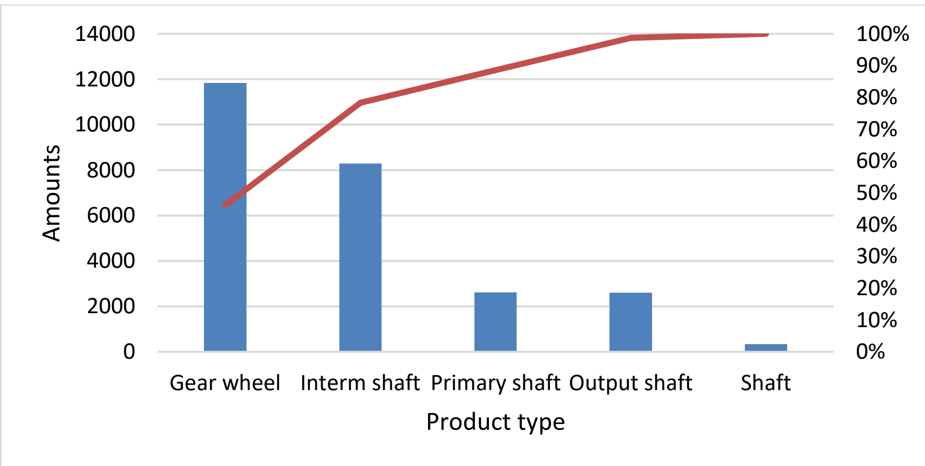

Figure 13. Distribution of manufactured products during the years 2016-2019.

4.2 Used production planning methods in the gear factory

Demand forecasting is done in the company Sales and Operations Planning (S&OP) department. S&OP does not use any mathematical methods in the demand forecasting process, like regression analysis or previous consumption analysis. This is because the individual orders are large and complex. S&OP keeps contact with the Konecranes dealers around the world and gathers the probabilities of leads and negotiations to become orders. A sale is considered probable when the probability of the sale is over 60 %, and the sale is generated into a "hot offer". The hot offers are gathered into two databases, which are managed by ports solutions and Industrial Cranes (IC) divisions. From the hot offers the S&OP goes through the sales funnel and identifies probable gears and parts to be included to the order (over 90 % probability to be included into the order). These probable orders are sent to the demand planner who combines the demand expectation with the probable gears used in these cranes. The probable used gears are evaluated according to technical guide's and history information. From this information a demand forecast is done in a PowerBI reporting platform. An example of a demand forecast report is depicted in the **Figure 14**. (Wahlroos 2019)

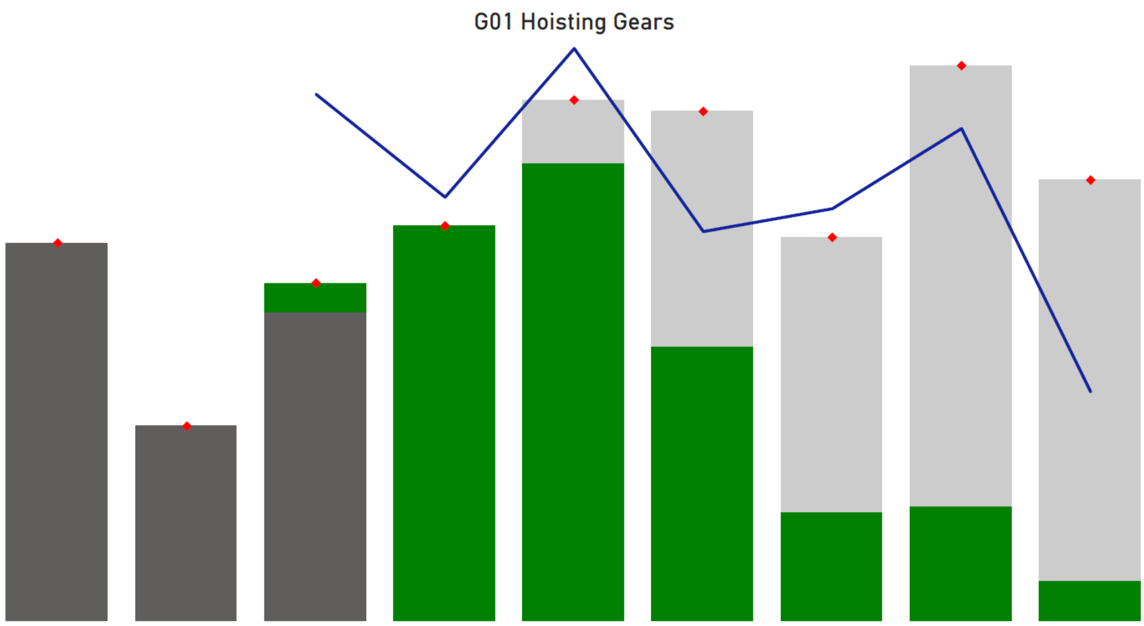

Figure 14. An example of a demand forecast graph provided by the S&OP division. In the graph there are manufactured orders (grey) planned orders (green), probable orders (light grey) and the capacity of the workcenter (blue line) depicted. (Wahlroos 2019)

When the “hot offer” is generated, the order specifics are sent to GOM-department (Global Order Management). The GOM-department assemble a slot reservation for the gear and parts for the gear, these are called planning BOM’s (bill of materials). From these the planning BOM’s material reservations are made and when the order is confirmed the hot offers and planning BOM’s are changed into a planned order. (Wahlroos 2019)

With the hot offers and planned orders, production planner makes rough capacity reservations for the gear assembly line. These capacity reservations are done using piece as a unit. This is because the products vary a lot, so product specific rough planning would be complicated. The software used in the gear factory production planning is SAP ERP system and some tailormade excel charts, which include some macro coding. The capacity reservations are done with different product categories. The categories for the capacity reservations are hoisting gears (G01), travelling gears (G02), machineries (G04), special travelling gears (G05) and drums (C01). Because the individual manufacturing times differ between gears, the capacity plan is not exact, but it brings abnormalities in the demand forth. When a lead realizes to an order and is changed into a planned order, the production planner picks it from the enterprise resource planner (ERP) and inserts it to the master production schedule (MPS). In the MPS, the production schedule contains only confirmed orders and not hot offers. The MPS reaches four months into the future and it does not consider the load occurring to component manufacturing line. The Make-or-Buy decision is done by the production planner in cooperation with the factory manager and the production coordinator in a monthly meeting about subcontracting and production choices. The basis for Make-or-Buy decision is the long-term production forecast, confirmed orders in the MPS and the amounts of products anticipated to be ordered in a certain time. If the decision to purchase the product from a subcontractor is made, the decision must be made at least three months before the needed due date to ensure that the subcontractor has enough time to deliver the product. (Rantasalo 2019)

About 80 % of the products are make-to-order products where there is no safety stock, but rest of the products are controlled as make-to-stock with safety stock. These are usually special travelling gears that are delivered to the Konecranes ports solutions. With the make-to-order products, when an order is made the whole gear assembly is put into the MPS and to the ERP and the ERP calculates it a date where the component manufacturing should be started and creates a BOM for the gear assembly. The production timing is done with backward scheduling so, the ERP calculates the start date according to the manufacturing time from the day when the product must be finished. With this data the production engineer divides the parts in the BOM to work phases. The amount of orders in the ERP are usually firm five weeks into the future.

The production assistant assembles the weekly production plan for the component manufacturing line, with the information from ERP and from the MPS. Usually the production is scheduled to end a week before the date it must be at the customer. The component manufacturing work phases are put into different weekly production plans, depending on their routings and the manufacturing times they include. With the safety stock products, when the predetermined alarm signal is reached it generates a production order for a predetermined amount for the product to be manufactured. This amount goes straight to the production assistant and it is put into the weekly production plan. Also, if there is demand for spare parts with a customer, the spare part orders are put straight into the weekly production plan. The orders that are generated from the Konecranes factories in different countries, are sent also straight to the production assistant. The weekly production plans are modified weekly, if there is production backlog from the previous weeks, the backlog is prioritized and goes to the top of the weekly production plan. Also, the production assistant can prioritize isolated parts, if the assembly line is waiting for them.

When the weekly production plan is done and the planned orders are changed into production orders, the weekly production plan is relayed to the production foreman. After the foreman receives the weekly production plan, the foreman divides the weekly production plan into daily production plans and with daily management, relays them to the factory floor. The production activities are not specified on a machine basis, but with the manufacturing cells. This is because in the ERP system the individual machines are not defined in the program. The production planning process is depicted in the Figure 15.

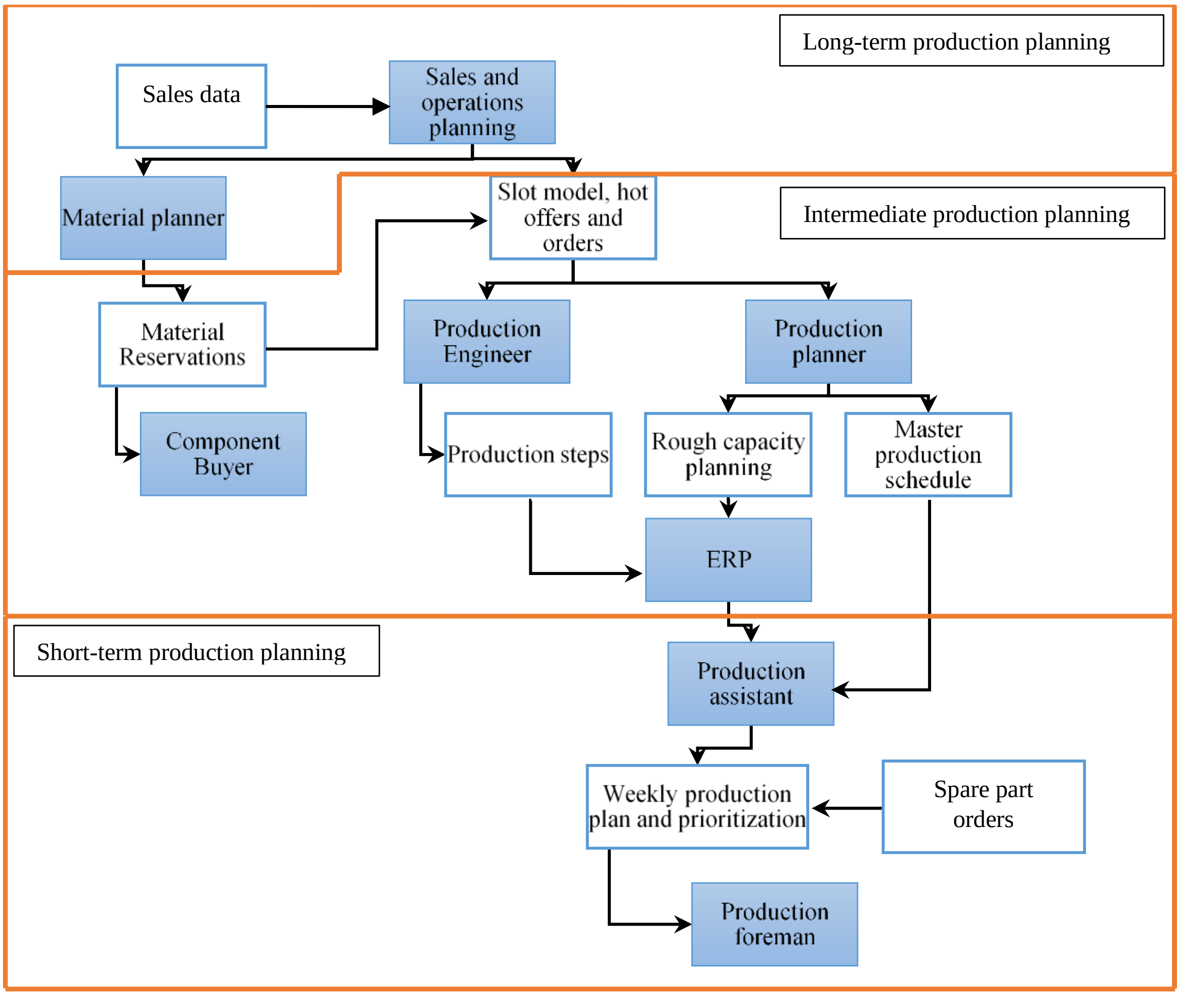

Figure 15. Production planning process of the gear factory. In the figure there are operatives (blue) and outputs and inputs (white) separated. (Wahlroos 2019; Rantasalo 2019; Rantasalo & Syrjänen 2020)

The production planning process of the component manufacturing line is highly dependent on the production planning process of the entire gear factory. Gear factory's capacity is planned according to the amount of gears that the factory can manufacture, and the component manufacturing line must fulfil the demand the assembly line has. The capacity of the component manufacturing line or independent work cells are not monitored in the intermediate production planning. The production foremen of the component manufacturing line, assembly line and drum manufacturing line inform the production planner of the possible capacity modifications, when there is changes in the production facility's capacity, for example vacation periods or long-term illnesses.

4.3 The intermediate production planning process in use on the component manufacturing-line

The whole production planning process of the component manufacturing line is done according to the needs of the gear factory assembly line. This is because the assembly line is the biggest and almost only customer that the component manufacturing line has. To ensure the production capability of the assembly line there is no reason to separate the lines production planning from each other. Intermediate production planning in the Hyvinkää gear factory is done by the strategic production planner of the gear factory. The position is new, and the process is still undefined and evolving. The intermediate production planning includes the scheduling and planning of the production of gears, components and drums. The actions of strategic production planner are reliant on actions of the previous operators in Sales and operations planning, global order management and the factory's production engineer. The inputs, outputs and roles of the personnel are illustrated in the swim lane illustration in the **Figure 16**. (Rantasalo & Syrjänen, 2020)

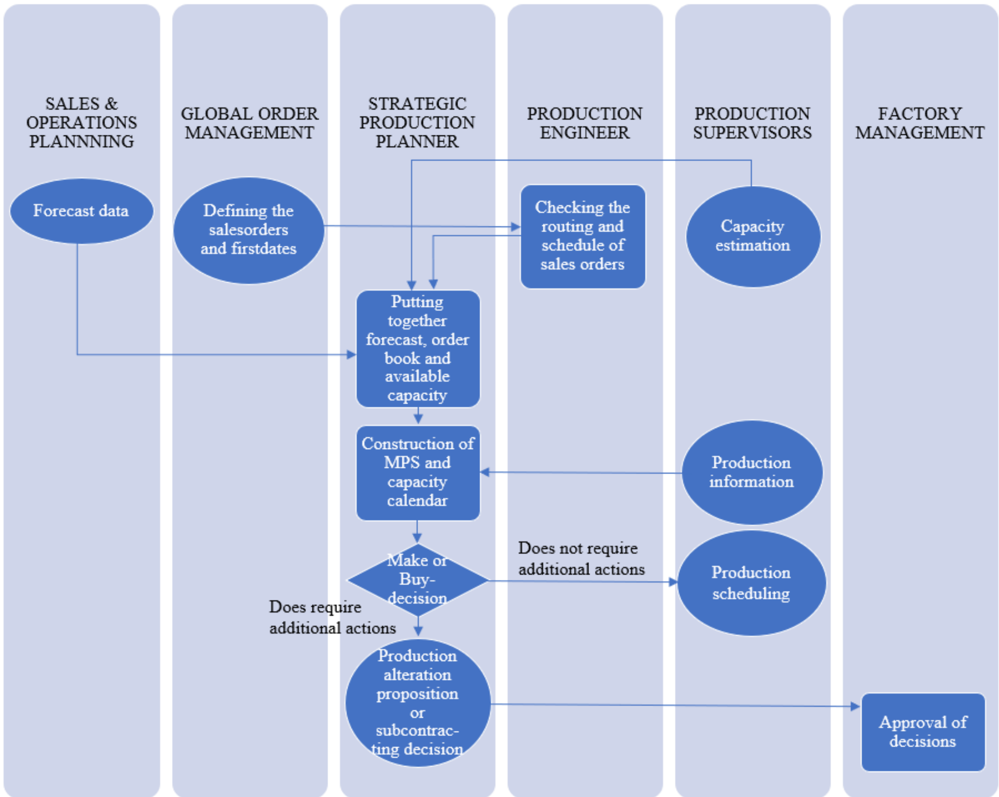

Figure 16. Swimlane illustration about the intermediate production planning process. Squares represent outputs, ovals represent inputs and rectangles represent decisions. (Rantasalo & Syrjänen, 2020)

The fact that gear factory cannot define the order amount itself makes the intermediate production planning more difficult and more rigid. The strategic production planner gets different kinds of data from different operators inside Konecranes, so the planner can compose the master production schedule and capacity calendar. The demand forecast data for the strategic production planner comes from the S&OP of Konecranes and global order management of Konecranes sends the confirmed sales orders to the gear factory's production coordinator. The production coordinator checks the manufacturability, schedule and routing of the product and inserts it into the ERP, from where the production planner can find it. Also, production coordinator makes the make-or-buy decision according to the component manufacturing lines ability to manufacture the part. With these information's, combined with accurate capacity estimation, which is sent from the production supervisor to the strategic production planner, the planner combines the master production schedule and capacity calendar. In the MPS, the production planner does levelling between production weeks. The levelling can only be done by moving production orders earlier, if production orders must be moved to further into the future, production planner has to inform the customer in question if the arrangement suits the customer. With the MPS and capacity calendar the production planner makes the Make-or-Buy decision, with consultation of the production coordinator and factory manager. From these decisions the production planner makes production alteration propositions or subcontracting decisions which must be approved by the factory manager. There are no specific signal values when the alteration decisions have to be considered and the production planner observes these situations individually. If the Make-or-buy decision does not require additional actions, it does not require factory managers approval either, the production orders move to the weekly production plan and to the production supervisors. (Rantasalo & Syrjänen, 2020)

4.3.1 Recognition of the parameters in use

The products manufactured in the gear factory are divided into four different product categories: G01, G02, G04, G05 and CHG spare parts. The production target for these categories are 20 pieces for G01, 50 pieces for G02, 80 pieces for G04 and 25 units for G05. There are no targets for CHG spare parts because the orders are not usually entire gears, but components. Spare part component orders usually come straight to production assistant. In the component manufacturing line, the daily production goal is 70 for each production step, including, turning, heat treatment, grinding and deburring.

Punctuality is one of the main parameters when the performance of the gear factory is measured. In the component manufacturing line, the punctuality is defined as the amount of operations manufactured in the right weekly production plan and operations completed in advance, divided by the amount of operations done in total. Punctuality is also one of the main reported values for the factory's manager to report to the manager of Konecranes Hyvinkää. As a reported value, punctuality is defined as the percentage of the value of on time manufactured products from all manufactured products. These products include spare part orders and orders for whole gears. All the factories of Konecranes Finland are measured according to this punctuality, but the measuring points vary across the factories. The goal of the punctuality in the component manufacturing line is 95 % as it is for the entire factory. In the component manufacturing line, a lot of things effect the punctuality of the line, for example, failures in the capacity planning, planned maintenance, machinery breakdowns and personnel absences. For production planning, there are no values defined for follow-up and measuring the successfulness of the production planning in the component manufacturing or in the gear assembly line. (Rantasalo 2019)

4.3.2 Comparing the key parameters from the production output to the production planning parameters

In the production planning process, the used parameter is the amount of whole gears divided into four product categories. Production planning does not take into account the amount of operations needed to carry out by the component manufacturing line or the number of components needed to be manufactured. The performance of component manufacturing line is measured by the punctuality of the line and the amount operations carried out weekly and the amount of resources tied into completed components is also measured. The amount backlog of the component manufacturing line is also monitored weekly.

4.4 Recognition of the possible problem areas effecting the production planning process

Component manufacturing line has many problem areas that cause uncertainties in the production planning process. These problem areas include absences in the workstations, machinery breakdowns, partial utilization of the data in hand, unsuccessful approximation of capacity, insufficient amount of personnel and quality problems in material and in manufactured products. In the intermediate production planning process, the production planner pursues to tackle these problems with working production overtime, workforce rotation changes, usage of subcontractors and moving the manufacturing or assembly work to the subcontractors. The possible problem areas are depicted in the Ishikawa cause-and-effect diagram in the **Figure 17**.

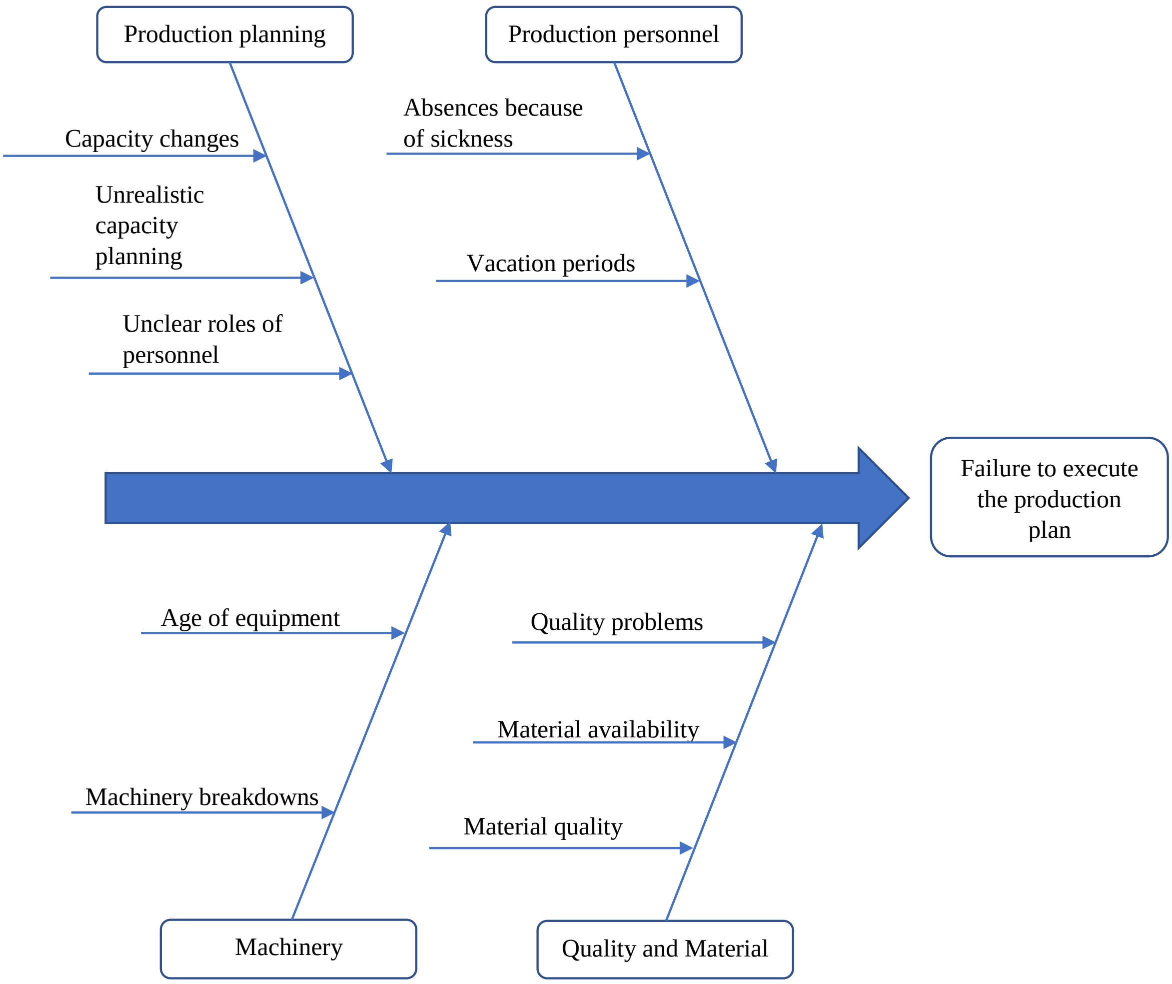

Figure 17. Ishikawa's cause-and-effect diagram about the production planning process when considering production insecurities (Haatainen et al. 2019).

From the **Figure 17** the different problem areas concerning production plan execution can be read. The problem areas are divided into four categories: Production planning, production personnel, machinery and quality and material. From these the categories are divided into smaller categories that have been identified from the production planning process.

4.4.1 Problem areas in production planning process

In the production planning process, there are a few different variables that effect the successfulness of the planned production amount. These include unanticipated capacity changes, unrealistic capacity planning and unclear roles of office personnel. In the intermediate production planning process, the production planner pursues to tackle these problems with working overtime, workforce rotation changes and moving the manufacturing or assembly work to the subcontractors. The capacity for operations for the component manufacturing line has been calculated to be approximately 1500 operations per week, but the range varies from 1000 operations during the vacation period to 2000 operations during a full work week. The demand that the component manufacturing line faces, is significantly larger. The average operation quantities of component manufacturing line with and without weekends and summer vacation period is depicted in the **Figure 18**.

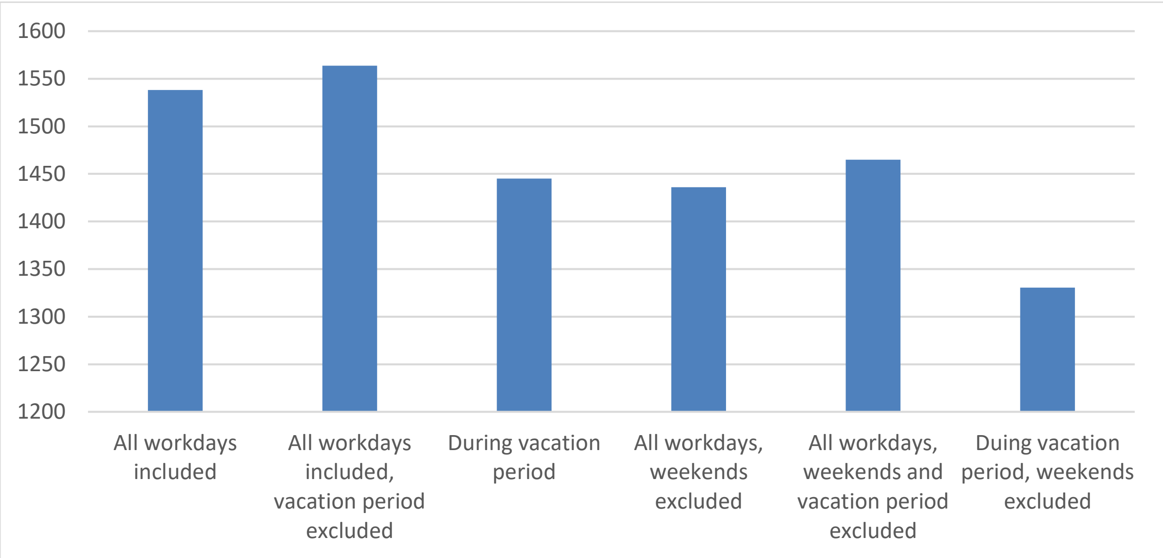

Figure 18. Operation quantity for the component manufacturing line.

Unanticipated capacity changes include possible projects, too late planned maintenance, rush orders that are prioritized by the company benefit and unanticipated shortage of production personnel, for example a strike. Unrealistic capacity planning usually results from, for example, over estimation of production personnel during a vacation period, over estimation of used machinery, unrealistic production goals and unbalanced order book. This can result into constant backlog forming and inconsistencies in the daily management in the office and in the production line.

Also, the underutilization of the Master Production Schedule can result into unrealistic production planning. MPS is the main tool for the production planner and it is used mainly for capacity planning and for production levelling. All the data in MPS is gathered from the SAP ERP system. The MPS does not take into account how long the order takes to manufacture, and the capacity is defined by past experience that how many gears can be manufactured in a week. MPS also does not consider the workload for the component manufacturing line, but only considers the capacity of the gear assembly. This can result into unintended overbooking on component manufacturing. The usage of safety stocks creates unnecessary confusion in the production planning process, because the production orders of safety stock products do not appear in the MPS. If safety stocks are unnecessary, they take up already limited amount of capacity in use without being planned. Safety stocks are a useful production management procedure with products with sudden demand spikes, but with the demand for the gear factory being somewhat constant, the availability of safety stocks decrease the flexibility of the component manufacturing line. Unclear roles of office personnel also are an insecurity as it creates confusion within the office and the production planning process and can result into failures in the production procedure. This is usually resulted because of misinformation or lack of information relayed within the office team.

The incoherence of the production system poses an insecurity to the gear factory and especially to the punctuality of the gear factory. The current situation is that the components are made to stock, but they have no inventory levels. Every component manufactured is started from customer need and an order, but the products are not allocated to orders but only made to inventory. This results into a situation that there are products in the inventory that are planned to fulfil an order, but anyone can get them from the storage for another order. During the study, this has resulted to numerous cases that the order has been delayed because the product has been delivered to a different order, especially this considers the spare part deliveries of the gear factory.

4.4.2 Problem areas in quality and material

Problem areas in quality and material consists of deficiencies in the billet material quality, deficiencies in the end products quality, failure of obtaining right kind or amount of raw material from the billet supplier. The number of material claims opened by Konecranes in the year 2019 was 11 and the number of billets included in those claims was 19. This amount amounted into 0.64 % of billets ordered from the supplier during the year. The material availability from the supplier has never been a problem for the gear factory. The number of billets is not always right, but the material availability has not been a factor for the gear factory, although it uses only one billet distributor. The delivery punctuality of the gear factory billet distributor, which included the late deliveries divided by on-time-deliveries, was 93.3 % for the year 2019.

The number of scrapped products from the production process differs from 0.18 % to 0.5 % depending on the workstation observed. The amount is taken from the number of scrapped operations in relation to the whole number of operations in the workstation. The reliability percent of the workstations is little distorted, because if the deficiencies resulted from the operation is not noticed right after the operation is done, the operation is checked and then the scrap will register to the workcenter in which the deficiency is noticed.

4.4.3 Problem areas concerning production personnel

Problem areas concerning production personnel can be various, and in the case of Hyvinkää gear factory, does not include the insufficient skills or professionalism. Problem areas in production personnel include vacation period planning, to ensure that the factory has enough personnel to achieve the production plan devised. The vacation periods during the summer effect greatly the amount of production that can be achieved in that period. This is because there are no additional personnel in reserves if someone is on vacation. Of course, there is some vacation period help hired during the summer, but the amount is still insufficient, and the skills are not on the same level as a regular worker. Hence the capacity is reduced in every role where a regular worker is on vacation. When a human aspect in production is in question, one must consider the possibility of absences because of sickness and their effect on capacity. The amount personnel at the present time is sized to answer the demand of the gear factory, se even a one person’s absence in the component manufacturing line can affect negatively to the capacity of the gear factory.

4.4.4 Problem areas in used machinery

Machine breakdowns and maintenance present a big insecurity in the component manufacturing line, because the capacity of the line is so limited that even the stoppage of a one machine in a crucial workstation can decrease capacity significantly. The age of machines in use vary a lot in the component manufacturing line, from new machinery to over 20 years old machines. The maintenance plan for the component manufacturing line is that every machine is scheduled to be maintenance annually, and these maintenances are planned, and so forth does not pose threats to production because production planning can plan for these. Machine breakdowns also possess a real threat to production because the gear factory does not have a method for controlling and monitoring the downtime of breakdowns or scheduled maintenance.

4.4.5 Other problem areas

During the research work, there was a different project going on where the bottleneck of the component manufacturing line was founded to be the workstation the shaft lathe workcenter, which consists of one CNC-lathe and majority of turned shafts go through that lathe. It is crucial to identify and define the bottleneck of a manufacturing line to ensure that the right step is developed.

Every week, the gear factory orders a billet for every single part that is planned to be manufactured during that week. In principle the billets are ordered for a production order, but in practice this is not the case. When the billets are delivered to the gear factory, they are received and put into the material storage on Thursday for the next week. Sometimes the billets are left unused because of a cancellation or a different reason, in these situations the billet goes to the material storage. The size of material inventory in the gear factory is approximately the amount of three weeks production. The existence of material storage is justified in the gear factory with possible problem situations with the material distributor, for example material shortage, that the manufacturing line can always operate. The Konecranes gear factory uses only one material distributor, so the risk is enhanced. In the material storage, three percent of the whole value of the material storage is spent in billets that have never been used during the time that Konecranes has used SAP in the gear factory. These billets are probably remains of the time before SAP.

5 DEFINING THE TARGETS FOR DEVELOPMENT

The Hyvinkää gear factory strives for continuous improvement in its processes according to Lean philosophy, so there are various developmental projects going on during the year. The areas in need of development in the gear factory are recognized through deviation observations and are modified into tasks through daily management.

5.1 Breaking down the recognized problem areas that effect the production planning process

The MPS in use in the gear factory poses a danger, because the MPS is separate database that is gathered from the SAP, but the information does not relay to anywhere. This may render the made production levelling ineffective, if it is not inputted to the SAP. The MPS problem could be evaded by moving the MPS and capacity planning to SAP, but this would require that the individual manufacturing times to be correct, which are assumed to be incorrect. Also, this would render the process of weekly production plan useless because the SAP moves production orders around depending on the basic finish date. This could be still a major improvement that could clarify the production planning process, but it would need significant development project and redesigning the whole production planning process.

The absence of component manufacturing from the MPS is troubling. It has been studied that the bottleneck phase of the factory is in fact the component manufacturing line, so it would be incremental to assure that no overbooking is done. The inclusion of component manufacturing lines in the MPS would be incremental also because if the amount of planned work to component lines workcenters is not monitored, it is possible that too large of a load is planned to be manufactured in a workcenter. This will cause backlog and delays of orders when the operations planned cannot be performed. The amount of operations planned was especially a problem during the vacation period (weeks 24-35) in 2019 and the amount of backlog exploded in the gear factory. This resulted into lots of late manufactured products. The amount of planned operations during the vacation period was not lowered but in fact raised. The target of the component manufacturing line weekly operation amount in the year 2019 was 2000 but in the week 32 there was 2750 operations planned. Also, the amount of operations done was heavily affected by the number of weekends used for overtime working. The relation between planned weekly operations and completed weekly operations is depicted in the **Figure 19**.

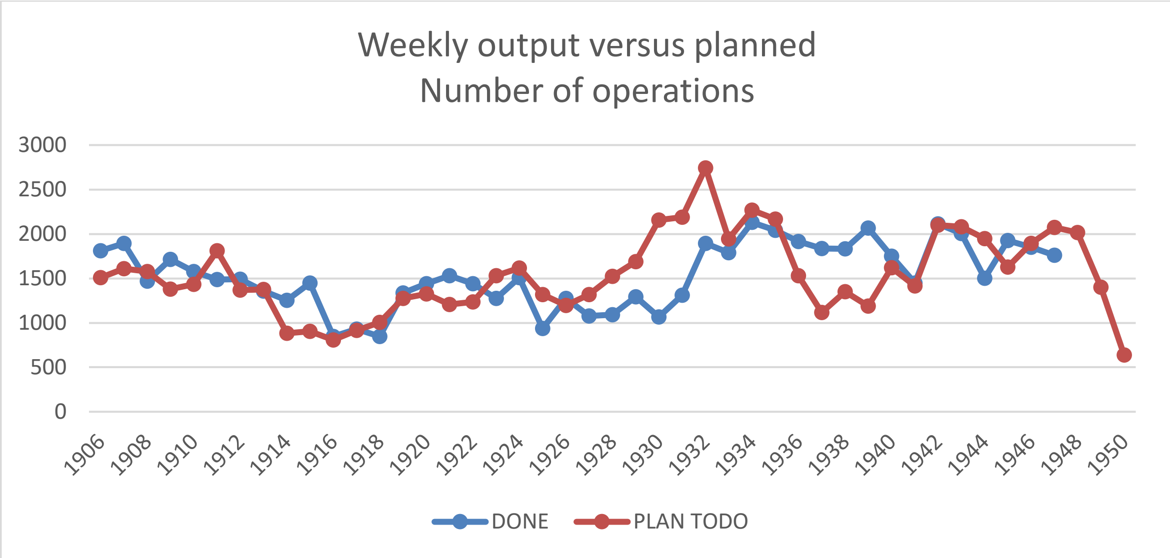

Figure 19. The relation between planned operations and done operations on a weekly basis.

The usability of the MPS is also problematic, because the MPS is only a separate Excel file. MPS is only used to help the leveling process of the intermediate production planning, as the weekly production plan is changed in the MPS the production order is firmed in the SAP. The firming action only locks the planned finish date to its place but does not allocate the order into a weekly production plan. When the weekly production plans are done, on the previous weeks Thursday, the firmed orders are also put into the weekly production plans. This produces waste as if the products production dates in the weekly production plan are moved the product is put twice into the weekly production plan, when the order is firmed and when the product is put regularly into the weekly production plan.

Machine breakdowns during the year 2019 have been various and numerous. Data gathered originally from the maintenance department of Konecranes Hyvinkää was strictly dependent on the invoices for maintenance assignments and the data did not implicate how long machine has been broken-down, but only indicated how many times in the timeframe a breakdown has happened and the cost of that breakdown. Also, the effect of the breakdowns couldn't be analysed from the production outputs from the MRP, because the MRP works with workstations which include numerous machines and not with singular machines. This also surfaced the problem that in case of machinery breakdown, the operation is moved to a different workstation if the workstation in question is not able to perform it, but the change is not recorded anywhere. This results in a distortion in the operation data. The amount of machine breakdowns of component manufacturing from January to October during the year 2019 was 53, from these over 50 % came from six machines. The number of machines in the surveillance conducted was 30. These five machines that had the most breakdowns are include the machines that have biggest workload in the component manufacturing line. The number of breakdowns for every individual machine is depicted in the **Figure 20**.

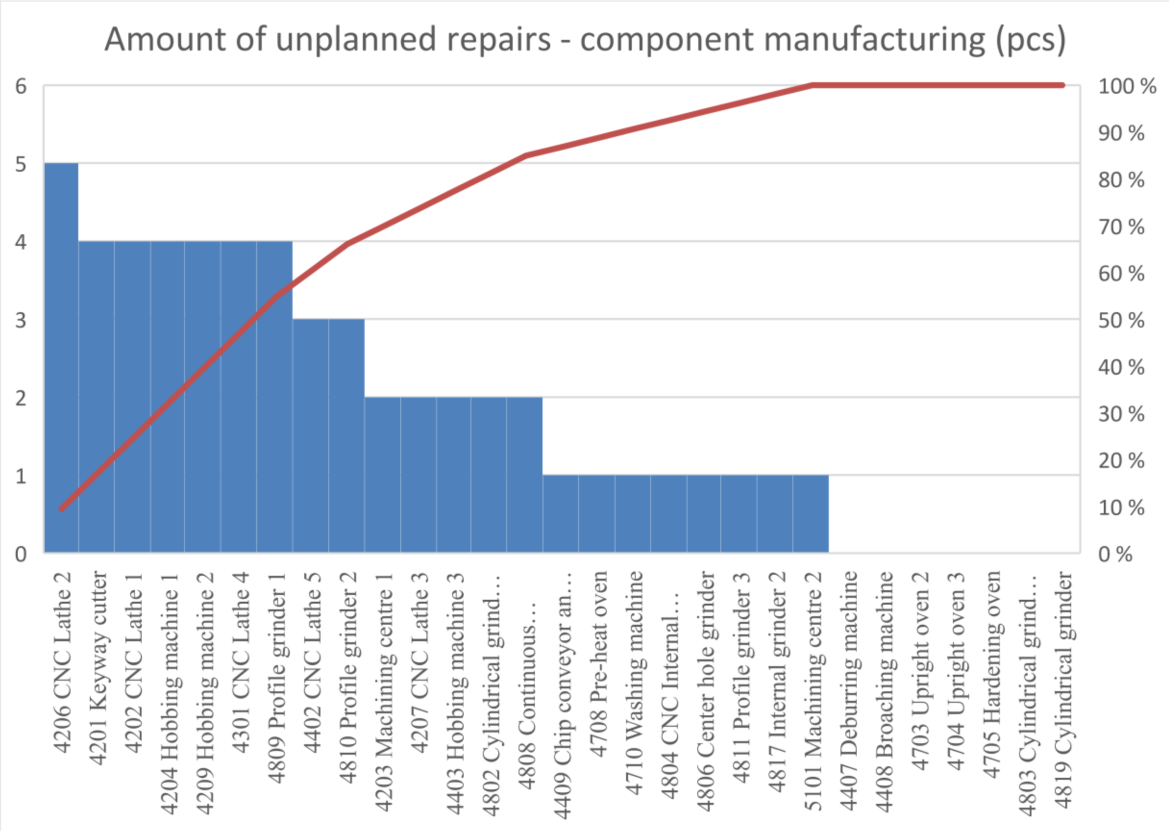

Figure 20. Amounts of machinery breakdowns.

When analysing the **Figure 20** data, one has to take into account that the data does not implicate the amount of time lost between the breakdowns. Hence this data can only be used when considering the individual reliability of different machines in the manufacturing line. The economical and productional implications of these breakdowns are hard to estimate, because there is no data of the amount of lost manufacturing time. If the breakdowns are estimated to last for a day the amount of lost days would be 53 and the average machines out because of breakdowns would be 1.23 machines per week. But the average machine breakdown time is not followed and there is no data about the duration of machine breakdowns.

Absences because of illnesses are a risk in the production environment which can effect the production capacity of the whole line. In the component manufacturing line 19 times in the year 2019 from January to October there was an absence because of a minor illness (one to three days) and eight times when the illness was significant (4-14 days). The amount of days these consisted were 41, which of 38 were working days. If it is presumed that the days missed with illness do not coincide and the amount of workdays in a year with basic manufacturing personnel is 264, the probability for a sick day is 0.14. Still even a one-person absence in a crucial manufacturing phase can impact significantly the capacity of that workstation. If the absences because of illness's coincide with each other, for example in the flu season, the risk of effecting the production capacity grows larger. Absences occurring because of a small illness could be tackled with a one additional multipurpose worker who would have the skills to replace a worker in any workstation. This could be achieved with rotating the person in a normal situation across the component lines machines. Still this option might be impossible to achieve, because the amount of personnel is already tight. The amount of absences caused by accidents in the Hyvinkää factory area was 23.8 days during the year 2019, including accidents that happened during commute and subcontractor accidents. Konecranes values safety in the workplace highly, but the amount of accident absences does not pose a major threat to the gear factory's production capacity.

The problem of the production planning in the current state is that the production capacity is not constant and that the planned amount of production is not constant. In an ideal situation the number of operations done, and the number of operations planned would be constant in a week to week timeframe. Of course, these amounts should be altered when there are some difficulties that affect the capacity of the manufacturing facility (i.e. strike, annual maintenance, etc.). From the **Figure 19** it can be seen that the number of operations done fluctuates a lot, the biggest difference is as much as 55 %. Also, the planned operation amount varies a lot, and the biggest difference between weeks is 65 %. This could indicate that the goals of the production are not clear, capacity estimation is not valid or the measuring of the operation amount of planned operations is not effective. These problems also lead into problems in the manufacturing floor, for example, in inconsistencies in the daily management and in drops in motivation. The biggest differences between of the number of operations done and planned operations can be also linked to the vacation period and the summer fill-in of production planners and production personnel.

The amount of operations done within a workstation during the vacation period varies a lot from roughly the same operation amount to as much as 47 % less. Some of the workstations clearly indicate that the insufficient amount of operations has been filled with working overtime and weekends. Also, with some workstations the deficiency in the operation amount has been filled with working an extra evening shift. During the vacation period there has also been some prioritization of personnel between workstations. The whole amount of average dropped operations was 193, but there is no clear way to measure the number of double shifts manufactured. The difference between the amount of operations completed during normal workweeks and the amount of operations completed during the vacation is depicted in the **Figure 21**.

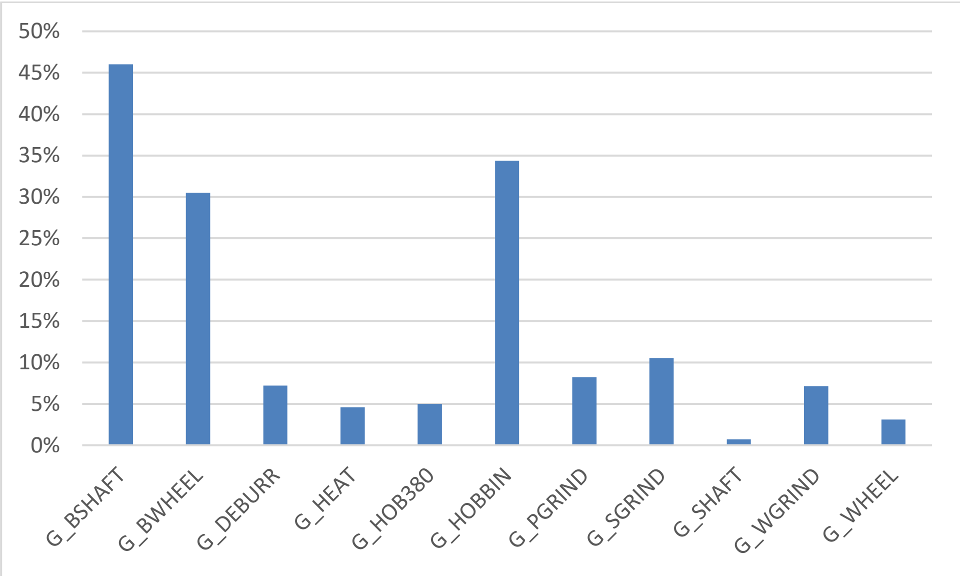

Figure 21. Change in percents between normal work week and vacation period production according to completed operations.

The figure 22 depicts the relation between risen backlog and the decrease in punctuality of the component manufacturing line. From the Figure 22 it can be seen that when operational backlog has risen, the punctuality of the component manufacturing line has dropped significantly, because component manufacturing line has had to allocate production resources to manufacture late production orders to minimize the backlog. It is crucial to depict the backlog amount in relation to the punctuality to ensure that there is no manipulation subjected to the punctuality value, otherwise one could only manufacture the products that are not late and keep the punctuality at 100% but the backlog would rise indefinitely.

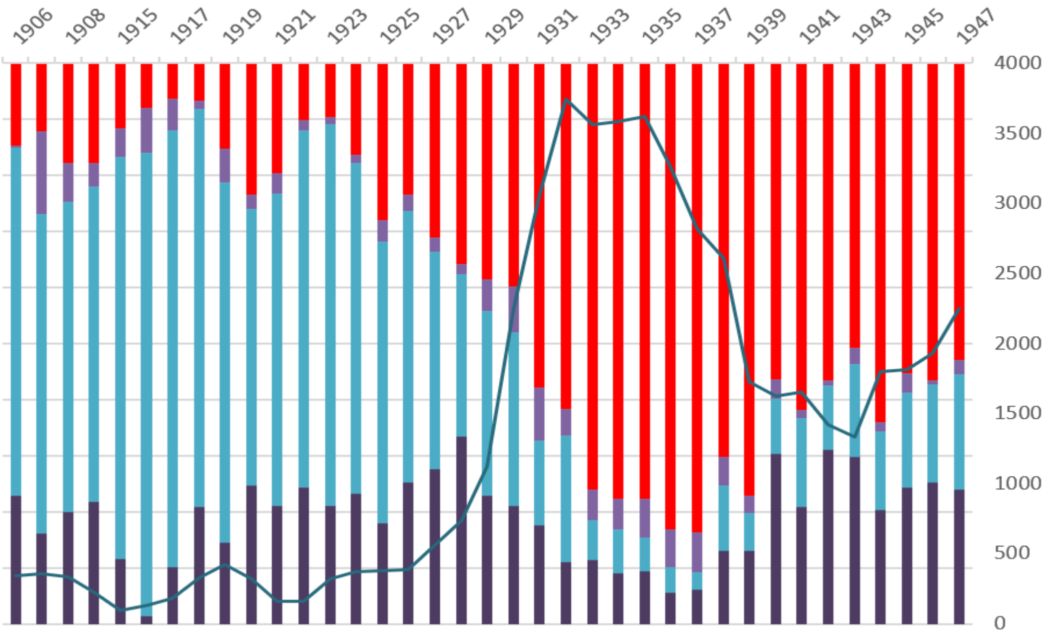

Figure 22. Punctuality (blue line) and the amount of operations done on time in relation to whole amount of component manufacturing line. The colours are as follows: done in the planned weekly plan (dark blue), done upfront of the planned weekly plan (light blue), done without a weekly plan (purple) and done late of the planned weekly plan (red).

The risen backlog amount can be linked to failure of planning the right amount of production to the component manufacturing line. The difference between output and planned production can be as much as 1200 operations, which is almost the weekly production amount of the line. Also, the number of weeks when the planned operations have been larger than complete operations is 21 which amounts to 45 % of the whole observed period. The overestimation on planned operations can be linked straight to the risen amount of backlog from the **Figure 22**. The failure of operation planning can be seen from the Figure 19.

5.2 Suggested changes for the production planning process

In the **Figure 23** is depicted the difference between how the punctuality is reported and how the gear factory itself measures punctuality. As it can be seen, the reported punctuality, which is measured with euros, is significantly higher during the summer and after it. This is because the amount of backlog accumulated during the summer to untenable heights and the gear factory had to manufacture that backlog away. This will lower the punctuality significantly because it is measured by dividing the operations completed according to plan by the total amount of operations. There can be significant uncertainty how the punctuality should be measured when the demanded values are different than the values that are studied within the gear factory, and one can question is it profitable to measure oneself differently than one is evaluated by.

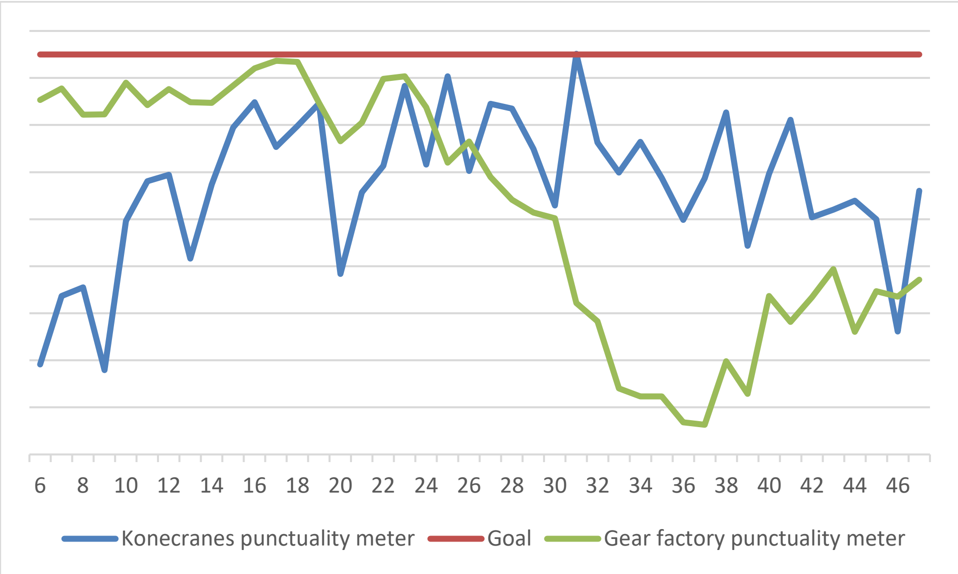

Figure 23. Difference how punctuality measured by the leadership in Konecranes (blue) and punctuality measured by the gear factory of Hyvinkää (green).

The MPS should include the component manufacturing lines key figures, if not for production planning measures, then for monitoring purposes and for ensuring that no overbooking is done to component manufacturing line. This could be done by following planned orders and production orders in the same way as the gear production planning is monitored in the present. When the order is processed in the GOM department of Konecranes and inputted into SAP, the production coordinator inputs the routing of the product into the material number. From these routings the MPS could be done independently or jointly between the workcenter in question. The technique behind composing the MPS could be used in the same way as composing the assembly lines MPS to manufacture the MPS for the component manufacturing line. Also, because the product mix varies a lot inside the component manufacturing lines products and the needed manufacturing time for different components vary as well, it would be beneficial if the manufacturing time could be observed when production planning is done. If this would be taken to the next level, the component manufacturing line could be monitored from the SAP itself with the SAP capacity planner, but this would need massive timing project to get manufacturing time, idle time and setup time to be valid on every product. The view what SAP capacity planner can provide is depicted in the **Figure 24**.

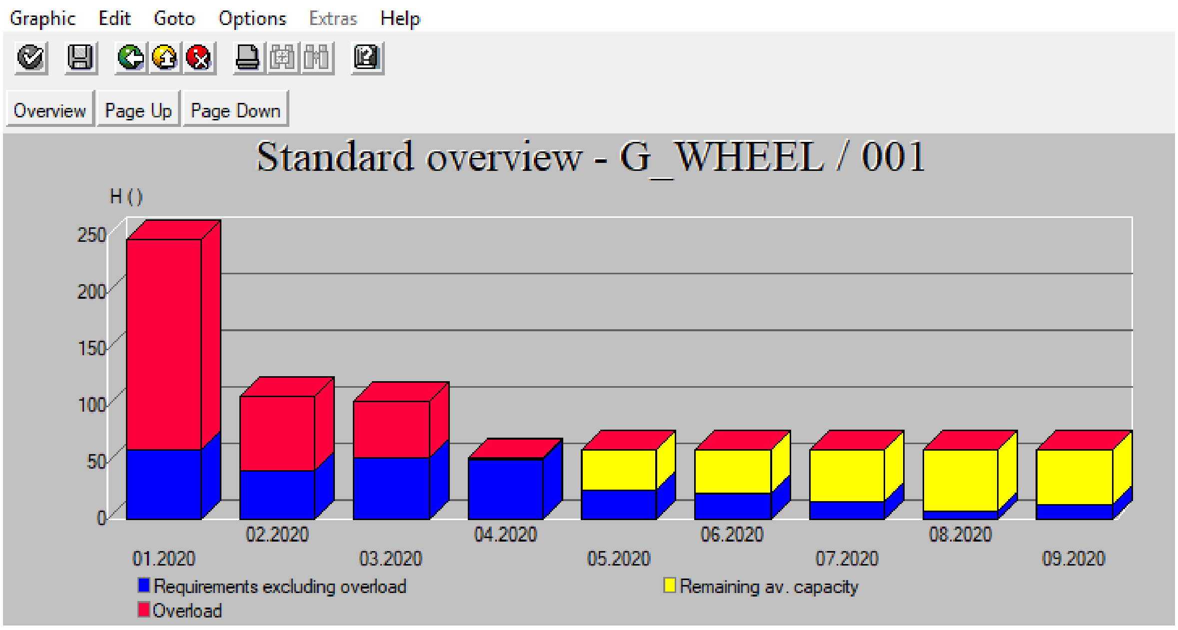

Figure 24. The SAP capacity planner in use.

If the times linked to the component manufacturing process could be updated to accurate ones, according to Lean philosophy the production planning should be modified to takt time and to answer all the demand from the customers, which in this case would be the assembly line and the spare part orders. This could push the development of the process in the component manufacturing line even further because the capacity as it is, is insufficient to answer the demand. This would need a vast project on mapping the times linked to the production process. The inclusion of Heijunka Lean method would be problematic in the component manufacturing line, as the product mix is so vast that effective production leveling would be too complex. Heijunka could be implemented into to the assembly line if the assembly workcenters would be more universal than product specific.

6 DEVELOPED SOLUTIONS TO THE PRODUCTION PLANNING PROCESS OF THE COMPONENT MANUFACTURING LINE

During the study, various developmental programs were launched to enhance production of the component manufacturing line and the production planning of the whole factory. Tools for mapping and measuring the risks involved for the component manufacturing were developed. These tools included a tool for machinery breakdown monitoring, capacity evaluation tool and a stacked chart for the production planning procedure.

6.1 Developed solutions for the production planning process

During the study some modifications to the production planning process were made. A chart for visual assessment of the load planned for the gear factory was made. The gear units planned to manufacture were converted to “universal gear units” to fit every kind of unit into a same chart, without making the chart unrealistic. With this chart the production planner can quickly check the amount of load planned to the gear factory in the coming weeks. The chart was assembled from the MPS database and its relevant six to eight weeks into the future. This takes the production planning process further and more visual. The chart also encourages the development of the assembly line to become more flexible and for the workstations coming more universal than model specific. The chart will also encourage the development of the assembly line to train the assembly workstations to be universal and not model specific. The universal workstations would also ease the workload of the production supervisor as the workforce movement would be easier between workstations. This was also pitched and developed to the S&OP division for depicting the demand for the gear factory Example of the chart is depicted in the **Figure 25**.

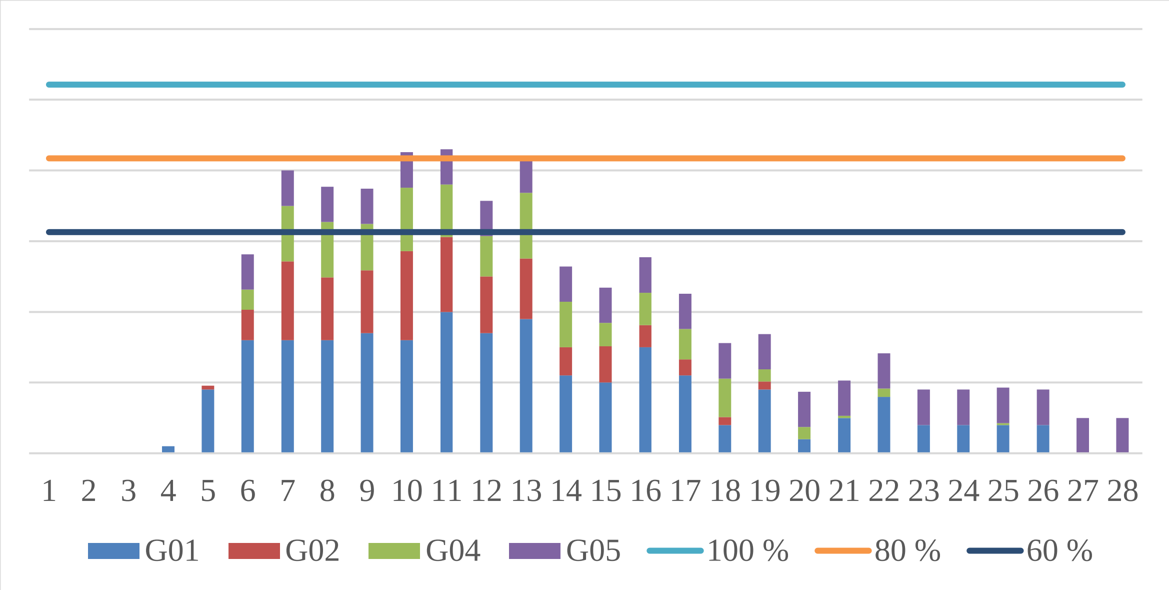

Figure 25. Stacked chart made from the MPS data.

The weekly capacity calendar for the factory was put into use and the calendar was shared to main sales divisions and to the trolley factory. This was an important development into assuring that no overbooking from the sales divisions is done. In the capacity calendar, the fluctuations of capacity, including national holidays, vacation periods and big projects, are monitored and the capacity is modified accordingly. Also, the available capacity is signified with colour coding. An example of the capacity calendar is depicted in the **Figure 26**.

Month	Jan	Jan	Jan	Jan	Jan	Feb	Feb	Feb	Feb	March	March	March	March	March	April	April	April	April-May
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
G01	20	20	25	25	25	25	25	25	25	25	25	25	25	25	20	20	25	20
G02	44	44	55	55	55	55	55	55	55	55	55	55	55	55	44	44	55	44
G04	64	64	80	80	80	80	80	80	80	80	80	80	80	80	64	64	80	64
G05	19,2	19,2	24	24	24	24	24	24	24	24	24	24	24	24	19,2	19,2	24	19,2
C01	16	16	20	20	20	20	20	20	20	20	20	20	20	20	16	16	20	16
G03																		
Soraluce																		

Figure 26. Example of the capacity calendar in use.

The process of how the fluctuations of demand forecasts are analysed was standardized and taken into use. The production planner saves the graphs that are provided by S&OP-division of Konecranes Finland are saved monthly, before the monthly subcontracting meeting with the factory manager, and studied if there are significant changes in the forecast between three and six months. Also, the reaction points to the demand forecast were defined and standardized. Reaction points were discussed and defined in a meeting to be if the demand of the individual product categories is under 60 % or over 100 % of the gear factory's capacity. These reactions start with the observation if the fluctuation is normal or if there are significant differences from a normal situation. If the fluctuation is significant, production planner must check the individual product demand forecast if the demand has just shifted to a different product category or if the demand overall has changed. From these observations the production planner makes the decision with the factory manager for subcontracting choices. (Rantasalo & Syrjänen 2020a; Rantasalo & Syrjänen 2020b)

6.1.1 Developments on the component manufacturing line

During the months of December and January, the amount of machinery breakdowns was followed, and the median of December was three machines per day were in an unusable condition and one machine was working with limited capacity. The number of machines with decreased capacity in the month of December was two on average and on median. During January the average amount of machines out was 1.9 machines per day and the median was two. For January the average amount of machines with decreased capacity was 3.5 and the median four. The amounts and medians during December and January are depicted in the **Figure 27**.

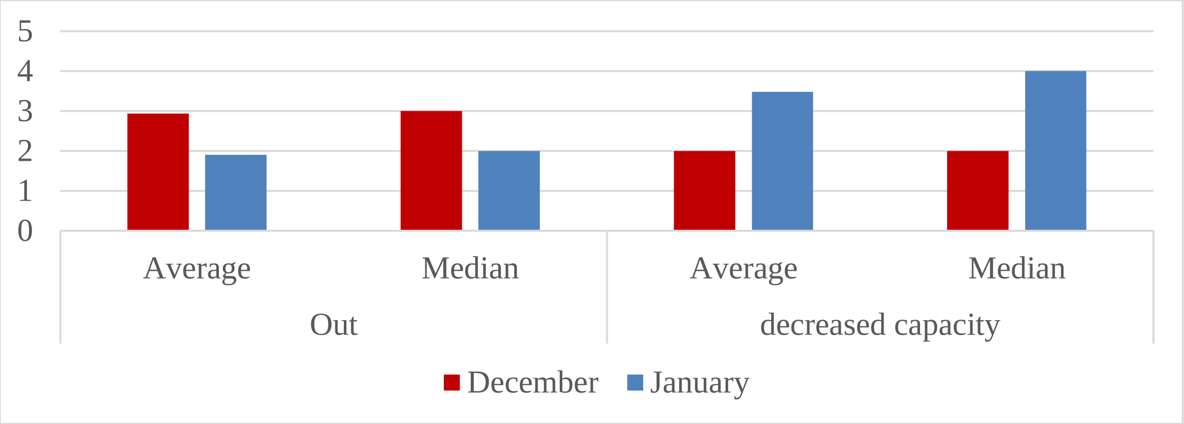

Figure 27. The averages and medians of machines out and machines with decreased capacity during the months of December and January.

The data from machinery breakdown monitoring tool was analysed and cross-referenced with the bottleneck analysis done by the Lean engineer and development engineer, and from this data a program to convert the lost machinery hours to lost operations. These lost operations are theoretical, because it does not take into account re-allocation of resources or movement of personnel because of machinery breakdown. Also, the theoretical capacity used is calculated from history information as an average, so it is only suggestive. The hypothesis is that the real number of lost operations is smaller than the theoretical one. The amounts of lost operations are depicted in the **Figure 28**.

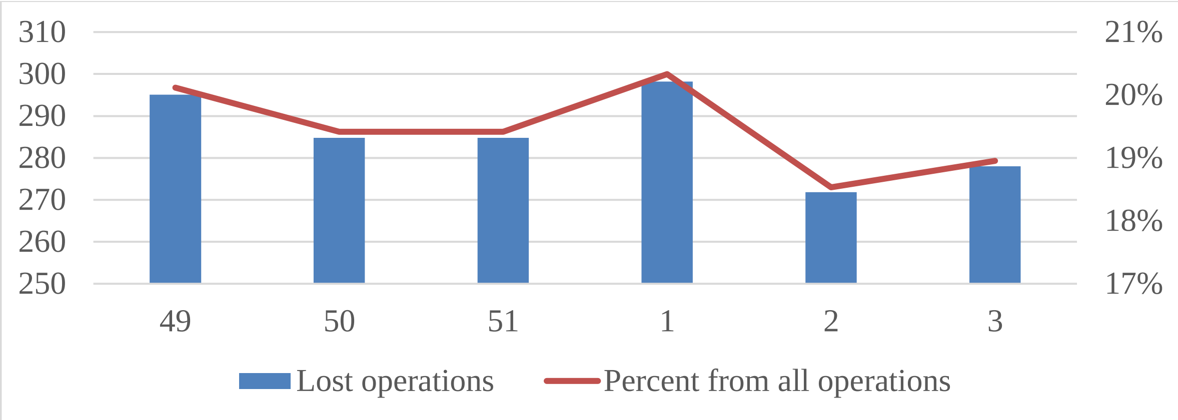

Figure 28. Amount of lost operations in relation to average amount of weekly operations.

During the research work safety stocks have been erased from component manufacturing, because of the confidence that the demand spikes can be smoothed with production levelling on week-to-week basis. This will ensure that the component manufacturing produces the right kind of products to a real demand.

7 DISCUSSION AND CONCLUSIONS

The study was done by using literature review as a tool for finding probable tools to use in the study. The mapping of the present state was done by gathering data from SAP ERP system and by using interviews as research method.

7.1 Reliability aspects of the research

Using a literature review as a data collection method is a method that is independent from opinions. With cross-referencing the references, the marginal for error in the review becomes less. The study used 8 scientific articles, 11 books and 4 commercial websites. Usually the information used could be found from different documents and the validity of the information could be confirmed. The development part was done by using interviews and meetings as a developmental tool. The individual responsibilities in the production planning process were developed according to Lean philosophy and the individual employee was taken into the development process.

It is hard to find public information of production planning systems in use in a similar kind of field, as the companies usually do not make this information public. Some benchmarking could have been done to ensure the functionality of the developments taken into use. Although because the interviewed personnel and employees included in the research have considerable proficiency and work experience from different companies from different and similar fields of industry, the results of this research can be considered valid. These employee opinions and interviews were also complemented by the literature used.

The used methods and developed solutions can be reproduced in similar kind of situations. The reliability of the research is affected by the interviews conducted, and the meetings kept as they were the basis with different kind of changes were made to the production planning process. The opinions of employees and interviewed personnel can change as time goes by, and because of this usage of interviews is kind of unstable way to conduct a research.

7.2 Review of the goals and the usability of the research

The main research question of the study was "What is the most optimal way to carry out the intermediate production planning of the gear factory's component manufacturing line?". The research showed that as the main customer of the component manufacturing line is the assembly line of the gear factory, the production planning of the component manufacturing line should be conducted according to the production planning of the assembly line. For the assembly line production planning the study developed a capacity calendar for the production planner to ensure that there is no overbooking done and the universal gear capacity measuring chart were made. The safety stocks of the components were removed to clarify the flow of the component manufacturing line and to ensure that the components are manufactured to a real demand. The first additional research question of the study was "How the demand prediction and the production planning for the gear factory is done?". The study showed and demonstrated how the production planning process is conducted from the demand forecasting done by the SO&P-division, to the weekly production plans that are relayed to the production floor. The second additional research question was "What kind of insecurities must be considered when intermediate production planning is considered and how are the insecurities measured?" The insecurities affecting the successfulness of the production planning process were identified and measured. One of the biggest problems were the lack of recorded data of these insecurities and the lack of measurement. The third additional research question was "What are the optimal parameters for intermediate production planning measurement?" This question links strongly to the main research question as the production planning should be done according to the assembly line, it is suitable to measure the production planning according to the demanded amount of gears. The study suggests with addition to this that alongside with the MPS used now, the MPS should also survey the amount of operations planned to the individual work cells. Also, takt-time approach should be studied if it could be used in the component manufacturing line. During the study, the capacity of the component manufacturing line was also studied and defined according to the history data of the year 2019.

The goals of the research were fulfilled. The punctuality of the component manufacturing line has been in steady rise since the research work was started. The punctuality of the gear factory was at its worse in the summer of 2019 under 30 % and has risen to over 80 % in the 2020 February. This probably is a result of different measures taken into use during the autumn, also the changes made to the intermediate production planning process will be seen only after a certain time period after the implementation. The demand prediction analysis has become a frequent part of the factory weekly management and the way the forecast is done is better understood on the factory level. The risk analysis part of the research has elevated some problem areas to the factory management and concretized the severity of the problem aging and unreliable machinery and the lack of capacity to fulfil the demand that is directed to the gear factory. This has resulted into that the machinery reliability has been rised to be the biggest risk in the factory management when the future and punctuality of the gear factory is considered. Also, the main Lean projects started were reviewed as was requested by the gear factory. The research can be used in the future when a production planning process is standardized or the company in question is wondering about the risks considering the production planning process.

7.3 Suggestions for further research and development

The monitoring of machinery breakdowns that was started during the thesis, should be developed even further and closer to automated process. The process used now is dependent on manual data input and the data comes from the production supervisor. A tool could be developed, where the workstations would record every single machinery breakdown by itself and data would be inputted into a database. This would reduce the amount of work done within the current process. Also, the data would be more reliable as it comes straight from the source and the hours down could be inputted more accurately. There is a study already about this from the year 2017 and a excel based tool was developed, but the research should be examined and tested thoroughly to ensure that the solution works in the current day.

The machinery reliability in use should also be researched further and tools for solving the large amount of machinery breakdowns. The increase in amount of the machinery is not a realistic option because of the limited space of the manufacturing facility. The possibility of renewing the machinery in use and the possible advantages of new machinery should be researched. The possibility of joining different work phases should be researched also. For example, the investment to a new lathe which could manufacture the keyways by itself and deburr the products automatically would render the deburring workstation useless. This would free the space and resources used now in deburring to different actions.

Taking the production planning to the SAP-system could be a major development in the reliability of the production planning and a major time saver for the production planner and for the production assistant. This would render the weekly production plan useless, but the weekly production plan was once made to make the MPS and SAP correlate. This would need a meticulous observation of idle-, setup- and manufacturing-times. The project to take this through would be vast and could take a really long time.

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