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Using agile capabilities to increase flexibility

Manufacturing in a high variation low volume production environment

Master's Thesis in the Master's Degree Program Supply Chain Management

FILIP ANDERSSON
ANTON BJÖRKLUND

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF SUPPLY AND OPERATIONS MANAGEMENT

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Report no. E2020:026
Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone + 46 (0)31-772 1000

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ABSTRACT

The emergence of agile manufacturing originates from the upcoming need to quickly respond to changes in the market. Agile manufacturing enables flexibility within the system and its main goal is to utilize the changes as an opportunity. The agile approach suits companies which offer customized products to its customers and have been proved to be suitable for companies which operate in a high variation low volume environment. However, all companies cannot use a generic approach of agile manufacturing as it needs to be adapted for the various prerequisites the company has.

The study was performed on a case company operating within the defense industry located in the outskirts of Gothenburg. The case company (TCC) offers highly customized products and the volumes are low compared to other industries. Their current production strategy is not adapted to the environment they operate in which has led to some disagreements. As the importance for TCC of being able to deliver the products towards the customers on time, delivery precision is an important metric. In order to ensure the ability to deliver on time, TCC has put in extra capacity to mitigate delays. However, with a potential increase in production volume, extra capacity will not be a long-term solution.

The aim of this report was to evaluate and analyze the potential performance outcomes and what type of production capabilities are needed for using a more agile operational strategy. Comparing what had been found in the current state and in the literature, four different agile capabilities were found and applied in two production sections. The capabilities were also the foundation of the analysis and to the performance outcomes. The outcome of using agile capabilities is to become more flexible in the production to better meet the customers demand. Flexibility could come in three different forms, new product-, product mix- and volume flexibility. TCC does however only need to increase the first two types because their order stock is planned years ahead. There was one further analysis performed which compared the two production sections against each other to see what they already did now which was aligned with agile manufacturing.

The study was limited to investigating two production sections, but the result and recommendations were intended to be applicable to all sections within TCC Gothenburg. However, since all sections produce different products and components, a modification must be done before implementing a method or tool. The recommendation is based on what is most important to start with according to a flexibility-prioritizing which consists of necessary-, sufficient- and competitive flexibility. However, many methods and tools have synergies and therefore is it recommended for TCC to focus on the necessary but also be aware of sufficient- and competitive flexibilities.

Keywords: *agile manufacturing, agile capabilities, HVLV, production strategy, flexible production, operational strategies*

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1. INTRODUCTION

The introduction chapter consists of a brief description of the case company used in the report as well as what the problem the study aims to answer to. Hereafter, the case company used in the study will be abbreviated as “TCC”. This chapter also presents the research questions and the scope of the report which will help the reader to grasp the thesis.

1.1 General description of TCC

TCC is a producer of world leading military defense and civil security solutions, operating on a global market. TCC is a Swedish founded company which main business is oriented in six different segments and in all segments, TCC wants to build long-term relationships with the customers. Therefore, service and quality are key aspects in their business in order to keep customers. TCC also has a subsidiary company, which is a consultancy firm with almost 2,000 employees specialized in industrial service and technology in mainly the defense industry. The facility in Gothenburg has both development and production as well as testing. The business area develops and produces various types of radar for naval, air and ground-based operations as well as various combat systems, electronic warfare systems and traffic control systems. Products can be sold both to internal to other segments and external to other companies or countries.

The company is divided into teams and this study is conducted within the team of Industrialization which is responsible for the development of the production. One of the goals for the Industrialization team is to improve the production layout and arrange the production flow for higher efficiency. Furthermore, the team is responsible for the design and development of future flow of products in order to match the estimated future demand from the customers. In addition, they are responsible to ensure the capability of the production, i.e. the ability to produce the products with the right level of quality.

The products vary from standardized to specialized items and the production processes varies between the different items. The standardized products are produced as make-to-order (MTO) and the specialized products are engineered-to-order (ETO) as they need to be developed towards a specific customer requirement. However, the ETO products are based on different types of standard products but some components may be changed to match the customers’ needs. The products are produced in low volumes and the ETO could be a competing strategy for TCC as the production have all the prerequisite stated by Jina, Bhattacharya and Walton (1997) to be defined as a high variation and low volume production (HVLV). The production is divided into a functional workshop with different sections for different types of products and operations. Some areas are flexible and can easily be changed to match the production of products while other areas are more difficult to change due to the accessibility of crucial facilities such as fixed machines or ventilation.

1.2 Problem description

The delivery precision at TCC has for a long time been an important metric for themselves as their contracts often include time requirements. To mitigate the delays in the production, TCC could use their relatively high resource capacity in the production facility and the ability to work extra shifts to handle the demand. However, the sales volume has increased the last couple of years which could develop into a steady high volume for a longer period in the future. This creates a problematic situation where it is not possible anymore to hide the problems in the production with overcapacity as the production itself cannot expand without any major investments. In order to increase the capacity of the production, the Industrialization team believes that the production needs to be developed and optimized. Furthermore, a project group have been created in order to evaluate if the production have the right operational strategy and the aim for the group is to find a long-term production strategy.

During the past decade, there has been a trend towards implementing a lean-based operational strategy at TCC, which in theory does not match a HVLV environment (Christopher, 2000). There has also been a goal to develop a common operational strategy or mindset which purpose was to permeate the organization. However, as TCC's production produces a wide range of various products and components there might not be one single operational strategy that could be claimed as the best, but instead a mix depending on which department or section it would be implemented in. It can be difficult to change processes and production flow for some sections as they are somewhat specialized, although there are some other sections that are more flexible in that matter. Within these more flexible production sections, there are some thoughts around implementing a more agile approach to manufacturing. However, there is a knowledge gap between the effects from the current production and the new approach which will be further investigated.

1.3 Aim

The aim of this study is to evaluate the potential performance outcomes of using a more agile operational strategy in two different production section compared with the current way of working, and what type of production capabilities are needed for such a development.

1.4 Scope

This study will include an analysis of the operational strategies at TCC and will be conducted within the transformer production section (Trafo) and the final assembly (Installation hall). After both sections have been analyzed, an additional analysis will be done with the two sections in focus. The recommendations will be in terms of what working methods should be prioritized for an agile operational strategy and what the two production sections can learn from each other, even though their activities are not similar. This study will end up in recommendations after what the analysis reveals about the effects from different operational strategies and ways of working. The analysis will compare the current state with the literature and what the production sections can learn from each other. Therefore, the recommendations will not strive towards finding best practice but rather close inform what the performance outcomes could be from the production flow and what type of capabilities are desired. The study will primarily focus on the internal flow inside the two production sections and how they are controlled and measured. The current flow will be analyzed but the manufacturing processes themselves will not be changed. Other aspects affecting the flow of products such as production planning or communication will be a part of the analysis and recommendation, but not the main area of investigation.

1.5 Research question

TCC sees an opportunity in developing a more agile operational strategy in some sections which they believe would benefit the production flow. However, there is a knowledge gap that must be filled before implementing any new strategy or make changes in the flow. Moreover, the performance in the production sections will be evaluated against a new, more agile, strategy. Therefore, this study seeks to answer the following three research questions.

RQ 1) What are the performance outcomes of the current operational strategy at TCC regarding the production flow, and what type of operational strategy is used?

RQ 2) How can flexibility be achieved in an HVLV environment with agile manufacturing and what theoretical working standards should be implemented at TCC?

RQ 3) What of TCC's current operational methods and standards that support agile manufacturing are transferable between the production sections and what are the conditions to transfer and adapt the useful standards?

Research question 1 will be answered in chapter 4, Performance outcomes of the current operational strategy. The second question will be answered in chapter 5, Flexibility in the HVLV production at TCC. Lastly, the third question will be answered in chapter 6, Analysis of transferable abilities. All three questions are also given a brief, more concrete, answer in chapter 7.1, Discussion of findings, where the answers are stated clearly as well as a short discussion of the results.

2. METHODOLOGY

The aim of this chapter is to describe the chosen methodology by presenting the research strategy and approach, research process and quality of research. These sub-chapters explain the reasoning behind the methodology and provide a base of understanding why the study is formed in a certain direction.

2.1 Research strategy and approach

The importance of a research strategy should be emphasized in order to find a good fitted strategy for the project (Bryman & Bell, 2015, p. 26). The research strategy is formed in two directions, either quantitative or qualitative, depending on how the research processes is conducted. A quantitative research strategy uses data to help to analyze the aim of the study while a qualitative strategy tries to clarify words, from e.g. interviews, seeking to understand what the stakeholder's beliefs and appreciation are. Bryman and Bell (2015, p. 26) also describes a third direction of a research strategy which is a mix of the two strategies previously mentioned. This mixed strategy is becoming more and more common and is appropriate when the study cannot fully rely on either the quantitative or qualitative research and therefore combines them to better support the analysis (Bryman & Bell, 2015, p. 28).

This study is focused on an ongoing operational strategy project where the Trafo production and the Installation hall will be analyzed. Data and statistics were gathered at the same time as interviews have been conducted which makes the study a mix of a qualitative- and quantitative research strategy. These two specific sections were chosen due to available resources for interview and due to potential improvement targets from the Industrialization team. Furthermore, the Trafo production was first chosen due to its improvement potential and that it fits within the scope of HVLV production. The Installation hall was a good comparative due to its relative long lead times on their system assembly. The differences between the two production sections was intended and gave the project a good insight in the various processes which TCC’s production has.

A study could have a deductive or inductive approach depending on whether its aim is to confirm or develop a hypothesis (Bryman & Bell, 2015, p. 11). The deductive approach is described by Bryman and Bell (2015, p. 11) as a strategy where the hypotheses are based on relevant theory and these different hypotheses are then verified on a real case in order to find if they are confirmed or should be rejected. The other approach is described as the opposite where the area of study, e.g. a company is analyzed, and the study aims to develop new theories.

This study has a deductive approach as the aim of the study is based on the analysis of what effects an agile operational strategy would give. The chosen approach is based on a request from TCC as they see potential effects on implementing methods and tools to increase the flexibility in the production. The research has therefore not been striving towards evaluating all various types of operational system but rather the potential outcome by using the agile approach and which elements or attributes is concerned.

The first research question will be answered in chapter 4, Performance outcomes of the current operational strategy, which will present the two production systems and their respective performance and operational strategy. The second research question will be answered in chapter 5, Flexibility in the HVLV production at TCC and the third question will be answered in chapter 6, Analysis of transferable abilities. Since the second and third question are analytical, they have followed a model for analysis based on Brown and Bessant (2003), Hallgren and Olhager (2009) and Chang et al. (2005) theory on agile capabilities and manufacturing flexibility which can be found in chapter 3.4, Key points from theoretical framework. The reason why this model, based on three articles, was created and used is because it enlightens all agile aspects of which TCC should focus on and was therefore suitable to apply on the research questions. The model is divided into two sections consisting of the four agile dimensions (strategy, people, process and linkage) and the core capability. The core capability further consists of two types of flexibility namely how to handle new products and the spectrum of the old product mix assortment in the production.

2.2 Research process

By the given mixed research strategy and the deductive approach, the research processes will answer what will be done in practice during the study. As a part of the study, a theoretical framework and mapping of the current state has been done. The literature framework is based on various operational strategies and how they can be applied. The literature review is focused on how the various strategies can be applied into the environment that TCC operates in which is high variation and low volume. Keywords used in the literature study was “agile manufacturing”, “agile production”, “flexible manufacturing”, in combination with “HVLV-production”. The literature has been taken from Chalmers library and are academic articles or similar with high credibility. After the literature study, the study continued with a data collection of the current state of the Trafo production and the Installation hall. The current state was analyzed with the theoretical framework developed by the literature study in order to give answers to the research questions. The study ends with recommendations of what different effects an agile operational strategy could give and what is needed to reach them.

2.2.1 Data collection

The data collection was based on three different steps: interviews, visiting the production to overviewing the processes, and collection of data from TCC’s internal ERP-systems. Interviews can be divided into structured, semi-structured and unstructured where the main difference is how follow-up questions could be used (Bryman & Bell, 2015, p. 466). The structured interview focuses on predetermined questions and if multiple people are asked in the same field, it is important that they get the same questions. On the opposite, the unstructured interview is explained by Bryman and Bell (2015, p. 467) as the ability for the interviewee to talk freely about a topic within certain frames given by the interviewer. The semi-structured is explained as something in between the structured and the unstructured where the interviewer asks different questions and it is possible to do follow up questions. This study has been conducted by using both semi-structured and unstructured interviews, see Appendix A for a full description of the interviews. The semi-structured interviews were used for the various type of managers, as well as members of the Industrialization team and with different experienced operators. The semi-structured interview questions can be found in Appendix B. The reason for the use of semi-structured interviews is to not limit the possible answers which a structured interview would have resulted in. Unstructured interviews are the least formal way of interviewing according to Bryman and Bell (2015, p. 467) but has been used when the production processes are explained by members of the Industrialization team due to the authors limited knowledge at that time. The Industrialization team also provided the interviewees that were relevant to start with.

The understanding of the production processes was done by visiting the production to see how the workers operate. The visual inspection aims to see how the various flows of products are structured in order to understand process charts. The visual inspection has also given a better understanding of how the various process steps are performed. To perform this study, data has also been collected from TCC's internal ERP-system. Such data are different throughput times, specific operation time, waiting time, number of orders, frozen plan and resource utilization.

Before the interviews were conducted, a member from Industrialization first explained briefly what the respective department or person had for role or typical work tasks. This was done in advance so that relevant questions could be prepared for the interviewee for the semi-structured interviews and so better open questions could be asked during the unstructured interviews. The follow-up questions were often used during many interviews so that various persons would provide a better base of the answer. The interviews were spread out over 1.5 months so that the data could be written down and sorted before the next interview. By not having used any structure interviews was beneficial due to that many of the interviewees had important inputs which directed the interview in various ways. To be able to ask follow-up questions provided data that otherwise would have been difficult to obtain.

2.2.2 Data analysis

The collection of the data from the interviews was first written and analyzed before it was applied in the current state. The analysis of interview data was meant to be as a structuring process for the current state. The answers that were provided was labeled and categorized in certain areas which later became the sub-chapters in chapter 4. The current situation has been further analyzed with the help of data from the ERP-system such as throughput times and product routing, i.e. when components needs be produced in order to be done for the assembly. Zohrabi (2013) mentions multiple strategies in order to ensure the internal validity of a study. One of them is to use triangular data, which is the use of multiple sources of data input and if they correlate, they can be assumed to congruence with the current state. In this study, the use of interviews, visual inspection and data from the ERP-system is the triangular strategy used to validate the result.

The information about the production and the workers within it will not be used in order to see what degree the workers can be further exerted by working more. On the contrary, the analysis will go into how they can work more flexible and likely less in order to be prepared for new challenges as the production will be flow- and not only resource efficient. By promoting the sustainable aspect of the people, the workers will likely be more motivated and stay longer within the organization.

2.2.3 Analysis of transferable abilities

In chapter 5, the two production sections were first immersed separately where the practice will be compared to the literature. When the two sections have been analyzed, there will be an analysis is chapter 6 between the two comparing their advantages in order to see what could be adapted or why it cannot because of certain conditions. By performing an overlapping analysis, an extended view beyond the sections alone can be enlightened and reveal new questions, control methods and ideals (Khan & Van Wynsberghe, 2008). Most importantly, the two sections could be compared with their respective strengths which later can be analyzed to see the potential of adapting way of working or methodology.

2.3 Quality of research

Trustworthiness as a quality criterion can have several meanings and can be improved or dismantled in many ways (Halldórsson & Aastrup, 2003). Trustworthiness is according to Halldórsson and Aastrup (2003) a combination of four combined qualities, namely: Credibility, Transferability, Dependability and Confirmability.

Credibility is not a single objective reality but instead only the construct of the respondent's reality. This means that the level of credibility is how well an author has “matched” the research data with the respondent's reality (Halldórsson & Aastrup, 2003). This thesis data comes mainly from tours in the production and interviews. To achieve a high credibility, the answers from the interview was directly read back to the interviewee during the interview so that misinterpretation could be limited. The interview themselves was also performed with the interviewee alone so that group pressure from colleagues or managers could be avoided. In addition, a team leader from team Industrialization has read and verified all data concerning the current state for an extra check.

Transferability is explained by Halldórsson & Aastrup (2003) as the extent to which the research can make general implications about the world. This can be described in other words as the external validity which is the generalization of a question. Time and space contributed to the ability of the application of the study which are the constraints of the application of the findings. Depending on the time pasted and the new space (environment) the study should be adapted towards, the transferability will have different level. This study is performed with a company which is in a niched industry which products are highly customized. In addition, agile manufacturing cannot be too generalized due to certain conditions for adaption, see more in chapter 3.2.2, Agile manufacturing – The agile approach of mass customization.

Dependability is according to Halldórsson & Aastrup (2003) the term of reliability which can be explained as the stability of data over time. It can be achieved when similar results have been proven over time with replicas of the same instruments. Stability could also mean the concepts of traceability which is the documentation of processes and audits. Reliability in this study is somewhat split. The data from the ERP-system is documented and the statistics could be verified for many years. However, regarding the interviews almost every actor had similar input which confirmed the data from the other interviews, but the study did not include all employees from every production section. This means that some data or opinions could have been missed, but since the information was confirmed by many parts, the dependability could still be considered as relatively high.

Confirmability is the fourth and final quality aspect of trustworthiness and it declares how much the result is biased from the researcher (Halldórsson & Aastrup, 2003). The findings, conclusion and recommendation should be traced back to their source to compare if they can be confirmed by the data itself. The interview questions were highly objective and allowed the interviewee speech freely however, the follow-up questions were directed towards certain areas which could confirmed e.g. a certain need. Furthermore, the various areas of questioning are somewhat subjective which makes the level of confirmability difficult to reach.

3. THEORETICAL FRAMEWORK

This chapter presents important theories and aspects for the reader to understand the current state description and later, the analysis. First, the reader is provided an overview of basic production knowledge of customization and HVLV and then the two different operational control methods (lean and agile) and, finally, the measurements of the different operational control methods are presented. In the last section (3.4) of this chapter, the analysis model which will be used in chapter 5 is presented as well as an overview of the theoretical framework.

3.1 The fundamentals of production

On the two very ends, production strategy can be divided into mass production and mass customization where the first one mainly focuses on reducing costs by striving to increase the production volume in order to gain economies of scale (Duguay, Landry & Pasin, 1997). It emerged during the industrial revolution in the nineteenth century in the US and it was adapted by Henry Ford which gave it further publicity due to its successful outcomes as he strived to find the “one best way” to perform each task in the production (Duguay et al., 1997). Some key elements of the mass production strategy are the assembly line, the high level of specificity on products and the focus on productivity. Furthermore, the mass production focus on a make-to-stock (MTS) strategy.

The opposite of the mass production is the mass customization which is a strategy focusing on the MTO strategy. The goal for the mass customization is according to Tseng and Jiao (2001) the ability to deliver products which fits the customers' needs in an affordable way. Mass customization is further explained as the ability to reach economies of scope rather than the economies of scale for the mass production strategy. However, the economies of scope should not be producing low volume but rather the ability to adapt products and services according to the customer's need (Tseng & Jiao, 2001).

The different production strategies have different application areas. Williams et al. (1987) mentions the great application of mass production where the production cycles are long, investments in machinery are high as well as low product variation. In the opposite way, Tseng and Jiao (2001) emphasize the great use of mass customization where the product life cycles are short as well as unpredictable demand. Moreover, companies facing more and more change and the mass production strategy has been to try to avoid it by creating a production system with e.g. buffers and high inventory levels in order to avoid problem (Duguay et al. 1997). However, companies are becoming more prone to adapt to the customization strategy in order to adapt to the changes rather than striving to avoid them.

3.1.1 High-variety-low-volume (HVLV)

The increased need to adapt to customization has challenged the conventional way of working and a mindset of “high-variety-low-volume” (HVLV) have been in focus (Tseng & Jiao, 2001). However, Jina, Bhattacharya and Walton (1997), emphasize the importance of not categorize every company with customized products as HVLV-companies. Their study compares an aerospace manufacturer to a construction equipment manufacturer. Both manufacturers face high variation in product specification to be able to satisfy the customers, but the differences in volume produced between the aerospace manufacturer and the construction equipment manufacturer are significant and they cannot therefore be both defined as HVLV-companies. Aspects which needs to be taken in consideration beyond just production volume and customization are supply chain network as well as the industry complexity. However, Jina et al. (1997) stress the problem with defining what a HVLV-company is as there is no hard limits.

Companies operating in an HVLV-environment need to have suitable structure and behavior compared to the setting they operate in (Gödri et al, 2019). Moreover, tradeoffs need to be done between different KPIs compared to the cost of the product. Gödri et al. (2019) emphasize the metrics of quality and service level to be critical for HVLV-companies and should therefore be non-negotiable which may cannibalize on other metrics, such as the cost. Further aspects which may generate costs is the difficulty to create a well optimized production system in an HVLV company as there is hard to customize it to all products (Guan et al., 2008). It is further stated to be beneficial to divide the products into product families in order to find similar flow between different products. Guan et al. (2008) suggest analyzing the products according to the pareto principle as there might be similarities regarding the manufacturing processes for the different products.

3.1.2 Production flow and layouts

There are four main types of production layouts which are functional layout (job shops), line assembly, production cells and lastly fixed positions (Jonsson & Mattsson, 2016, p. 227). In this chapter, functional layout, production cells and fixed position will be described as they are in the area of study. Furthermore, flexible manufacturing cells presented by Kostal et al. (2010) will also be described, which a type of production cell is.

The functional layout is according to Jonsson and Mattsson (2016, 227) the only process-oriented layout and is based on the variation of processes in different sections according to their functionality. A basic example for a mechanical workshop to divide e.g. the lathes, drilling and grinding machines in different sections. The main advantage of using the functional layout is the flexibility (Silva & Cardoza, 2010). The high level of flexibility enables various quantities and product mixes to be produced. This type of layout is also less sensible for disruptions in the flow (Jonsson & Mattsson, 2016, 227). Regarding the disadvantages of using the functional layout, there is not possible to use a continuous flow in the production, but it rather promotes to work with batches (Silva & Cardoza, 2010). This is further stated to be one reason to quality disruptions as a whole batch may have been produced before a quality defects are identified (Silva & Cardoza, 2010). The process-oriented focus in the functional layout leads to high level of work in progress (WIP) between the processes which leads to tied up capital (Jonsson & Mattsson, 2016, p. 227). Furthermore, the high level of WIP generates long throughput times.

The cellular layout is based on the sectioning of products with similar production attributes such as shape or production processes needed together in order to create effective production (Silva & Cardoza, 2010). The cellular layout has similarities with the line production and have in general short throughput times as well as low WIP (Jonsson & Mattsson, 2016, p. 230). Furthermore, it is more flexible and less sensitive for disruptions compared to the line assembly as the production is not fixed according to the workstations. Silva and Cardoza (2010) mentions the drawbacks with cellular layout as relatively low level of flexibility and is not a good option if the product mix is changing. Furthermore, the use of cellular layout could generate duplicates of machinery which may be impossible as a result of high cost of machinery. With the use of cellular layout, it can be hard to achieve a high level of capacity utilization as the layout is product oriented and is focused on flow efficiency (Jonsson & Mattsson, 2016, p. 230).

However, if the cells are designed as flexible manufacturing cells with an agile aim and not large batches, the production time and cost could be improved (Kostal et al., 2010). A flexible manufacturing cell allows a production of a smaller number of products than regular cells but with a larger range of products. Kostal et al. (2010) explains that the main attribute must be flexibility in order to succeed in making these cells, because the total production time is very dependent on the time between tasks. To achieve an optimized material flow, the flexible cells depend on supporting activities such as material and tools supply or fixtures to shorten the passing times when the product is at the station. Kostal et al. (2010) also mentions that automatization can be difficult at these types of stations because change is continuous between the rebuilds and therefore is humanization of the workplaces a way to achieve faster through put times and secure quality.

For large products which are not possible to move during assembly, the only layout possible is the fixed position (Jonsson & Mattsson, 2016, p. 231). The fixed position requires the material to be moved to the position in order to be assembled. The material flow must be of high level in order to generate an effective assembly process as if too much material is delivered too early, the material could disturb the assembly while material shortages may disrupt the process (Sassani, 2016, p. 31-32). Therefore, process and material planning are crucial in fixed position assembly.

3.1.3 Work in progress and throughput times

WIP is the definition of the inventory of products between the first and last process, otherwise it is defined as raw material respectively finished goods (Conway et al., 1988). WIP can be both advantageous and disadvantageous depending on the context it is used in. Conway et al. (1988) mentions two different aspects for WIP to be useful which are the location and quantity of the products. WIP should be used to manage short term disturbance in the flow, and not long-term imbalances generated by the flow itself. The lack of knowledge of the difference between the various horizons is one reason many companies have excessive WIP according to Conway et al. (1988). Production flows with bottlenecks can use a buffer strategy in front of the bottleneck in order to maximize the resource efficiency (Leitch, 2001). It is however stated to be a tradeoff between increased capital cost and longer throughput time versus focusing on the resource efficiency for the bottleneck.

Long throughput times are, in addition to tied up capital, an increased risk for long delivery times towards the customers as well as obsolescence's (Jonsson & Mattsson, 2016, p. 235). According to Little's law, if assuming a steady state condition, the number of products waiting in the system is equal to the waiting time multiplied with the number arriving products (Little, 1961). According to this theory, the throughput time is depending on both the number of WIP as well as how long time each product takes to produce. According to Jonsson and Mattsson (2016, p. 236), production flows and layouts which generates lower number of WIP would then also generate shorter throughput times. Hence, depending on if the production system is either product- or process oriented, it will influence the throughput time.

3.2 Different methods of operational control

What type of manufacturing strategy and operational control to use depends on the prerequisites of the company. Christopher (2000) exemplifies the agile and lean approach to be applicable in various environments which is based on the three different aspects of variety, variability and volume. Variety is exemplified as the number of stock keeping unit (SKU) and the variability as the predictability of the demand. Figure 3.1 illustrate Christopher's (2000) matrix of when agile and lean works best. However, the third aspect of volume is also stated to be critical where a high volume suggest the lean approach and a low volume suggest a more agile strategy. Christopher (2000) gives examples of companies which started to implement lean, and thereafter turned to a more agile strategy as they perceived it would suit them better. This is not stated as a bad strategy as there is lean methods which also can be applied in agile companies.

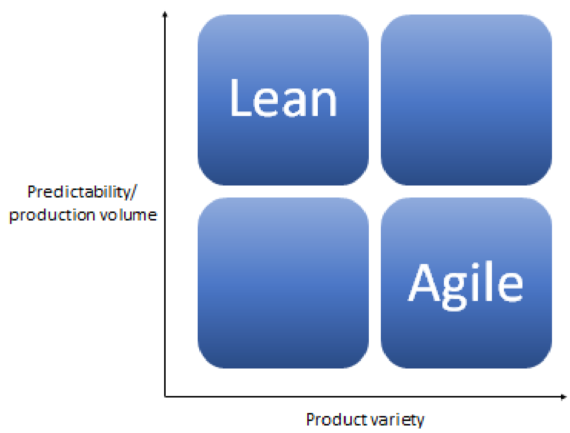

Figure 3.1. Different dimensions affecting the use of operational strategy. Inspired by Christopher (2000).

Manufacturing strategy has become more and more important for companies to enhance their competitiveness (Gunasekaran, 2001). Gunasekaran (2001) defines in various reasons why manufacturing strategy has increased in importance. One reason correlate to the will of producing globally which puts pressure on the international manufacturing efforts. Another describes the potential gains in development when introducing a strategy which aligns a company and thereafter improves the ability to grow. Gunasekaran (2001) implies that the manufacturing strategy should improve the productivity and quality which it has had during the last decades when lean manufacturing has been frequently implemented/used. However, due to new manufacturing environments of the 2000s which has remarkably increased the level of information technology, new ERP-systems have entered the industry which leads to the possibility of using a different management and yet reach a high level of productivity and quality.

In the chapters 3.2.1 and 3.2.2, two different methods of operational control will be explained and presented. They all have different philosophies and advantages in different production environments which also will be explicated and reasoned around. A general description of what performance a typical production usually measures as well as what an agile production should measure or which attributes it should focus its resources on.

3.2.1 Lean principles – applicable for a flexible manufacturing

The concept of lean or lean production was created to respond to the need of a strategy to improve all work, and not just within the manufacturing even though that is the main idea (Petersson et al., 2015, p. 45). Lean has its origin in Japan but some of the original ideas comes from North America, anyhow, lean is very much rooted within the automotive industry. Even though lean was used at large companies it took a long period of time before it was a common practice globally. During the oil crises during the 70s, Toyota manage to still gain market shares and profit due to their new efficient operational control system and thereafter the concept spread among the industry of Japan rapidly (Petersson et al., 2015, p. 45).

The main implication of lean production is to use the right resources, with the right amount of resources at the best possible way which means that less resources is not necessarily better (Petersson et al., 2015, p. 79). This is presented as the concept *heijunka* which means leveled production and is the trade-off between flow- and resource efficiency. This trade-off is very apparent when looking at a hospital if e.g. the patients are the products and the processes, the waiting rooms are the flows and stocks and the doctors are the resources (Tay et al., 2017). The hospital wants to both use their resources as much as possible at the same time as they want to achieve high customer satisfaction, which consist of the quality of the doctors and the overall service time.

When is lean appropriate?

Lean Production is, because of its origin, often associated with manufacturing in large volumes with relative standardized products, however that is not the case according to Petersson et al. (2015, p. 17-18). Every flow, no matter industry or sector, has its flaws in their flow or waste activities which then could be improved. Petersson et al. (2015, p. 18-25) argues that lean can achieve improvements in several activities such as cost savings, reduction of lead time or even raise the employee health attendance. At the same time as the strategy can be used in many industries, it is not always appropriate in every environment such as HVLV or in facilities that have a job shop layout. Irani (2011) explains from a material flow perspective that job shops which produce with high variation and low volumes will have a large cobweb of different routes. This makes some lean principles very difficult to implement and sometimes not good to use at all. Irani (2011) also lists the lean principles that he believes would make a good fit.

Tools that function in job shops

- 5S
- TPM
- SMED
- Poke-yoke
- Quality at source
- Employee involvement
- Strategic planning
- Visual control/visual management
- Standardization of processes and tools
- Jidoka
- Top-down leadership
- Right-size machines
- Standard work

Tools that may not function in job shops

- Value stream mapping
- One-piece flow cells
- Product-specific kanbans
- FIFO sequencing at work centers
- Pacemaker scheduling
- Heijunka (level loading)
- Single-function manual machines
- Assembly line balancing

Figure 3.2. What type of lean principles are suitable for job-shops. Inspired by Irani (2011).

As Irani (2011) describes, various lean tools can be applied to job shops with a more flexible manufacturing and still work effectively. Some of the tools and methods that are promising for an HVLV environment will be further explained. The tools that may not work in job shops will not be explained because that they are very limited to line production with few product variations.

Lean methods and tools applicable in HVLV environment

In this section, typical lean methods and tools within manufacturing will be presented and explained. A note to this is that there are more tools than what is presented here and lean as a strategy is also more than just methods for manufacturing. However, these are a selection of tools that would work in an HVLV environment and what further will be touched upon in the study.

5S

It is almost impossible to follow a working standard if the workers must look for tools or documents before they perform the operation (Petersson et al., 2015, p. 133). A well-organized working space will therefore raise the productivity in the production or at any working space. The aim of the method 5S is according to Petersson et al. (2015, p. 310) to create a structured working area but also an understanding and behavior to achieve order. 5S is a five-step method that is working on a continuous basis where each step is named according to the appropriate "S" to explain the meaning of that move. Petersson et al. (2015, p. 310-312) give raised productivity, lower buffers and shorter throughput times as examples of effect. The different steps will be briefly described.

- *Sort* is the first step and aims to sort the different tools and material that is used on the working area. Sorting should be performed so that clarity is reached and to bring the most used tools closer and the less used further away or sometimes removed.
- *Set in order* relates to sort and places each object on the right place so it is easy to find as well as visualizing if something is missing.
- *Shine* or *clean-up* is not about how "clean" the area is but rather systematically oversee and clean up when it is needed to make sure everything is up for running.
- When the three first steps are done, *standardize* is applied as an agreement to the new structure and routine that is supposed to stay that way. It's important to keep a schedule so that the first three steps are followed, for instance in the end of every day.
- *Sustain* is the fifth and final step but also the hardest because it handles the attitudes and behavior of the workers. It is important for team leaders to grasp this challenge and see that the workers are committed.

Standardization of tools and processes

Standardized work is not a very used lean tool for companies according to MÍkva et al. (2016), yet one of the most powerful. Standardization of tools and processes can be, according to MÍkva et al. (2016), divided into three main methods namely, 5S, standardization of processes and finally visual management. 5S is the organization of the workstation, which is describes in the previous section, but it associates much with standardization of processes. Standardization of processes is a document of the current best practice and is the baseline for continuous improvements. MÍkva et al. (2016) explains that customization is a competitive strategy which needs quality and flexibility in the manufacturing to function well and therefore, quality management play a big part in standardization of processes.

Standardization of processes is a key to continuous improvements according to MÍkva et al. (2016), and it also makes the measuring of KPIs easier. When a process should be standardized, the implementation and the continuous work will be more productive, and quality assured if it is visually managed and controlled.

Visual management and control

A standard should also be as simply as possible to follow for the workers and therefore, visualization is important (MÍkva et al., 2016). Visual management is about making the work that is needed more accessible and understandable for the workers as well as when something goes wrong. To have visual guiding tools in form of documentation of processes and orders which include material and flow, will increase productivity regarding faster learning and response and communication.

The functionalities of visual management are many and can be applied in every level in an organization (Tezel, Koskela and Tzortzopoulos, 2009). Transparency is one of the functions and it is described as the ability of a production process to be informative and communicative to the people in touch with it. A process should therefore be visual and understandable for all involved so that it can be improved (Tezel et al., 2009). Another function is On-the-job training which is a way of integrating working with learning. Tezel et al. (2009) describes this function as experience sharing between workers while the work is less disruptive. Including visual elements will help the progress of absorbing competence and is also good to mitigate errors. A final function that Tezel et al. (2009) brings up is simplification which the process of making all information visible and organized so that it easily can be accessible for workers and management. However, simplification need the quality of the information as well as the gathering of the information to be on top.

3.2.2 Agile manufacturing

Agility in manufacturing involves the ability to quickly respond to the changes in the market effectively and work proactive in developing and retaining market position regarding competition (Brown & Bessant, 2003). The authors therefore suggest that agility includes two main ingredients: responding to changes (known and unknown) and the ability to take advantage of these changes and turn them into opportunities. Agile manufacturing can namely be described as proactive and reactive flexibility for the manufacturing capabilities where they are based around different questions depending on where they should be focused on in the organization.

The driving force of agility is according to Yusuf et al. (1999) *change*, and in which way a company can adjust to it and become competitive and it relates indeed to Brown and Bessant's (2003) definition. However, one dimension that Yusuf et al. (1999) enlightens is opportunity of synergy for the manufacturing requirements. In order to produce flexible to meet demand at the same time as being cost efficient and innovative is difficult but if synergy of knowledge is spread through the organization it will have increase the conditions.

Strategy in agility manufacturing

Manufacturing strategy should help the organization to configure the production as well as its capabilities and it should support the organizations overall strategy (McCarthy & Tsinopoulos, 2003). Overall competitive strategies stated by Hallgren and Olhager (2009) are either cost leadership or differentiation. The agile manufacturing supports the differentiation strategy and enables high flexibility within the manufacturing. How the agile strategy within manufacturing performs depends on various underlying variables such as the JIT strategy in order to be successful (Brown & Bessant, 2003). Hayes and Pisano (1994) suggest that e.g. JIT should not be part of the manufacturing strategy, but rather just a tool to improve the performance.

Many organizations are according to Brown and Bessant (2003) stuck with old strategies and changes takes time and effort. The strategic intent of the company is often set on top management level and it is not unusual with a mismatch between company strategy in relation to the manufacturing strategy. One reason to this is the long development time for manufacturing regarding its operation and capabilities (Brown & Bessant, 2003). The term "hyper competition" is used by Brown and Bessant (2003) which describes competition in fast moving industries due to innovation and the necessity of short lead times. It is further stated that companies require to be flexible to adapt to such changes. However, as earlier described by McCarthy and Tsinopoulos (2003) it is important to connect the overall management strategy to the manufacturing strategy in order to be successful.

Agile capabilities

Capabilities within an agile approach consider the degree to which they are suitable for their environment (Brown and Bessant, 2003). A manufacturing capability defines what could be accomplished and what the company can produce. Brown and Bessant (2003) describes four key parameters/dimensions that are important to prioritize for an agile manufacturing, and these are:

1. Agile strategy – aligning the strategy to the markets need while understanding what type of customization is needed. Further, the company needs to communicate its strategy to all employees.
2. Agile process – the provision of the processes and facilities that generates the functioning of the organization.
3. Agile linkage – working and learning from the whole supply chain including customers and suppliers.
4. Agile people – developing a multi-competent and flexible staff with a culture that supports and allows creativity and initiative.

One further dimension to agile capabilities is mentioned by Hallgren and Olhager (2009) which is the capability of the production system to develop new and change between old products without making any investments, thus being flexible and yet cost-efficient.

Flexible manufacturing

To manufacture flexible and work proactively is what an agile company would aim towards, but flexibility can imply various meanings. Chang et al. (2005) has clustered flexibility within manufacturing in three different types and manufacturing proactiveness in five different dimensions. These types and dimensions are presented in figure 3.3.

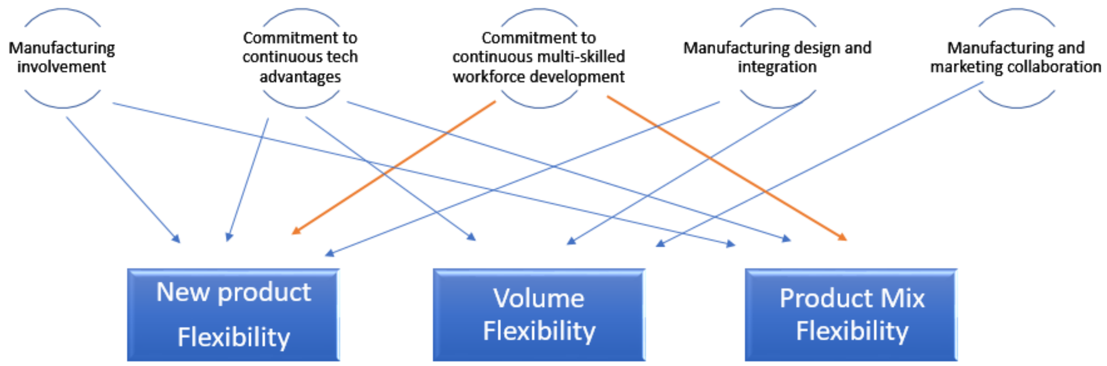

Figure 3.3: The interlinks between agile capabilities and flexible manufacturing. Inspired by Chang et al. (2005).

What types of flexibility that will be focused on is the new product flexibility and the product mix flexibility due to that they are effects of the HVLV environment while differences in volume is not. The reason why one dimension is enlightened is because it is the one that only concerns the two mentioned flexibilities and is linked the a*gile people* which was earlier described. Manufacturing and marketing collaboration will in the same reason not be described as it only connects to volume flexibility which is not a major concern for HVLV.

Manufacturing involvement and flexibility implies that the production can prepare tools and material in an early stage of the development so that to total lead time can be reduced (Chang et al., 2005). This is a flexibility that helps planning the schedule so when a product is supposed to be produced, it does not have to wait on material supply. Chang et al. (2005) explains that information and visibility is needed to achieve this dimension. Advancing technology in manufacturing, the second dimension, can be an investment for the information system that is needed, and it can also be an aid for the manufacturing process itself. Another way to decrease the lead time is through manufacturing and design flexibility which can make both the assembly/manufacturing process faster as well as the new product development process. Chang et al. (2005) mentions that designing so that similar tools can be used, and modular thinking is one way to both achieve flexibility and standardization.

To actively foster multi-skilled operators who can handle many products and possesses the competence to transfer a variety of tools and fixtures in the production, is considered as important for the flexibility to handle product mix (Chang et al., 2005). A way to develop multi-skilled workers is, according to Chang et al. (2005), to implement job-rotation, skill-based compensation and job enrichment. With these three initiatives the workers will have a broader competence and skill to perform new operations and allows the production to be more innovative and increase the flexibility for product mix.

However, to reach flexibility in product mix and new products, Chang et al. (2005) suggests three managerial implications for the manufacturing strategy. First the managers must commit significant resources to the development of multi-skilled workers. Secondly, there should be an encouragement to the personnel to involve themselves to participate in business-level decisions. Jonsson and Mattsson (2016, p. 235) also suggest encouragement for the workers to increase the competence by using financial incentives as well as for the organization to offer the training needed. Finally, it is important to manufacture and design practices such as job-rotation between functions and even between manufacturing and design for higher personnel involvement (Chang et al., 2005).

How to measure flexibility is according to Narain, Yadav, Sarkis, and Cordeiro (2000) a difficult task to perform. Different types of measurement have been tested but no universal method exist on how to measure flexibility. One of the reasons are according to Narain et al. (2000) the theoretical scope of some measurement and how to implement them in practice. Therefore, what units to use in the measurement have not been established which makes it hard to develop quantitative relationships for different types of flexibility. Narain et al. (2000) further mentions how different scholars have been striving towards measuring flexibility with monetary values, but no consensus has been reached. Narain et al. (2000) rather suggest a classification of the different flexibilities depending on their impact and on which organizational level they should be set. The different groups are necessary flexibility, sufficient flexibility and competitive flexibility.

Necessary flexibility is on the operational level and constitutes elements such as if the machines and labor can produce the range of products as well as if the materials handling is sufficient for the production. Narain et al. (2000) states that it is necessary for all companies which strives towards decreasing lead times and increase the production quality to achieve the necessary flexibility.

The sufficient flexibility is on a tactical level in the company and focusing on the flexibility regarding processes, operations, and materials. The sufficient flexibility concerns how a company can have a wide mix of products without the need of long set up times between different types of products. Narain et al. (2000) suggest that a company should focus on the sufficient flexibility after the necessary flexibilities are reached. Furthermore, the sufficient flexibilities are stated to be beneficial for companies striving towards customization.

Competitive flexibility is the third dimension and should be set on a strategic level according to Narain et al. (2000). It mainly concerns how a company should strive towards creating long term flexibility and avoid large investments to be able to handle new products. Competitive flexibility could therefore have a strategic focus on designing products which are able to produce with the machines already existing but also invest in machines which will be able to produce products not yet fully developed.

The agile approach of mass customization

One aspect of the agile manufacturing approach is the ability to offer customized products towards the customers (Brown & Bessant, 2003). By using an agile strategy, the organization could use it as competitive advantage, given the situation where other companies are not able to provide customized products. Advantages will be generated if the organization is able to provide a manufacturing environment which enables capabilities such as high quality and well-developed process technologies while providing the customized products.

According to Brown and Bessant (2003), the general understanding within industry is the interlinks between the agile approach and the high level of customization. Their perception is how these various terms often sees as interchangeable and not how they affect each other in practice. The words are perceived to just become words which many people talk about, but not what they mean and how they could be implemented within a company's strategy. However, Brown and Bessant (2003) argue about the importance of implementing the agile approach within turbulent and fast changing industries rather than using the right labels of the strategy. They emphasize the importance of becoming flexible, both by working proactively and reactively.

The trend towards customization of products have led to several strategies in order to adapt to the changes in industry (Stump & Badurdeen, 2012). One of them is presented as the agile strategy and can be used to create a responsive manufacturing to meet to changing environment within industry. However, Stump and Badurdeen (2012) argues how different parts of other operational strategies, such as lean production can be useful as well and a strict agile approach may not be the only option. What level of agile approach depends on the level of customization and should be adapted to each company's preconditions and strategy. Stump and Badurdeen (2012) distinguish why agile manufacturing and mass customization should be two separate paradigms. The difference is described as agile manufacturing focus on mitigating the effects as a result from the variability of products while mass customization is the ability to produce specialized products to the customers.

Knowledge driven enterprise

One of the core concepts of agile manufacturing according to Yusuf et al. (1999) is knowledge driven enterprises. This concept refers to the importance of keeping the knowledge and develop people in order to develop the organization further. One important strategy for companies striving to become agile is to train, develop and motivate the personnel. Yusuf et al. (1999) describes it as "knowledge is power" and refers to the importance of preserve the knowledge to create a successful business. Successful agile companies are stated to be good at using the personnel's combined knowledge as the company's solution products. The solution products are referred both to the actual products but also to support services towards the customers in order to increase the life span of the product.

Chau, Maurer and Melnik (2003) describes how small companies with an agile approach can use low level of documentation and focus on verbal communication instead. This is stated to create a lower risk to not have documentation which are not up to date. However, the need of documentation is stated to be effective in large organizations as it is not possible to achieve verbal knowledge transformation. Chau et al. (2003) emphasize the importance of training and the value of developing knowledge within an organization. Chau et al. (2003) suggest informal training within companies using the agile approach as it is less expensive compared to the formal training and it is easier to perform when appropriate situations occur. Such training could be based on job-rotation where the expert in one field instruct a coworker to help him or her to gain knowledge for that specific work task.

3.3 Different types of performance measurements

Suitable performance measurement varies in organizations depending on the different prerequisite the production has. De Toni and Tonchia (1996) exemplifies different areas of measurements for various production environments. The measurements are divided into four different categories which are based on the two dimensions of product complexity and representativeness of production. The complexity is based on the extent of bill of material (BOM) and the repetitiveness on how often the time interval between entry and exit of the production system. De Toni and Tonchia (1996) have divided the performance measurement in three aspects of time-, quality- and cost performance as these aspects are stated to be the most important. De Toni and Tonchia (1996) explains the matrix visualized in figure 3.4 as what to measure depends on the different contexts given by the two dimensions of complexity and number of products produced. For a high repetitive production in a low product complexity environment, it is stated to be more important to measure the throughput time such as pieces/minute compared to lead time for low level of repeatability in terms of minutes/piece.

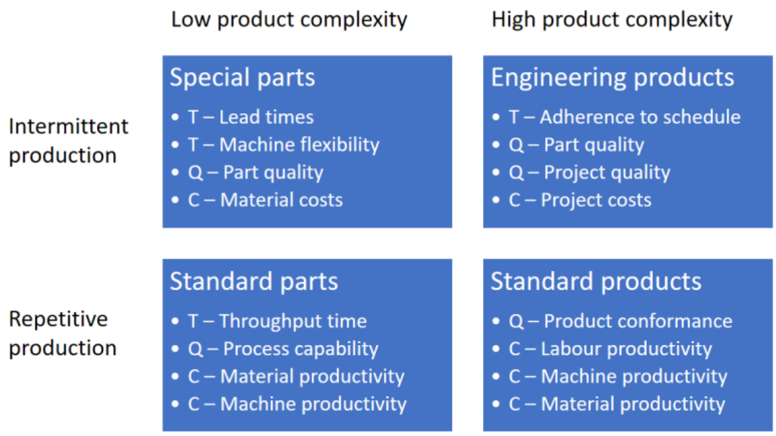

Figure 3.4. Suitable performance measurement in different production environment. T = time, Q = quality and C = cost. Inspired by De Toni and Tonchia (1996).

De Toni and Tonchia (1996) also explains how the aspects of measuring time, quality and cost changes for the different environments. Production environments with high product complexity and with low scale production (Engineering products) is recommended to focus on quality measurements and with an increased volume of production (standard products), cost performance indicators become more important while quality matrix remain the same level of importance. On the contrary, De Toni and Tonchia (1996) suggest that time performance become less important for high scale manufacturing within high complexity products.

Ghalayini and Noble (1996) describes how performance measurement traditionally have focused on financial measurements such as output per labor hour. Financial measurements are stated to have limitations as these metrics were constructed by textile and steel mills and may not be applicable on every company. Furthermore, they are often lagging, and the results can only be identified weeks or months after the identified period. Moreover, some metrics can be hard to quantify in monetary terms such as the adherence to schedule. Ghalayini and Noble (1996) suggest time measurement to be better of use as the result can be directly identified and the reduction of time is always beneficial. Furthermore, time reduction will have positive benefits on the costs. Ghalayini and Noble (1996) divide the suggested time performance measurements in four areas:

- New product development - time from first idea until it is available on market
- Decision making - time lost waiting for decisions
- Production - value adding time in relation to total elapsed time, time in inventory and cycle time
- Customer service - response time (percentage delivery of time)

The advantages of using time performance metrics alone is the easy understanding and usage of them. However, the disadvantages are stated by Ghalayini and Noble (1996) to be the lack of focus on quality- and cost performance.

Two perspectives often used to measure manufacturing performance is resource efficiency and flow efficiency (Petersson et al., 2015, p. 198). The flow efficiency is the value adding time related to the total lead time while the resource efficiency is a measure on how much the various resources in a flow such as machines are used in relation to the total time. Modig and Åhlström (2015, pp. 16 & 45) exemplifies how the perspectives both can be hard to achieve where high level of both is described as the perfect state. In order to achieve the perfect state, it is recommended to first focus on the flow efficiency as aspects such as throughput time will be affected which generates customer value. When a high level of flow efficiency is reached, the organization can thereafter begin to change in order to increase the resource efficiency.

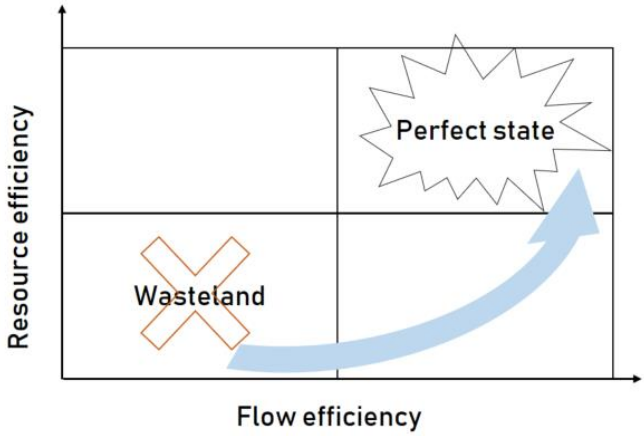

Figure 3.5. Resource efficiency versus flow efficiency. Inspired by Modig and Åhlström (2015, p. 121)

Petersson et al. (2015, p. 256) mentions the importance of using performance measurement in order to know what to improve. One tradeoff which needs to be taken is how detailed the measurement should be. Too detailed measurements can in worst cases reduce the performance as the administrative tasks takes too long time to perform. However, if the measurements are not detailed enough, the results from the performance measurements may not be adequate. Petersson et al. (2015, p. 259) further states the benefits of reporting disruptions in the production which may have effects on the measurements as it is important to know the root causes. However, a usual mistake is according to Petersson et al. (2015, p. 260) to only report large disruptions as the perception is that it is only them who will have any effect on the performance output. Nonetheless, the small disruptions may be the easiest to solve in order to increase the performance output.

3.4 Key points from theoretical framework

The important points for the reader to consider from this chapter are the three lean tools that was provided in chapter 3.1 and the various agile capabilities and flexibilities provided in chapter 3.2. The lean tools were 5S, Standardization of tools and processes and Visual management and control. These three tools will be analyses in chapter 5 and 6 and be a part of the third research question. Another point for the reader to consider is from chapter 3.3 is that companies should focus on measuring the right aspects depending on the condition they are in. For companies within agile manufacturing, it should mean flow efficiency and focus on time and service while deprioritize cost.

To answer the second research questions with the challenges described in the current state, a model based on the agile capabilities and flexibilities will be used. The model is based on Brown and Bessant (2003), Hallgren and Olhager (2009) and Chang et al. (2005) theory on agile dimensions and manufacturing flexibility and what types of improvements are needed.

The theory together with TCC’s desire of becoming more flexible and shorten lead times has led to the following model illustrated in figure 3.6.

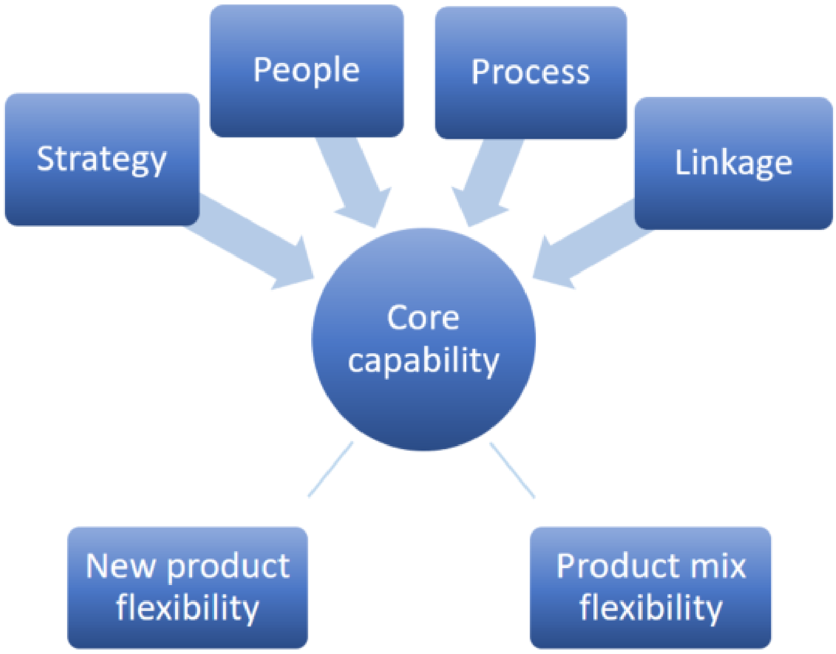

Figure 3.6. Model for analysis, dimensions of agile manufacturing.

The agile capabilities and dimensions are the base for the analysis and the model is presented in figure 3.6. The model is based around the four capabilities (strategy, people, process, linkage) which all contributes to the core capability. The core capability is what Hallgren and Olhager (2009) described as the production systems own capability, the ability to produce new and change between old products without making any investments, thus being flexible and yet cost-efficient. The core of the production system is therefore the ability, or the level of flexibility, to develop and produce new products without any major investments at the same time as it should be able to handle the broad spectrum of the existing range of products to meet the customer demand. The customer demand is boiled down to quality- and service level which suits TCC’s global strategy. This will be further analyzed in both research question two and three to oversee how flexible the production sections are. Figure 3.6 illustrated how the dimensions of agile manufacturing correspond to the four capabilities and how they all contribute to the core capability. Figure 3.6 further illustrates how the core is founded on the two types of flexibility relevant for an HVLV manufacturing environment.

4. PERFORMANCE OUTCOMES OF THE CURRENT OPERATIONAL STRATEGY

This chapter gives a description of the two production sections at TCC used in this study, the Trafo production and the Installation hall. This chapters aims to answer the first research question ("*What are the performance outcomes of the current operational strategy at TCC regarding the production flow, and what type of operational strategy is used?*"). The answer for the first research question will also be provided in brief in chapter 7.1, discussion of findings. The chapter includes a part (sub section 4.3) which aims to describe cross functional activities which affects both the Trafo production and the Installation hall. Cross functional activities include the planning department as well as how the various sections communicate with each other.

4.1 General description of the Trafo production

The Trafo production produces different types of transformers used in various types of products. A transformer is a device that enables the change of voltage between various components with electromagnetic induction without any change of frequency (Kulkarni & Khaparde, 2013 p. 1). The main attribute of the transformers is the thread winding around the core in order to create the magnetic induction needed. The transformers produced at TCC vary a lot in both its attributes, but also in size and shape depending on which product they are aimed to operate in. The production processes may vary depending on what type of transformer it is but are in general similar. Trafo has several hundreds of various products which they aim to be able to produce. Trafo mainly produce transformers for old systems that customers have sent back to TCC for reparation. However, production of transformers for new systems also occur, but not in the same extent as many of the new products are bought from external suppliers. This leads to a wide range of products produced, but it also generates production of very old components as there is no hard limit on how old the returned product from the customer may be.

Figure 4.1 shows the number of shop order per product the Trafo production have had the years between 2016-01-01 – 2019-12-31. The most reoccurring product have been produced 36 times which stands for 4% of the total volume manufactured. The median value of the number of shop orders for a unique product is 2 and the average value is 5.8. 61 of the unique products have only been produced once and this represent 29% of the 210 unique products and 7% of the total volume.

Products produced three times or more in this period accounts for 83% of the volume produced, however they only represent 103 out of the 210 unique products which means that over half of the product range is only produced one or two times over a four years period. This gives the diagram a long tail of products, which could be similar, but most often include variation which makes them differentiated.

Figure 4.1: Pareto diagram of the number of shop orders between 2016-01-01 - 2019-12-31. Each bar represents one unique type of product.

The production steps within the Trafo production contains of a lot of manual work. According to the operators within the Trafo-production, the manual work is a craftsmanship and it takes a lot of time to learn how to perform the various steps. Due to the high number of unique products, it is according to the operators almost impossible to learn how to produce the various products within all production processes. This leads to a high specialization within the Trafo production, where the operators focus on learning one process step very good in order to be able to produce every product rather than learning all the various process steps within the Trafo production.

4.1.1 Production processes

The production processes are order start, winding, test, bonding, core gluing, casting or impregnation and final assembly. In general, all products are passing all production processes. There are however exceptions for some products where they are not e.g. casted or impregnated depending, on which final product they are produced to fit. The process time for each production step varies a lot depending on the product's attributes and application area.

Every order starts with order start and consists of the material preparation for the product. By reading the documentation of the product, the operator will identify the type of product and which process steps it will have to pass, as well as what type of material and tools that are needed for the product. The operator collects both the input material and the tools needed for all production processes. If material or tools are missing, the operator will not in theory begin to produce the product. The documentation can vary a lot, depending on how old it is and who has written it. According to one operator, the material is often easy to find but on the contrary, the tools needed for the specific product could take long time to find as they tend to be poorly marked.

After the operator have collected all material, the wires may be needed to be cleaned depending on what product the transformer should operate in. Thereafter, the operator starts winding the wire around the core with the help of a winding machine. The machine has similarities to a sewing machine where the operator starts the rotation of the shaft in the machine by pressing the foot on a pedal. This process is stated by both the operator and line manager to be a very critical as it is extremely important for the wire to be placed right, with the right number of laps. There is sometimes a need to use e.g. extra insulation to create the right quality according to instructions. In the documentation it could be as little information as the number of laps the wire is needed to be winded, the rest of the process is decided by the operator based on experience.

After the winding, the transformer is tested to ensure the winding to be successful. After the test, the wire ends are bonded together with the use of soldering and thereafter tested again. If the test should not be successful, it may be possible for some products to adjust it. For the other products, the only option is to redo the product all from start. If the product passes the test second test, the cores are glued together, and the product is tested a third time.

When the cores are glued together, the next process step for many of the products are either impregnation or casting. Both processes apply the same physical attributes for the transformer which is the insulation to surrounding objects. The difference between if the product is casted or impregnated is the supposed application area where the casting enables a higher insulation to the transformer as the cores are inside the casted object. The impregnation is performed by immersing the transformer into an impregnation liquid and thereafter let it dry before it is placed within an oven. This process time is a minimum of approximately six hours and therefore they strive towards placing the transformer in an oven before the shift ends as it is possible for it to be longer than six hours in the oven. This means that the process is done when they arrive the next day.

The casting is performed by placing the transformer within a fixture and cover it with casting compound. The fixture is placed in a vacuum chamber in a couple of hours to reduce the air bubbles within the compound and thereafter in the oven for additional hours to let the compound harden. The vacuum chamber can only be used for one type of compound at a time due to various parameters such as temperature and pressure within it. If products do not have the same compound, only one product can be in the vacuum chamber at each time. Furthermore, the setup time for the vacuum chamber is approximately two hours and is the only process step which have a machine specific set up time as the other processes' setup time consists of searching for tools and material. After the impregnation or the casting, the transformer is tested and inspected one final time before it is packed and transferred to storage either in house or in an external warehouse.

4.1.2 Production flow and layout

The production flow of the transformer production is relatively simple due to its limited space and production volume. The layout design should represent a functional layout where the rooms contain similar equipment for a process step. As earlier explained, a transformer may vary much between products and the rooms does therefore have most of the necessary equipment in the nearby area. The movement of products can be made by hand because the products are small and not too fragile. The production flow itself is thereby not complicated but rather straight forward between the different areas.

The first room for the transformer production includes processes as material preparation, winding, test, bonding for the outer component and for the core and some assembly. All steps except for test is done in the same area. This area is equipped with winding and soldering machines, certain air flow and assembly stations. Within this room there is a highlighted safety area that is only used as a testing station and has therefore an extra safety level in terms of clothes and equipment. The floor in this area is also made as extra protecting against electrostatic discharge (ESD) which could interfere with the electric-sensitive components.

The second and third room of the production are used for casting and impregnation and all the supporting activities as well, such as cleaning and drying for the tools and molds. The fourth room is designed for impregnation and has a fume cupboard that removes the toxic gas that spreads with the impregnation oil. The third room has a casting fume cupboard which is more solid and a vacuum chamber for the products that is casted instead of impregnated. Ovens are according to the operators in abundance and are in all rooms but are most often only used in room three.

The fifth room is in theory a workshop which all operators can fix smaller problem on the components or manufacture fixtures and new tools that are needed for the production process. However, the room also contain molds and other equipment that does not fit in the other rooms. There are some fume cupboards, one sander and an assembly station that can be used if some casting needs a final touch regarding the shape. The product flow is not a straight line but rather a transition of ownership between the operators. The products do however move between the rooms in the order that is described but since it is a relatively small production and the products are manageable, there can be flexibility in movement.

Just outside the production is an open area with computer stations that is a room for the production engineers and the production planners. This area is also used as a meeting room for the daily meetings with the production engineer and the line- and production manager.

4.1.3 Operational strategies

During the past decade, TCC has been striving towards implementing lean concepts into all production units. According to the Industrialization team, the results have been varying depending on which preconditions each production section has. For the Trafo production, it has not been a good strategy to implement the lean concepts according to the line manager as their processes are very manual and the number of unique products is high. When TCC wanted to implement lean production at all production sections, Trafo was no exception. However, due to the manual and non-repetitive working process, lean did not have the right qualification for an effective operational strategy and thereafter dropped in priority. Since then there has been no clear strategy within the Trafo production according to the production manager and the strategy have been to produce according to the frozen plan. The frozen plan is a three-week period of what the production section can promise to produce, in hours or products. However, there have been a backlog within the Trafo production for a long period of time and the strategy have mainly been focusing on reduce the backlog by working overtime on weekdays as well as working on the weekends.

To be able to adapt the production at Trafo to all various types of products, there is a perception from the line-, project- and production manager that the Trafo production needs to become more agile, but what such strategy requires in practice is not yet examined. Furthermore, it is stated by the line manager to not have the time to developed and implement such strategy as a result of the constant backlog which is time consuming.

4.1.4 Performance measurement

The performance of the Trafo production is mainly done with three different KPIs: on time delivery (OTD), planned versus consumed time and operator efficiency. According to the line manager, the OTD metric is the most used within the Trafo production. The OTD metric is based on the ability to deliver according to the frozen plan. The frozen plan is printed and placed on the wall inside the production section. When a product is finished, the operator makes a note on the paper that it is finished. This list of the frozen plan and which orders are finished, and which are not is used as a check list for the line manager. By communicating with the operators, the line manager can e.g. ask the operators for overtime in order to be able to finish what is promised to produce within the frozen plan. In the ERP-system, the burndown chart for the frozen plan period can be visualized as in figure 4.2. A burndown chart is a list of orders which should be delivered within a certain time. The chart does often include, as it does for Trafo, the planned schedule compared with the actual result. The burndown chart is however not available for the operators to see inside the production area. The chart in figure 4.2 describes the products that are promised to be manufactured according the frozen plan, over three weeks. The reason why the number continuous to –5 products is because Trafo has a backlog which they always try to catch up to when time is available.

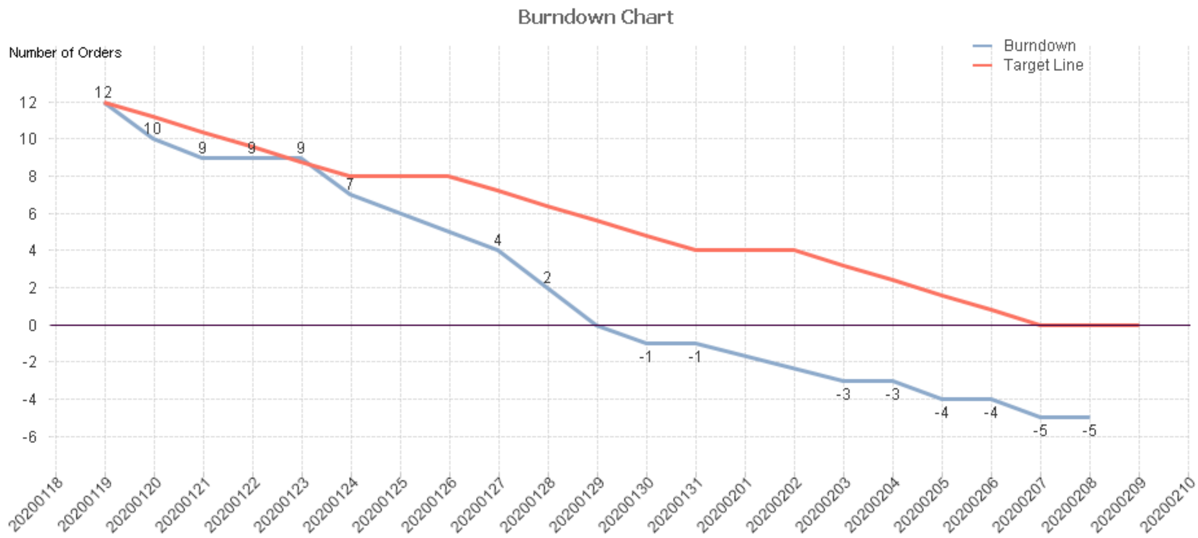

Figure 4.2 Example of burndown chart for the Trafo production

Another metric used by the line manager, but not in the same extent as the OTD is planned versus consumed time. This metric measure how long each operation takes compared to the estimated time which is a time developed by statistics in the ERP-system. The estimations of time cover both the process time for each operation as well as the setup time needed. The estimation of time also has a process step called engineering time which works as a time buffer if something would occur during production. The planned versus consumed time for each process step is according to the line manager not a good measure as the planned time are just estimations and they might not be as reliable as they should. The line manager describes how the total time of the planned versus consumed time may be better than looking at each individual operation. For the Trafo production, the planned versus consumed time for the period between 2016-2020 is 13374.4 versus 20650.2 hours which results in 54.4% extra time needed in order to finalize the products.

4.1.5 Distribution of information and competence

As mentioned earlier in the study, each person has become specialized in one certain process in the Trafo production according to the operators. However, this is stated by to the line manager not to be an expressed strategy and should rather be the opposite where every operator is able to perform most production steps within the Trafo production. Due to the high number of products and manual processes, this is not possible in practice as there would not be possible to learn all production processes. Therefore, the line manager has split the assemblers into two different teams within the Trafo production where one team specializes in winding, bonding and core gluing and the other one on casting, impregnation and tests. The operators should be able to perform each task as the team is responsible for in order to replace colleagues if they are absent from work for a shorter time. Except replacing each other on rare occasions, the operators do not perform any job-rotation.

However, the operators themselves sees that the work is not always balanced between the two separations in the production where they would want to help if they could. One operator explains that if there are any disruptions in the later processes, he tries to help as much as he can instead of starting new orders. But unfortunately, the competence is a crucial factor to be independently working. In combination, the frozen plan should be delivered as promised and thereafter the orders should be running in the flow.

As of today, it is hard to define when an assembler knows the process steps in the Trafo production in order to be defined as fully learned. The time it takes to learn the process steps are long and due to the number of unique products, it might arise problems where the operator have not done the product before and do not know how to produce it, even though he or she has been working in the Trafo production for a long time. The term independently working has previously been used but the problem with this definition is the level of subjectivity according to the line manager. It is hard to define what working independently of others is and how it works in practice. Due to the level of manual work and sometimes many years between the manufacturing of the same product, there is often a need to ask other operators for help in order to produce the product. There is an ongoing project focusing on developing a framework that includes the basic knowledge required for each production step which will be used when a new person is introduced and starts its learning in order to be able to define when he or she knows the basic tasks.

The focus on specialization within one process was previously more widespread compared to the current state. Situations were one operator focused on e.g. just winding for decades occurred which led to a high competence in that area. As a result, from this type of organization, the operator had all knowledge of how to produce each product and it was not documented in any way. The historical lack of documentation as well as the transformation of knowledge to other operators has created a knowledge gap that they believe still has a negative impact on the organization.

One of the issues regarding competence is according to one operator how the knowledge is transferred between the personnel within the Trafo production. As previously mentioned, the knowledge on how the various process steps should be performed are stored within each operator and is rarely documented in any way. When a new person is introduced and shall learn the processes, the knowledge transformation is mostly done verbally. One operator specialized on the winding process refers to the knowledge gap between him and the one specialized on the winding previously him as a result of the verbal information and lack of documentation. The operators within Trafo are positively to a wider knowledge of the processes to be able to help each other if one process have much to do or if there would occur any absence such as sick leave. It is however stated by one operator to be nearly impossible to enable the time needed for the training as a result of the backlog they currently have.

4.1.6 Documentation of production processes

The documentation of the various products and how they should be produced are critical at TCC. The documentation enables standardized work in order to always ensure the same quality of the products. Furthermore, it is a way to be able to produce old components that are needed to repair already existing products. The documentation of how the products should be produced is developed by the production engineers and they perceive a dilemma in how to write such documentation as if it is in too much detail, it takes too long time for the operators to read it, and on the opposite side, if it is too short, some important details may be missing. It is further stated by both the operators and the production engineers to find an effective way to update the documentation if it is something missing or something wrong in them. The operators need to inform the production engineers if they perceive updates of the documentation is needed. However, they do not always have time for it and the documentation will therefore not be updated. This could create a situation when the next product of the same type should be produced as the same error might occur again. Furthermore, the non-standardized way to report faulty or insufficient documentation hide how big the issue is.

According to one operator, they are not able to update the documentation themselves, either the mechanical design engineer or the production engineer needs to be involved depending on what the issue is. However, due to the backlog the Trafo production have had for a long time, they do not have the time to update the documents even if they were able to do so. The same operator also describes how this issue is not unique for Trafo but also occur for other production sections as well. Some operators in other production sections write analogue notes on how to produce some products if the documentation lacks quality as this way of working is faster than let either the mechanical designer or the production engineer to update the documentation. However, the analogue notes are stored in binders and when the operator quits, the binders will be hard to understand because of the simplicity of the notes. The operator further describes how the documentation within Trafo has become better over time, but the documentation for the old products lacks in quality. The operator explains how the description for e.g. the winding process could be as unspecific as the number of laps the wire should be winded. In some cases, for old products where the documentation is almost not existing, there can happen that there is also no operator who have produced the product before occurs sometimes. In such cases, the only option is to try to produce it by using the experience the operator has. If the winding does not pass the test afterwards, the only option is to start over and try again.

Old documentation rarely contains any visual instructions on how to perform each production process. According to the line manager, all new documentation for new products should have visual instructions such as photography for critical steps. This is however not fully developed and could be further improved according to him. The line manager sees a potential for the operators to be able to see how to perform the various tasks and which tools to use rather than just read the instructions.

4.1.7 Standardization of work routines

Standards are difficult to implement in a production where the products are high-quality craftsmanship and the machines within the facility are almost handled fully manually. The competence is as mentioned build over time by watching and learning from more experienced co-workers which in turn leads to more difficulties of building a standard way of working because the manufacturing becomes subjective. In this meaning, subjective could intend as different opinions on quality, speed or design.

Standards are a prerequisite for continuous improvements and do also secure a more reliable level of quality. The line manager and one production engineer explain that this has been a topic for long but is very difficult to develop since there are many products that can be produced which has not been produced for as long as 50 years. This is a challenge where standards are needed but is tough to maintain over such a long time. There is a tradeoff between working and documenting, according to the line manager and the production engineer. If the documentation and standards should be updated as the product may not ever be produced again and the cost for the work needed should then be proportional to the output generated.

Both the line manager and the production engineer highlighted the need for a more technical guiding platform, but even more for a systematic structure regarding the material in the workshop. Today the structure for the tools and material is somewhat organized yet diffused. During a workshop observation, one operator was looking after a fixture and had done so during the past 15 minutes. He explained that if he did not find it soon, he would eventually have to make a new, which is possible in the same production section, nevertheless time-consuming. The materials and fixtures are placed in cabinets and containers in the production section which takes up much space. The containers have tags on them which explains what they contain, and the tools and fixtures should have a marking on them in order to find the right one in a short time. However, the use of markings may vary as it may have fallen of or it have not been updated when the organization have changed ERP-system. Moreover, the location of the tools and fixtures is not consistent and is one further aspect of the problem as the operator do not know where to start looking.

The workers in the Trafo production are very capable and have good insight in where material can be located. However, all actors connected to the production share the same interest for a systematic approach to handle material and tools. According to the line manager, the problematic issue correlated with the lack of standardization of material and tools is the lack of time, but they need to create a structure for the tools and material to reduce the backlog. This makes a problem-loop where the operators need time to save time.

4.2 General description of the Installation hall

The Installation hall consists of a large room where the final assembly of the final radar systems is performed. The Installation hall consists of seven different assembly stations which are used as building places for the final products. The assembly stations are similar in its attributes, i.e. all systems can be produced at every location and there is no difference between them. The Installation hall handles all final assembly for radar systems aimed to be operated on surface level and the products can be divided into two groups: new products and upgrades of old existing systems. The upgrading of old systems is performed when a customer already has an existing radar but due to various reasons needs to upgrade it. Such reasons could be when TCC has developed new technology for the same system and the intention is therefore to increase the performance.

Many of the final products are constructed to be placed on trucks and they use both roll on-roll off containers as well as specialized swap bodies to assemble the systems onto. However, some of the systems is mounted directly on the customers vehicle, see figure 4.3. By using this way of working, the products can easily be transported when they are finished, and the next product can be started produced shortly thereafter. However, it requires space inside the Installation hall to load and unload the roll on-roll off containers and swap bodies.

Figure 4.3. Examples of systems assembled in the Installation hall. Note that the vehicles are not produced by TCC and is provided by the customer to either directly assemble the radar system on it or provide portable solutions with the roll on-roll off containers or swap bodies.

The throughput time in the Installation hall can vary a lot between various products. Without any major disruptions in the assembly process, the throughput time can be around three months. If disruptions occur such as material shortages or lack of documentation of how to perform certain assembly steps, the throughput time can be up to more than a year. Therefore, there is no major difference between the upgraded systems and the new ones. The throughput times are according to one production engineer heavily depending on the need to try find the right way to do. For new products which have never been produced before, there is a constant need to develop the right work sequence and methods in the same time as the product is produced as there is never a prototype produced for complete system. Such dilemmas could be the same for systems that are upgraded as just that specific upgrading have never been done before.

4.2.1 Production processes

The production processes are different if the system is produced as new or if it is a rebuilding of an old system. The production processes for new systems contain activities as assembly and testing while systems rebuild to be upgraded consists of cleaning, dismantling, changing of components and thereafter assembled again and tested. However, the structure of work is the same if the system is old or new and is based on the division of the internal and external assembly however, new system does not have to dismantle. The assembling and dismantling for old systems can be done in some degree parallel due to the division between internal and external work.

Every production process is stated on a paper visualized near the assembly for each workstation and is used as the plan and schedule for the work with the radar system. This paper states in which order the dismantling and or assembly should be performed in and is called the routing. For each process step, there is a work package available for the assemblers to read in order to see what material to use, where it is located as well if the right quantity is available. Furthermore, the work package shows a 3D-model of how the component should be assembled and the part to assemble is highlighted in order to make it more visual for the assemblers. The routing on the paper is based on the assembly schedule of the product which is the estimated time needed to perform each step and is calculated by the production engineers. According to one production engineer, the accuracy on the routing becomes better when a couple of the same system have been produced.

The routing states in which order each assembly step should be performed in. However, it may be situations where material shortages occur, and it is possible to change the order of the assembly. As earlier explained, the internal and external assembly are often independent of each other, which enables internal assembly if material for external assembly is not available and vice versa.

The visualization of process steps is structured the same for old systems as for the new ones. However, the rebuilding consists of dismantling processes. When an old system is upgraded, some of the components should be used again, but needs to be dismantled in order to install other components. When dismantling old components which aims to be used again it is needed to mark them properly and store them in the same way as new components in order to easily find them when they should be assembled back together again.

The assemblers follow the various process steps stated in routing and perform each work package in the order it is planned to do. However, if disruptions such as material shortages occur, it is sometimes possible to switch order of the assembly if the upcoming step is independent on the previously step and the change will not affect future assembly. According to the production engineer at the Installation hall, the order of the assembly can often be changed as many parts not directly affect each other due to the size of the entire system. If the disruptions for one workstation would generate a situation where no assembly can be performed at all, the assemblers can help other workstations until they are able to continue the work at their own workstation.

4.2.2 Production flow and layout

The carriage vehicles are transported through a gate directly from the nearby loading area outside the Installation hall. When the carriage vehicle is inside the hall, it is directly placed in one of the seven areas. Components and tools are in the nearby environment, if schedule is up to date so that dismantling and assembly can be started right away. Some of the material, the carriage vehicle included, is bought from suppliers and are supposed to be delivered as Just-in-time due to certain lack of space. The products that are produced in-house should also be delivered when it is needed which can sometimes be problematic, this will be further explained in the production planning chapter.

The material is structured in various packages with a list connected to it and when material is bought from suppliers, it is desired to be as module as it can be for easier and faster assembly. However, some component cannot come in finished modules and must be dealt with on site. The material is placed along the walls in the hall and sometimes between the workstations too. Some material is heavy and needs a lifting machine which is in the roof and reached the entire hall which gives increased flexibility regarding the placement of the stations. The needed material does unfortunately take much space and is therefore according the production engineer the most critical daily issue. The space requirements for the material, scrap and tools are according to the line manager the bottleneck within the Installation hall. There is often no space available and one part of the assembly processes is to move the material and tools. The production manager sees this material handling as one of the largest areas of improvements in the Installation hall.

The flow of the processes does not necessarily have to be in a specific order, the initial plan provides one, but it can be somewhat agile depending on what material is in place for the system. The operators can therefore have some degree of flexibility regarding operations that still would have been performed. As mentioned earlier, the assembly inside and outside the carriage vehicle can be done in parallel and the work can therefor also de concentrated to one if the other is missing material. Some operations, however, does need some special competence as power up and testing. The production manager does not want these special competences to be known by few, single competence, because they will interrupt the flow which that operator was currently working on.

4.2.3 Operational strategies

The strategy within the Installation hall is according to the production manager to follow the routing made for each system. The routing is developed with consideration to be used as the schedule for a full assembly. By following it, the production is done in the right order and follow the time schedule which were initially developed by the production engineers in consideration to the plan given from the project office. According to the production manager, the start of an assembly of a system should not be initiated before all components are available. However, this way of working is not always followed, and a system is started to become assembled with the expectancy that the missing components will be ready when needed. The assembly of a new system is initiated when there is an available workspace.

Another strategy within the Installation hall is to divide the workforce into teams based on which system they currently assembly. By using daily meetings, the line manager can see if they are working according to plan. If they notice that a system will be finished later than expected, the project office decides if the delays are acceptable or if it should be solved by working overtime. According to the line manager for the Installation hall, the reason for delays in the assembly compared to the plan is if the assembly takes longer time than expected or if the estimated time for each process is not accurate. According to the production manager there is an expressed strategy to have a close collaboration between the assemblers and the production engineers and the line manager. This is stated to reduce the time between disruptions and the support in the Installation hall.

The Installation hall have a new way of working which is based on one assembler responsible for respectively workstation. This person is responsible to report to the line manager if disruptions occur and report how they perform according to the schedule on the daily meetings. The person is also responsible to divide the work to the other assemblers in the team, which maximum consist of four people. The responsible person also has the duty to ensure that the material is structured in a good way around the workstation. The line manager perceives that all assemblers should have the possibility to become responsible for the assembly of one system. However, nobody should be forced to be the one responsible and the assemblers therefore have the possibility to say no. As of today, there is no financial incentive to become responsible for the assembly, but there is some discussion about it as they perceive it to be beneficial. The output with a person responsible for respective workstation is according to the line manager an improved communication between her and the assemblers and it is stated to be easier to have a holistic overview of the workstation's performance.

One expressed strategy by the production manager and he line manager is to widen the competence of the assemblers within the Installation hall. According to the line manager, there is an ongoing work to enable every assembler to be able to perform all assembly steps and to be able to work on every different system handled in the Installation hall. However, there is some special work tasks which requires certain qualification to perform such as some electrical installation, hydraulic installation as well as truck license to move the load carriers in and out from the Installation hall. The target is for every operator to be able to perform all mentioned step as well, but as they need extra training for performance and safety measures, the operators will get such training when they are more experienced assemblers and can perform all general assembly tasks. There are no specific financial incentives if the assembler can perform all steps or just the basic assembly as it is not negotiated with the union. However, there is one aspect of versatility, but it fulfilled when the assembler can perform the basic tasks.

The reason for the expressed strategy of wide competence is the ability to easier create work teams for respectively workstation without becoming restrained due to which competence each assembler has. The objective for each workstation is to be able to perform all tasks on the system without any help from another team. According to the line manager, this strategy is well working with some exceptions as there is currently only one operator with truck license and hydraulic knowledge which create a dependency on that specific operator.

If an overcapacity occurs in the Installation hall, the operators can be moved to other production sections and help them. Where they are moved depends on which section who needs help, if the operator have previously experience from that area. Furthermore, if the Installation hall wait for a specific component, they strive to help that specific production section in order to get the components faster. The general perception from the line manager is that the number of personnel is in the right level, but the workload may vary in both directions.

4.2.4 Performance measurement

The main performance outcome which the line manager is following day by day is if the projects and systems are corresponding to schedule and if they can be finished in time as promised. The line manager does, however, not follow the frozen plan in promised products as widely as other production sections. For the Installation hall, throughput time for a system can be up to a year which mean that there could go months before a system is finished and reported. That is why the line manager compares the promised capacity (man-hours) instead of products, ergo planned versus actual times consumed. The measuring of man-hours is something that is wanted according to the production manager as well.

The time of an operation can sometimes be hard to both predict when it is a new system and measure because the operation time is only reported in when a full operation is completed, and not after every work package. This raises the issue of lost control and overview of the production and the line manager would want a more continuing flow of information. The time can also be difficult to measure is not all operators work in the same way and thereof perform both different quality and speed. The planned is however always compared to the consumed and if there is a remarkable time difference, actions will be made.

The routing is also a part of the daily meetings where their status is compared in practice to the routing schedule. Resource allocation can be a possible solution if some system is behind schedule and other are not. If some operation has taken too long compared to what the routing says, it should be changed immediately so that the next routing is more correct. Since the routing is not checked after every finished work package but instead in batches of whole operations, the progress of the routing on the daily meetings is analyzed with a high degree of gut feeling.

In the Installation hall today, it is no problem for the workers to be informed what the status is in the various systems but for the manager and the project leader which want to be informed, it can be harder. One action towards this is the visual routing on the working package but the visual board is not online or linked to any system. The production manager explains that if all systems status was visualized on a screen, the control need of the project leader would be more satisfied and the operators would not have to explain the progress which can sometimes be a time consuming. The measurement should only have to contain a bar over the progress so that the actual versus the planned overall status can be compared instantly.

4.2.5 Distribution of information and competence

The various tasks for the assemblers in the Installation hall is many and according to the production engineer, it is not possible to learn each step to perform them without any instructions. However, the general perception and way of working is to create the prerequisite for the assemblers to be able to do all various types of work inside the Installation hall. The standardized work is a prerequisite for the assemblers to be able to perform each step and to be able to assemble different types of systems. The documentation and the 3D models are used in such way that it should be possible to perform the assembly even if the assembler has not built that specific system before. However, it requires a basic knowledge of how to assemble as the documentation is on a level where it requires a certain competence of understanding to perform each step.

When there is a new operator in the production, he or she will be assigned a mentor which often is working in the nearby environment to support and supervise during the first period of the employment. The mentorship successively goes from aiding and inspection to more of quality check in the end which all operators has which often is perform by the system responsible. The line manager wants to develop this by doing a template over what the basic knowledge should be for an operator. It could however be difficult to develop a template covering the whole installation due to new products enters every year and that the technology is continuing forward. Yet, there is many operations that are very similar.

When a new system should be started producing, the line manager decides which assemblers who should work on it. However, the assemblers are not fixed to one specific type of system. The general idea is that every assembler should be able to work on every type of system handled in the Installation hall. However, the assemblers usually assemble one full system and do not change between workstations if it is not required. This is stated by the production engineer to be beneficial as the assembler's gain knowledge of the system they are working on and know exactly which step they are on. As explained in the production process chapter, it is possible to change workstation and help colleague's assembly another system if disruptions occur such as material shortages. With the use of the assembly plan as well as the work packages, it is stated by the production engineer to be relatively easily for the assemblers to help each other.

The Installation hall does not work with the definition of “fully learned” or “working independently” as of now. However, the line manager is currently developing a competence template which is a three based scale where one is beginner and three is self-driven. There is also a fourth level where the operator is both self-driven and has e.g. taken a curse within the field and therefore can act as a teacher. The time required to learn the assembly techniques are estimated to be a couple of months for each area. The different type of system assembled in the Installation hall can be new even for an experienced worker as they do not work with any prototypes and the first system assembled of any kind should have the quality to be sold to a customer. Therefore, the knowledge of the assembly techniques is stated by the production engineer to be more important rather than the knowledge for each system as the way of working is similar even if the systems are different.

The competence is the Installation hall is both in the ERP-system and in the operators. A production engineer and the line manager explain that it is unavoidable for the whole competence to lie within the system because even the Installation hall is sometimes a craft even if most of the operations are assembly. The line manager further explains that there is no difference in the potential quality between new operators and more experienced, but there are differences in the throughput time. Experienced workers often learn some tips and tricks that makes the assembly more efficient. There are also some special operations that include e.g. truck driver license, power station or hydraulic that the operators can educate themselves when there is a need. These special competences are only offered to some due to cost and demand and therefore are not everyone offered the opportunity.

4.2.6 Documentation of production processes

The documentation of processes is not descried in a step-by-step procedure with each operation explained in detail. The way of working is instead to provide tools and aid in machinery and software so that the operators can independently perform a task with some guidance from the production engineers. The documentation that is visual at each station is the routing that is the schedule for the assembly but according to a production engineer is the routing almost never fully complete for the first system. The first routing for a new system is therefore made after experience and is thereof somewhat inadequate, however after every finished package the routing is reviewed in an HWR (hardware review).

The HWR is a type of cross functional activity since the mechanical design department is involved and so are the operators and production engineers in consultation in order to make the new instructions more accurate. The digitalization of the routing should make this process more easily to access and to follow up on a continuous basis. The digitalization is a visual board that has been implemented at one of the stations. The tool also provides the possibility for the working packages to be unchecked more in real time than before. This makes it easier for other operators to start working where another operator ended as well as for new eyes in the production that want to quickly understand the fulfillment.

It is also important to constantly change the planned time for the routing and working packages for the internal budgeting. The internal budget is a system where all departments fill in their hours with various orders depending on what value the activity has added. Every department has a certain quota to fill and the planned hours in the production follows this so that a department in theory should not be congested. If a routing of a system contains some bad planned operations, the internal budget will also be affected.

4.2.7 Standardization of work routines

The work in the Installation hall does not consist of any general instructions, but rather use the previously mentioned work packages. The work packages are used as a standardized way of working by collect the material and see where the material should be assembled. Furthermore, the 3D model helps the assembler to understand how the component or module should be assembled. The 3D model is based on the CAD model constructed by the mechanical design department. It is therefore possible for the assembler to see exactly how the component or module were intended to be assembled. Furthermore, it is possible to rotate the model as well as hide and unhide the other components in order to make it more visual. It is stated by the production engineer to be very useful and it is more intuitive to use this way of working compared with only written descriptions.

In the work packages, it is stated where the material is located, and they use location number of the placement and register it digitally. The material should mainly be placed at pallets stored in racking systems. However, due to space limitations, the material is also needed to be placed on the floor, both around the system for each workstation but also on other locations in the Installation hall. As a result of the space limitations in the racking system, one workstation is used as a storage location and material is placed on the floor in that area. According to the production engineer, it may not be harder to find the right material when it is not placed in the racking system. However, situations where the material blocking the assembly occurs and it sometimes require time to move the material in order to perform the assembly.

The Installation hall has had a work like the principles of 5S in order to handle the problematic around the amount of material and tools needed for assembly. The work is though described as not very continuous and is hard to sustain do to the large volume of material that should be nearby and soon to be assembled. The sustaining has become better since the work of one responsible assembler has been implemented and further developed.

Every operator has a computer on a movable wagon. These wagons enable the possibility to have the computer near the operator and it is easy to look at the 3D model and read the work package parallel when the work is performed. Furthermore, if the assembler should need to change workstation and help colleagues to assemble another system, it is easy to move the wagons with the computer to the other workstation. The goal with the wagons is according to a production engineer to be able to work more flexible and the implementation is stated to be successful in the Installation hall.

One workstation has started to use a digital form of the assembly plan and the work packages in order to make it more visual and it should be easier to see which operation is currently active. The digital visualization is Excel-based and have the same principles as the one on the paper such as the layout and structure. The visualization uses different colors depending on which status each moment has. For example, if the moment is finished, it is green and if it is active but not finished, it is yellow. The idea stated by the production engineers is to develop this digital visualization to replace the paper system for the other workstations as well. The analog paper routing function is all what the operators need in practice yet, as the line managers mentions, paper seems to disappear. The outcome of the digital routing depends though on how often the operators fills in the information. Some fill in the data after every finished work package and others more on a weekly basis.

4.3 Cross functional activities

The cross functional activities are activities that is necessarily for every production section, but which work is performed outside the production with a cross functional structure. The two supporting activities that will be described in this chapter are production planning and communication between departments. The description will explain what they are, why they are needed and how they are performed.

4.3.1 Production planning

The project and planning department is a separate unit in the organization at TCC. When a customer orders a system, the project-, product- and production planners contribute to break down schedule how and when the different components should be produced in order to be able to deliver the system to the customer on time. The main performance measurement of scheduling for the production sections and the managers is by following the frozen plan.

The frozen plan is according to a line manager the main objective to achieve and the most targeted measurement. The frozen plan at TCC works as a schedule over what available capacity every production section can produce over the next coming three weeks. The available capacity is the operators' time to work which is subjected with the planned time to produce the new orders. The product manager explains that they must plan after what capacity all production section have but also what resources they have because many sections have "specialized" operators which competence sometimes does not cover the whole section. Thereof, when there are many similar products that are supposed to be produced, the production planner cannot promise all available hours due to that not all operators possess the needed competence or at least raise the planned hours needed to fulfill the task.

The people that works with the frozen plan must be well familiar with the available capacity and the actual capacity, otherwise the frozen plan will most likely include more orders than can be produced. However, if there are more time needed at one station in a production section, the operators explain that they always try their best to focus the work around that process and sometimes work overtime in order to achieve the promised orders.

The production is planned and measured on each production section where each section should do value adding work 88% of the available time, called DN-measurement. It is the line manager for each section who is responsible for the operators to achieve this level. However, the measurement is well known by the operators and can be contra productive according to a production manager, as this measurement may lead to lower producing pace if the operators know that all products will be finished within the frozen plan. Furthermore, it also stated to detain alternative work tasks such systematic cleaning as it is better according to the measurement to start producing a new product instead.

Product planning
Almost all information concerning the production can be found in TCC's internal ERP-system which is configured to include the processes and product orders, which makes it easy in theory for project- process- and product planners to plan. A prerequisite to use the information is of course if the numbers are correct and updated which sometimes can be problematic. However, daily meetings and good communications between departments gives the planners a fair chance to complete missing information.

One type of information that is showing is the order stock and backlog that is used for planning various projects. The product planning manager explains how Trafo is one of the initial sections for some products which makes other sections dependable on it. The product planner can see that a project will be delayed a certain number of days if no prioritization is done and thereafter can a decision be made of either delaying the project or upgrade the projects importance. The Installation hall experience the opposite of this problem due to that they are in the end of the production. The bottleneck of time waste depends much on material shortage either from suppliers or from the internal production.

All products at TCC consists of many components and when a product has been ordered by a customer, the first planning step is to break down each component and when they need to be done in order to be able to deliver the final product. The product planners need to analyze the dependability between the various components in order to plan when each component needs to start producing. Transformers are usually the first component needed to be finalized in order to be able to continue the production of the product. As figure 4.4 shows, delays in the beginning will directly affect the ongoing production. The delays of the production of various components often affects the Installation hall as it is the last step in the production flow.

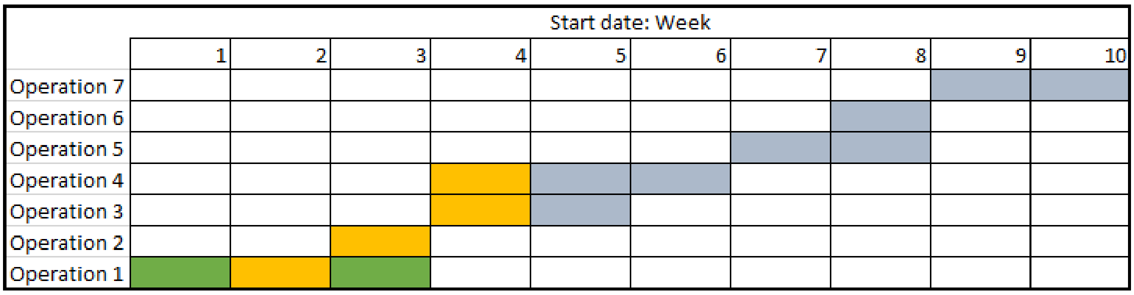

Figure 4.4. An example of a break down schedule over a 10-week period for a product with 7 involved production sections.

The picture describes what will happen in TCC's production when an operation at a production section is delayed of any reason. Due to the operation depends on the steps before, the rest will have to be on hold until it is produced. This is an example where the Trafo production can be seen as operation 1 and the Installation hall as operation 7. The project- and product planning manager explains this as an example where Trafo was the initial production section which was supposed to produce a product that was the core of the end-product. There was a delay in the beginning (the yellow week in operation 1) which was the root to all other delays (other yellow weeks). So, when the schedule is in the beginning of week 4, operation 2 can start instead of operation 3. This means that the final assembly that is planned to start at week 9 will most likely have to wait at least one week.

Production and material planning

All production sections at TCC has their own production planner and there are about ten planners in total. The production planners have their own production section which they are responsible for. However, when there is time left, they help each other cross sections. The Trafo production is small compared to other sections at TCC and has 5 full time employees, which are as mentioned experts within just this field of manufacturing. The production planner has however nothing to do with the order schedule nor the flow within the production. According to the production planner, the job is to maintain the order flow so that the workers always have some level of order stock and to order the bill-of-material together with the order document. The components are picked at a warehouse located a couple of kilometers from the production and are sent in packages daily. Therefore, no product can start the manufacturing but not be finished due to material shortage, since the material needed are either fully at the production section or at the warehouse. The production planner task for the Installation hall is thereof also very orientated towards material supply.

The planning process or prioritizing process is only about the date when the product is needed so, according to the production planner, it is the frozen plan that is the right sequence. The frozen plan within the production is a three-week production plan which cannot be changed without any directives from the upper management. With the frozen plan, the planner sees what should be manufactured and thereafter calculates the time of the orders after a "labor run factor" which is the available time of the operators of every week. Thereafter, the production planner can approve if the frozen plan can be followed without any overtime or extra resources.

Process planning

In the production section Trafo, there is an analog order board that contains all active orders (WIP), where they are in the flow and which worker that is current “owning” it. Before an order bar (a small documentation of order number) is placed on the board, it is in a waiting pile beneath the board. It is the workers themselves that decide which order to start, how long they should work on it and when the ownership of the product should shift between workers. There is no regulation or restriction of how many products there can be in the flow, neither how long a product can be waiting, but the workers do prioritize the orders after the dates. The line manager describes this order board as insufficient in many aspects. The board of various manufacturing processes is described as too general where the activities are not representing the reality. The line manager sees the importance of a process chart where all orders can be visualized. However, he sees the potential of investing in something more advanced for more synergy between the workers.

In the Installation hall, there are analog boards showing where the respective process for the system are and if the processes are behind or ahead of schedule. All assembly operations are briefly described, and the operators can easily find the work package on their own computer to follow. The process is not itself described in the work package but instead a 3D CAD program with the material list connected to it. The production engineer explains that it would be almost impossible to explain the process thoroughly, instead the operators are given the 3D program so that they with their knowledge can figure out how to assemble the components. The work package also include which tools should be used and where they are located so that there is limited time waste in non-value created activities.

Recently, the analog process boards have started to be digitalized with an excel tool that is explained in the chapter describing documentation of production, 4.2.6. This was initiated as an aid for the workers to more easily see the progress a station has in different stages with color coding and dates. This tools also makes it much easier for any personnel that visits the Installation hall and want to familiarize themselves quickly to the current situation.

4.3.2 Communication between different departments

A department that needs an operator's competence is the Mechanical design department which design and write the technical specification, specify the material and so forth for the products that should be produced both in-house and outsourced. The mechanical design manager explained that the competence that all production workers possess is crucial for the mechanical designer so that the product can be made with the current production presumption as in tools and machines. One mechanical designer also explained that a product that has never been made will first be produced as a prototype which the operators tries to manufacture and afterwards gives feedback on the specification. If something was missed or perhaps needs more clarification, the mechanical designer can finalize the specification in case of the product should be produced again. The Installation hall have the mentioned HWR and the Trafo production has more spontaneous meetings which is more based on personal contacts according to the mechanical design engineer. The Trafo production has not always been this way, and therefore some documentation for old products, as mentioned, is lacking information. Both the production and the mechanical design department appreciate this collaboration, the only obstacle is that much of the collaboration comes from personal communication which means that for products which are bought from suppliers are much harder to control and correct.

The Trafo production has a line manager and a production engineer, who works for the Industrialization team, to oversee different implementations or improvements in the production environment. Both the line manager and the production engineer engage in daily meetings and work close with the workers which makes the information concerning Trafo communicates fast. However, the production engineer's workspace is in the office area in the building and not nearby the Trafo production. The Installation hall works in the same way with their production engineer and line manager. However, the Installation hall always have a production engineer located within the assembly area. Another difference between the sections is that technical changes will be reported in the Installation halls work packages for the future, which means that the documentation is continuously updated.

When a product which have not been produced within the last three years occur in the frozen plan, the ERP-system will give a notification. The notification will be received at the meeting for that frozen plan period. The information should thereafter be transferred to respectively production engineer for the specific area in order to oversee if any updates needs to be done in order to produce the product. Such updates could be of e.g. the routing and which tools to use.

5. FLEXIBILITY IN THE HVLV PRODUCTION AT TCC

This chapter aims towards analyzing the current operational strategy, using the empirical findings, in relation to the model derived in the theoretical framework presented in figure 3.6. This chapter is structured after the model which includes four agile capabilities (strategy, people, process and linkage) which all contributes to the core capability. The core capability further consists of new product- and product mix flexibility. The second research question (*"How can flexibility be achieved in an HVLV environment with agile manufacturing and what theoretical working standards should be implemented at TCC?")* is analyzed and answered in sub-chapters 5.1 and 5.2. The analysis of the two production sections are separately analyzed but in the same perspective. The operational principles that should be implemented are analyzed from the literature and in what way they are relevant for the production in practice. The answer for the second research question will also be provided in brief in chapter 7.1, discussion of findings.

5.1 Analysis of the Trafo production

In the chapter of the Trafo production analysis, the production section will be analyzed after the following four capabilities: strategy, people, process and linkage. Ways of working, standards and other relatable areas from the current state and literature review will be compared and enlighten. Whether or not the practice and literature correspond, the analysis will contrast and give implication on what could be done in Trafo in relation to what the literature describes.

5.1.1 Agile strategy

The Trafo production can be defined as an HVLV-production according to the definition given by Jina et al. (1997) where the production should have low volume, high customization, as well as complex supply network and industry complexity. Figure 4.1 is one example of why it should be defined as HVLV as the most produced transformer is only produced 36 times during the four years of measurements and the mean value of two of number of times a component was produced. The HVLV definition of the Trafo production will therefore suggest an agile strategy according to Christopher (2000) as the repeatability is low and the variety is high. The strategy used in the Trafo production is however somewhat missing and there is no expressed way of working. The increased importance of a manufacturing strategy is according to Gunasekaran (2001) due to its effects of increased productivity and quality. For the Trafo production, the quality level of the products produced is high and well developed due to the high number of tests between various processes which identifies the quality error. However, the productivity issue could be improved with an expressed strategy as a considerable part of the operators' time is wasted on tasks such as searching for the tools and materials as there is no expressed way how to work with tasks such as 5S.

Brown and Bessant (2003) describes how manufacturing strategy takes long time to develop, and it becomes a result of long time of development. This is the case for the Trafo production where the production has been developed for decades without any major changes. If the used strategy is the best one may not have been of focus to increase the output of the Trafo production. As the manufacturing strategy should match with the overall strategy as stated by McCarthy and Tsinopoulos (2003), the strategy issue of Trafo may be needed to be investigated on a higher management level. The manufacturing strategy should be set from top management according to McCarthy and Tsinopoulos (2003) and permeate into all production sections in order to enables synergies within the company.

The guiding strategy used in the Trafo production today is to follow and produce according to the frozen plan to not delay any other sections in later steps in the production. Furthermore, the use of two teams in the production for the processes is somewhat also an expressed strategy from the line manager. However, other aspects of strategy such as knowledge transformation, training of new employees and standardized work may not be in the scope of the strategy used today. As a result of not having all aspects included in the strategy, it may cannibalize on itself as the lack of standardized work has shown to give negative effects of achieving the frozen plan. The strict focus on the frozen plan and the need to deliver products for the short-term demand may however also be negative in a long-term strategy. As stated by both the line manager and the operators within the Trafo production, there is no available time to do any continuous improvements, such as implementing 5S, which is a well-developed lean method and according to Irani (2011) a promising tool for HVLV environments. However, if time is not invested in developing such projects, the issue with time consuming activities such as searching for material and tools will continue. The lack of systematic structure within Trafo as well as the stated issues of the constant searching for tools and materials indicates the need of make short-term time investments in order to developing long term strategic success.

De Toni and Tonchia (1996) argues how performance measurement vary depending on the prerequisites for different production sections. The two most important dimensions are stated to be production volume and product complexity. Their definition on product complexity is based on the BOM and the Trafo production can therefore be seen as low product complexity as the number of components is relatively low. Trafo production would therefore be in the scope of special parts in the framework of De Toni and Tonchia (1996) which suggest measurement of lead time, machine flexibility, part quality and material costs as four different suiting measurements. The performance output of the Trafo production is mainly measured in OTD, planned versus consumed time and DN-measurement. None of these measurements is fully in line with the measurements given by De Toni and Tonchia (1996) which would indicate the use of wrong scope of measurements. The planned versus consumed time is a bit like the lead time measurement. However, the planned versus consumed time measurement only focus on the process time and not the throughput time. This measurement will therefore only identify how close the actual process time is in relation to the estimated process time in the routing. It will not give any indication on how long time the product needs to be in the production flow in order to be finished. Furthermore, the focus on planned versus consumed time results in unreliable statistics as it will not measure what the operators perform between each process step. In order to identify it to reduce no value adding activities between the processes, it needs to be measured. Such measurements could either be included in the ERP-system or as simple as an analogue documentation just to get a hint on how big the problem is. The focus on planned versus consumed hours could still be included as a KPI but focus should be towards reducing total throughput time.

The OTD measurement is not in the framework by De Toni and Tonchia (1996), but the use of it could be argued to be useful. Time measurements are stated by Ghalayini and Noble (1996) to be useful as it is easy to understand and use, compared to monetary measurements. Ghalayini and Noble (1996) divide time measurements in four different categories where one is customer service with an example of measurement of percentage delivery of time. Regarding the DN-measurement efficiency of 88%, neither De Toni and Tonchia (1996) or Ghalayini and Noble (1996) suggest such measurement and instead of generating the effect it is intended to do, increase the output of the operators, it is rather contradictive. The measurement forces the operators to start with new products, which may not be critical in time, instead of doing e.g. 5S-work or learn other processes in order to increase the knowledge.

5.1.2 Agile people

According to Yusuf et al. (1999), knowledge driven enterprise is one of the core concepts for agile manufacturing. To engage people and develop them is one way to develop the organization further. However, it is important to preserve the knowledge to create a successful business. The Trafo production has a high level of expertise in the people, and not in the system. This leaves many questions around how the competence should be treated.

The training is a crucial part of the knowledge driven enterprise and it can be performed in various ways. TCC is a relatively large company with several hundreds of workers in the production which according to Chau et al. (2003) should mean that there should be a high level of documentation, since the risk of losing information in verbal communication becomes higher. But Trafo itself can also be seen as a small stand-alone production unit which then should focus on verbal communication instead. Smaller organizations could instead focus their knowledge distribution on informal training. Trafos personnel is no more than five operators which would make informal training generally easier to learn from, but since they belong to a large organization which have many departments involved and a high level of product variation, thing becomes more complicated. Even if there were one operator which is an expert, he or she would still face tasks they have never done before which indicates the need for documentation. Therefore, when the knowledge is learned by one worker, the training to pass on the knowledge would preferably be in the "field" by the new expert acting as an instructor. This would mean that the competence distribution would be based on job-rotations where one operator can learn from other more experienced.

By documenting the competence at the same time as rotating for enhancing a more multi-skilled workforce, issues as single competence could be avoided. Single competence is something which Trafo is heavily affected by due to several of reasons. Some reasons are that the field needs a high degree of specialization, the products are a handcraft, comes in many forms and so forth. However, since there is lack of documentation and standards, two operators could perform the same activity in different ways even for the same product. This could mean different level of quality in the end as well as different throughput times. It is also difficult to improve a process if there is no standard as standard is the key to continuous improvements (MĺKva et al., 2016).

The job-rotations, which are not systematically existing, are only performed when there is nothing to do at one workstation. Trafo is divided in two teams which is appreciated by the workers, but it means that they know very little about the other team's area of knowledge. It was expressed by the operators that they believed it was better to become experts in one area rather than know less about the whole production. There are arguments to back this statement, but their impression of the situation is based on that there is very limited documentation. In addition, becoming experts will mean that they foster single competence and hinder the need of documentation since an expert does not need it in the same way. Developing experts does not necessarily implicate single competence, if they for instance function as teachers. But if there is no job-rotation or if the experts do not fill out any documentation or create standards, their knowledge will go on with them when they leave the organization. The learning stage for other employees to take over will be long to reach.

The lack of teaching and learning and somewhat job-rotation and documentation is an outcome of some resource-, but mostly, time shortage. Trafo as a production section has had a backlog of orders for a long period of time which have put pressure on all operators as well as the line and production manager. The line manager expressed this as it is difficult to rotate the best operators when there are still promised products left to manufacture. This have created a vicious circle where there is a need for aiding improvements but there is no time to improve. Actions should be made even if it means a temporarily set back in order to get a more multi-skilled workforce (Chang et al., 2005).

To succeed with job-rotation, it is important to first dedicate resources and secondly consider how to motivate the operators to broaden their competence and reward them for achieving it (Chang et al, 2005). It was stated during the observations of the current state that it is almost impossible to identify when an operator is fully learned, but as expressed by the Industrialization manager, maybe a potential skill matrix should measure the “base knowledge” needed and not how to become an expert. The dedication of resources should perhaps not be in form of more operators since there is already at this point space and machine shortage. Trafo should instead get better access to production engineers and tools so that aiding activities such as documenting, preparing fixtures and visualizing the orders can be more automatically driven. The job-rotation should be based on a skill-matrix that include the whole production section (and maybe more) and define what basic knowledge is needed. The rotation could be in form of some hours per week so that the operators still could perform their usual tasks.

5.1.3 Agile process

The layout within the Trafo production can be discussed to be both functional and cellular based on their prerequisites according to the definitions by Jonsson and Mattsson (2016, p. 227-230) and Silva and Cardoza (2010). The functional layout is stated to be very flexible according to Jonsson and Mattsson (2016, p. 227) which would be beneficial in order to strive towards an agile production, but it is resource efficiency oriented and generates long throughput times with WIP as a result. The cellular layout is however better in that matter to handle throughput time and WIP according to Jonsson and Mattsson (2016, p. 230). The cellular structure would therefore be a good layout for the Trafo production, but due to competence gaps, the flow of products cannot follow the structure the layout is supposed to generate.

In order to become more flexible within the production processes, Kostal et al. (2010) suggest using flexible manufacturing cells as the layout. The flexible manufacturing cell is stated to be of well use when the batches are small or one-piece flows and the overall costs can be improved. This production flow can improve the overall throughput time if used in the right way such as have supporting functions to the production flow. The supporting functions can be material preparation and premanufactured tools. Such type of layout would be possible for the Trafo production both due to the products they produce, but also the non-existing automation in production which is one hinder for flexible manufacturing cells according to Kostal et al. (2010). However, the supporting function may have to be changed and improved in order to achieve the flexibility. Example of changes which needs to be made within Trafo is to let the mechanical workshop build the fixtures and not let the operators perform such task in their own small workshop.

As mentioned earlier, the Trafo production focus on resource efficiency which in practice means that the operators should do value adding work, even if it cannibalizes on the flow efficiency by starting new orders which generates more WIP as well as generates higher level of capital costs (Leitch, 2001). Modig and Åhlström (2015, pp. 16 & 45) argues the difficulty to achieve both resource and flow efficiency. The first dimension to focus on is the flow efficiency as it reduces costs by reducing the WIP, but also by generating customer value by shortening the throughput time. The focus on resource efficiency for the Trafo production could be contradictory to what Modig and Åhlström (2015, p. 24) suggest. The flow in Trafo are controlled by the operators where they decide which process steps they can perform on each product and how many products they have active in the flow. They start a new order if they cannot perform any more step on the product they currently are producing, instead of doing alternative work such as documenting processes.

WIP can be used between processes in two different ways, to mitigate short term disruptions or long-term imbalances created by the flow itself (Conway et al. (1988). The WIP in the Trafo production is a great example of how it is created by themselves as a result of not being able to perform all process steps. Some WIP will be needed to handle various fixed process times such as for the vacuum chamber and may not be the main issue. However, in order to become more flexible, WIP generated by lack of process competence should be strived to be minimized. The focus on starting new orders could be a result of the use of the DN-measurement which would reward the focus on resource efficiency. Such focus does not match the manufacturing strategy given by Modig and Åhlström (2015, p. 24) to start with the flow efficiency first. The backlog the Trafo production struggle with and striving to reduce would also indicate the need to focus on flow efficiency, even if it will affect the resource efficiency negative at first.

Technical aid is one parameter suggested by Chang et al. (2005) to increase the new product flexibility as well as the product mix flexibility. The aid can be both for the production itself such as new machines, but also as a support in the production facilities. New machines are something which both the line manager and the operators in the Trafo production have discussed about, mainly concerning investments in new winding machines. According to the dimension of commitment of continuous tech advantages given by Chang et al. (2005), such ideas of investments should be elaborated further as it may give a significant effect on the production. The effects could be both shorter process time, but also increased quality assurance.

Technical aid for process support could be visual management, which is one of the lean tools applicable in an HVLV environment. MÍkva et al. (2016) discuss how visual management can be for both tools and process steps, but also visualization on the progress for each product. The Trafo production have a low level of visual management in both aspects. Regarding the tools and process steps, there is no visual aids in order to help the operator such as pictures on how the various steps should be performed or how the tools looks like. Such technical aids could mitigate the risk of errors as well as reduce the time needed to search for materials or understand how to perform a process step. Regarding the visual control within the flow, they do have the board on the wall where they can move magnets with the order number depending on which process it is currently on and which operator who is responsible for it. The magnets on the board do not visualize all important parameters such as how long time it is supposed to take to produce. A digital screen may be of better use and be in line with the dimension of commitment to tech advantageous given by Chang et al. (2005). It could generate more information to both the operators as well as to the line manager. By using a digital screen, the information visualized could easily be changed when needed such as during the daily meeting or when there is material shortage.

5.1.4 Agile linkage

The agile linkage capability according to Brown and Bessant (2003) is how well a unit works together with other parts of the supply chain such as customers and suppliers. However, the linkage could be analyzed on different levels and its main attribute is the interaction between them. Within TCC, the departments are as various units and how they collaborate with each other would therefore be the linkage within this study.

One of the dimensions of flexible manufacturing presented by Chang et al. (2005) which can be clustered within the linkage capability is the manufacturing involvement. This dimension focusing on how departments in the company support the production. The Trafo production have a production engineer which helps with various types of problems which may occur in the production. However, the production engineer is not stationed nearby the Trafo production, and the communication is stated to be of concern. If small problems occur in the production, the operators sometimes do not take the time to contact the production engineer, or when he is not available. A higher level of involvement between the operator and the production engineer could be a solution and a way to increase the flexibility. To increase the involvement, the production engineer may be needed to be stationed nearby the Trafo production or be more actively involved through visual management and digitalization.

Another aspect of the manufacturing involvement dimension is how fixtures and documentation could be improved in order to support the operators within the Trafo production. As of today, there is much focus on what to produce within the frozen plan, that it may hinder the editing of documentations and producing new fixtures, which will affect the production when they start producing the product. The three-year notification given by the ERP-system could be an area of improvement. As stated before, it may be too late when it is already placed in the frozen plan and such supporting activities as editing the documents and creating fixtures should be notified earlier than three weeks. The three-year timespan can be also be argued if it is suitable. Shorter timespan would generate more work for the production engineers but may be required in order to produce the products with less disruptions.

The other dimension in agile linkage is the manufacturing design and integration. This dimension is concerning how well departments collaborate with Trafo in order to generate a good producibility and get the operators input on how to produce the products. The mechanical design department states to have a good communication with the Trafo production, but it is rather a result of personal relationship than an expressed way of working. The mechanical design engineer for transformers are sometimes present in the Trafo production to get their input on a specific product and how some parameters should be set, such as for the winding. The risk with this type of way of working is to not follow any standard. With a new mechanical design engineer for the Trafo production, the communication may not be the same.

Modularity thinking is another aspect within the manufacturing design and integration dimension in the framework by Chang et al. (2005). It will foster synergies when similar tools can be used, and it will increase the flexibility within production. The level of modular thinking of the transformer products is low, which generates many various transformers they should be able to produce, with various sizes and attributes. However, due to the varying applications areas for the transformers, there is a need for the large number of different products where it is impossible to use the modular thinking. In addition, as there is no upper limit on how old transformers they produce, the range of products will just continue to increase.

5.1.5 Core capability

The core capability is the production systems capability to produce new and change between old products without making any investments, thus being flexible and yet cost-efficient (Hallgren and Olhager, 2009). In the analysis model, the core capability is related to new product flexibility and product mix flexibility which determine the production systems flexibility.

The two different flexibilities of product mix and new products can be argued to be the same within the Trafo production. As a result of the low level of documentation of the products and the needed processes, old products will many times need to be handled in the same way as new products. Hence, the product mix flexibility is low, and will be one area of improvement when striving to an agile manufacturing strategy. However, there are some aspects regarding the product mix which will enable a flexible approach for Trafo. One of them is an add-on in the frozen plan with a notification for products which have not been produced during the past three years. It will help the production engineers to support the operators regarding the manufacturing in order to strive towards product mix compared to new product.

The other aspects are the tools and machines within Trafo. It is possible to produce all products within the area with the same type of machines, which is a result of the good communication between the operators and the mechanical design engineer. However, the issue regarding the product mix is the high level of single competence which will hinder the ability to be flexible regarding the product mix. Thus, the single competence is based on process knowledge and not product knowledge, which would result in the same type of flexibility for the full product range compared to if single competence of products was the issue. Chang et al. (2005) suggest that the workers should be able to perform various types of processes in order to generate a multi-skilled workforce to increase the product mix flexibility. For the Trafo production, the process know-how should be further developed of how it is transferred between the operators and strive towards a broader process knowledge. Regarding the product information, it should be detailed documented within the ERP-system and always accessible for the workers.

Regarding the new product flexibility, the communication with the mechanical design department previously mentioned is a critical issue of being able to introduce new products to the manufacturing. However, the low level of modular thinking generates a wider range of product attributes which will be negative in the new product flexibility aspect. Another aspect of the new product flexibility within Trafo is how the supporting functions could facilitate the operators in a more extended way. Old products where e.g. the documentation is of low level or if tools or fixtures are missing, that is rather in the spectrum of new products than as in the product mix. However, the supporting activities such as creating a new fixture is performed by the workers themselves and not by the full-scale mechanical workshop in the basement. This would indicate how an old product is assumed to be in the scope of product mix, while it operates as a new product in practice.

The core capability according to Hallgren and Olhager (2009) is to be flexible while still being cost-efficient. For the Trafo production, it can be discussed if they fulfill the capability as they somewhat missing the product mix flexibility. Furthermore, the cost-efficient aspect could be assumed to be both regarding investments as well as utilizing the existing resources well. For the Trafo production, the operators need to perform supporting activities as mentioned before which is time consuming and one of the results of this issue is the constant backlog. This could be assumed to not be the most cost-efficient way to work and will therefore not be in line with the definition of flexible manufacturing by Hallgren and Olhager (2009).

Single competence within the Trafo production would not support the necessary flexibility stated by Narain et al. (2000) as the risk of not being able to produce a product due to competence if a person is absent is high. However, the machines may be old in the Trafo production, but they fulfill the ability to produce the product range which is one of the criteria to be defined as necessary flexible Narain et al. (2000). However, improvements need to be made regarding the structure of the tools, which the use of 5S would support in order to fulfill the necessary level of flexibility.

5.2 Analysis of the Installation hall

In this chapter, analysis of the Installation hall, the production section will be analyzed after the following four capabilities: strategy, people, process and linkage. Ways of working, standards and other relatable areas from the current state and literature review will be compared and enlighten. Whether or not the practice and literature correspond, the analysis will contrast and give implication on what could be done in the Installation hall in relation to what the literature describes.

5.2.1 Agile strategy

The Installation hall is according to the definition by Jina et al. (1997) an HVLV-environment as they fulfill the four different aspects of production volume, customization, complexity of supply network and industry complexity. The Installation hall also fulfills the three different dimensions given by Christopher (2000) of variety, variability and volume which support the Installation halls aim towards becoming more agile. The Installation hall do have some dimensions mentioned by Chang et al. (2005) of the agile manufacturing such as focus on a multi-skilled workforce as a part of the strategy. There is no expressed agile strategy within the Installation hall, but the routing and flexible resources function as one.

The output of a strategy is according to Brown and Bessant (2003) the performance of underlying tools such as Just-in-Time. JIT could be argued to be the most optimal way of material supply for the Installation hall since the material requires relative much space around the workstations, but since material shortage is affecting the production section it may need buffers. The material should come in a sequenced way, but since the amount of material nearby the workstations is high, the sequencing and supply could be improved. Material shortages is one common disruption in the flow and extra material is often useful to work on alternative work packages on the routing.

Following the routing as a strategy within the Installation hall is stated to work well and it works both as the time schedule, sequencing of material and guideline of work tasks. One reason to have a well-developed strategy is according to Brown and Bessant (2003) the necessity of short lead times. The environment the Installation hall operates in, HVLV, the definition of short lead times can be discussed. However, by decreasing the lead time, the throughput time will also decrease which will have a positive impact on the capital cost (Leitch, 2001). The routing which works as the strategy does not have any expressed focus on neither flow efficiency nor resource efficiency but rather a combination of both. The use of the DN-measurement would indicate focus on resource efficiency as they strive towards finding value adding work for the assemblers. The assembly teams help each other in order to complete the different systems which would also indicate on resource efficiency. Helping where there is a need is both agile and somewhat flow oriented. If they help only to increase their DN-measurement it could mean that they are not helping the flow but instead their own efficiency. Hence, some measurements of man-hours are perhaps not suitable for the aim towards decreasing the throughput time of a systems routing nor aiding activities such as material supply and 5S. The Installation hall should focus their measurements on the systems routing and how they can follow schedule and thereafter shorten the routing. According to Leitch (2001), shorter throughput times will have positive effect on the capital costs for the production.

In the framework by De Toni and Tonchia (1996), with the two parameters of volume and product complexity, the Installation hall can be defined in the category of engineering products due to the high number of BOM used. The framework suggests the four measurements parameters of adherence to schedule, part quality, project quality and project costs. The measurements used in the Installation hall are daily reports of the systems progress which are communicated between the assembly teams and the line manager, DN-measurements and lastly how the Installation hall follow the frozen plan. Compared to other production sections, the frozen plan here consists of man-hours instead of the number of produced products due to the long throughput times. The use of time instead of number of products is good according to Ghalayini and Noble (1996) as it easy to understand and reduction of time is stated to always be beneficial.

The daily feedback between each workstation and the line manager is in line with the measurement stated by De Toni and Tonchia (1996) as the adherence to schedule. The daily updates give feedback on the progress of the assembly of each system, and it enables the possibility to adjust to it with overtime or if the project office can accept a later delivery of the system. The measurement of the frozen plan does not match any of the examples of measurement given by De Toni and Tonchia (1996). However, the measurement is given in time which is recommended according to Ghalayini and Noble (1996). The DN-measurement is according to the framework by De Toni and Tonchia (1996) not a suitable measurement for engineering products. However, according to the time measurements given by Ghalayini and Noble (1996), the DN-measurement is a production time measurement where the assemblers value adding time is set in relation to the total elapsed time. However, DN could generate negative effects on alternative work tasks as it is not defined as value adding time. In order to use such measurement, it is important to define what type of tasks should be defined as value adding and/or at least needed. Furthermore, the measurement does not indicate if the output is right just because the DN-quota is fulfilled which should place the measurement as secondary.

One further aspect of the measurements is the reporting into the ERP-system. With the analogue system used with the routing for all workstations except one, the time reporting will not be reported continuously and will therefore generate peaks and valleys in the system. According to Petersson et al. (2015, p. 259), continuously measurements are important to be able to do follow ups in order to improve the performance. This is an issue which the digital routing would improve remarkably if used in the right way. With a systematic way of working, where each step is reported into the system, the reporting issue will probably be minimized. However, there is a risk of excessive work for the assemblers with extra administrative tasks which they may have some opinions about. This is also stated by Petersson et al. (2015, p. 259) as the main drawback of frequent reporting as it will take time from the ordinary work tasks. If some reporting activities could be digitalized and thereby autonomous, both time reduction and quality of the data will be improved.

5.2.2 Agile people

According to Yusuf et al. (1999) and as mentioned in the previous chapter, knowledge driven enterprise is one of the core concepts for agile manufacturing. To motivate people and develop them is one way to further develop to organization. However, it is important to preserve the knowledge to create a successful business. The Installation hall has come a long way of broadening their competence but still have some areas of improvements. In the same way as Trafo could be a small stand-alone unit from TCC's production, they still would face the same challenges with working within HVLV. This mean that informal training is not enough to distribute the competence (Chau et al., 2003), and especially not since the knowledge is in the work packages.

All workers in the Installation hall has their own wagon with tools and computer which is portable. This is one way of dedicating resources to the operators to make them more agile within the production. It does not however make them more multi-competent, that requires a working procedure too. The workers "jump" between system when there is a need for it, but otherwise are dedicated to one system at a time. When the system is almost completed, the team splits up and are placed on other systems successively. Thereafter, a naturally job-rotation is created both with colleagues and working tasks. The only drawback is that the period of the job-rotation could be up to a year, even if the activities within a system can vary a lot and be like other activities in other systems. The similar activities and process steps for the work packages is what Yusuf et al. (1999) mentions as synergies in an agile production where knowledge is saved and applied in other tasks.

There have been cases where there are workers which have become specialized in a certain system after many years and suddenly got promoted and left before a proper handover had been done. Single competence is something that exists in the Installation hall in some special activities such as testing but should not be hard to avoid. The competence itself is not a threat for the production but rather an obstacle since it will draw that specific worker from his or her current operation and keep them busy until e.g. the testing is done. If it was possible to educate two or three workers in total, it would be easier to perform these activities without interrupt the routing too much.

Single competence in the matter of assembling, which is the main activity in the Installation hall, is not a threat to competence distribution nor quality. In the current state it was clear that the quality of an installation, completing a work package, was not affected by the workers expertise but instead only the time. There can of course always be some errors and flaws in practice, and that is where the mentor and system responsible comes in. Every new assembler in the Installation hall gets a mentor as shadow for a while, and the mentor overview the new colleague and should be available. The system responsible does also have some overall responsibility for the result of the systems and evenly checks up on the quality. This methodology combines informal and formal training which would according to Chau et al. (2003) a well-structured way of working with competence distribution.

The work with a training template for new employees and a skill-matrix is currently under development. The training template and skill-matrix does associate and goes hand in hand because they are based on the same scale. The scale goes from 1-3 in the activities in the production where 1 is beginner and 3 is working independently. There is also a possibility to reach level 4 on the scale where a worker has succeeded to be working individually and have the skills to act as an instructor. The skill-matrix will show managers clearly which workers knows what and who needs to know more and thereafter be able to create assembly teams depending on the competence. The skill-matrix is based on the routing and work packages which are the foundation of the Installation hall. The work packages and the documentation they contain made the template and matrix possible. Without the clear standards and documentation, it would be very difficult to determine when a worker has learned enough and if he or she has learned the necessarily parts. What would be the only challenge is how the workers should be motivated. There is, of today, no rewarding system for employees who has a broader competence which can be useful in order to raise the personnel involvement (Jonsson and Mattsson, 2016, p. 235). This may not be a big issue, but it could grow bigger if the employees see no motivation of becoming more multi-competent.

5.2.3 Agile process

The production layout within the Installation hall is structured in a fixed position due to the large products they are assembling. Jonsson and Mattsson (2016, p. 231) mentions how fixed position is the only option for a production layout when the products are too large to move during the assembly. As a result of not being able to move the products, the Installation hall have instead focused on the movement of the assemblers by creating movable wagons with tools and computer. The wagons increase the flexibility both around the workstation, but also the ability to move to another workstation. The movement of the assembler's wagons is stated to be a competitive flexibility according to Narain et al. (2000) as it creates a versatile workspace when the systems are not able to be moved. However, even if the assemblers become flexible and easy to move, the material supply is one of the issues inside the Installation hall. Sassani (2016, p. 31-32) argues how material flow is one of the most crucial parameters for the fixed position layout which also can be identified in the Installation hall as the main cause for disruptions. The material is strived to be delivered in the right sequence, but there are issues with too much material in the workspace which will block the assembly. One aspect of creating a more flexible production in the Installation hall is to enable the change of order for assembly to be able to mitigate various disruptions. To do so, large number of components needs to be stored nearby the workstations. However, this requires space for pallets which are a scarce resource today, but it could be improved with a greater use of racking systems.

Sequencing the material is used today and is functional due to the routing and that the routing include what material is needed for all operations. There are no visible flaws in the routing, but instead the delivering of the material which will be further analyzed in agile linkage. The work packages are also structured so that the workers will have certain material packages which contain every needed component. However, even if the material located in the Installation hall is structured, it takes up much space on and between the working stations. The tools needed to operate does also need much space which create an issue with standardizing and sustaining.

As a result of the lack of space in the Installation hall, the use of 5S have been beneficial according to the line manager. The structure of the material is good with different specified storage positions and good structure of labeling, but due to the large amount of material, it can still be hard to find the right pallet as it might be placed on the floor. Furthermore, there have been some issues regarding the fifth S, sustain. One part of the aim of using 5S is according to Petersson et al. (2015, p 312) to change the behavior in order to keep the structure and maintain it over time. This is one parameter which have been lacking in the Installation hall where the change of behavior may not have been successful. The use of one responsible worker for each workstation have however increased this aspect.

Except from the 5S, standardized work is one of the lean methods applicable for HVLV production (Irani, 2011). Standardized work is a well-used method of working within the Installation hall by working with the routing and the work packages. In order to improve the process with continuous improvements, standardization is the key to enable it (MĺKva et al., 2016). Improvements in the Installation hall is performed by updating the routing if they perceive changes should be made. Such changes could be in what order something should be assembled, but also how long time it takes to assemble it. As a result of not producing any prototypes in the Installation hall, the first produced product of a system is only based on estimates, but by continuously updating the routing according to the actual assembly, the routing will be improved to better reflect the reality. By working according to the standardized work and continuously improve it, throughput times can be reduced. Due to the long throughput times, three months to over a year, improvements could be assumed to give significant effect. According to Leitch (2001), shorter throughput times will have positive effect on the capital costs for the production.

One aspect regarding the standardized work within the Installation hall is how to work with documentation of the process steps. Each system requires many assembly steps which would be problematic to write down as the documentation would be very long, and the assemblers would not be able to read all the necessary documentation. By following the work packages with digital 3D models, the standardization is a type of visual management tool which fulfills the prerequisite stated by MĺkvaMĺkva et al. (2016) that it should be easy to follow and use. However, in order to be able to perform each standardized step, there is a need of a basic assembly knowledge as presented in agile people. The work with scanners and visualizing the progress should also be pushed to be implemented since it simplifies the process, minimize errors and mostly, giving the workers no room to slack on filling in the information.

The third lean tool applicable in an HVLV environment according to Irani (2011) is visual management. Visual management in the production processes is well used in the Installation hall as previously mentioned with the 3D CAD model in the work packages which visualizes how the component should be assembled. However, regarding the visual management such as control of the flow is not that well developed within the Installation hall. The routing is, for all workstations except one, analogue with a large paper visualizing the process steps which are in various colors depending on the type of task. This could be further improved, such as for the workstation which have started to use a digital routing instead. The production manager sees an opportunity to have a large screen within the Installation hall to see the progress for each system in relation to where they are supposed to be. The production manager also wants screens on each workstation where some more details on the progress can be visualized which reduce the disturbance of the assemblers. This would be in line with what Tezel et al. (2009) exemplifies of how to create transparency within the production facility. The project office would also gain by such implementation as the progress will be more transparent outside the Installation hall which will decrease the need of asking the assemblers what the status on the different systems are.

5.2.4 Agile linkage

The Installation hall is the final assembly of the production and is therefore more or less linked to all previous production sections. This means that they are heavily dependent on the material supply since the production does not work with MTS and therefore is the work with planning and linking the schedule of high importance. When the material is on site, it is also important to handle it directly since the Installation hall has space shortage. Agile linkage can be both between production sections and departments but also between roles in the same section, this is clear for the Installation hall.

The routing is as described the foundation of planning the resources and products and contains all the necessarily information about documentation and time schedule. Because of that the systems are similar in many ways, operators can both be rotated within the same system and change between depending on the need. The routing lets the operators see which work packages are done so that they can continue where another assembler stopped. This is a result of both the routing and the modular thinking which the construction department stand for. When the systems and their routing are being developed, the modular thinking of what can look or be assembled in the same way by the same machines are always there. The modular thinking therefore also actively reduces cost for machines and material.

The routing which is an analog paper today is basic but does fulfill the agile linkage needed for the operators to familiarize themselves, but it can be more difficult for the project managers as described in the current state. The project managers come down evenly to check up on if their specific system is on schedule or not which then an operator must take time to explain in detail how it is going. This control-need could be solved if the routing were to be more continuously updated and visually digitalized as it would become more accessible and understandable (MÍkva et al., 2016).

The digitalization of the routing has begun and further investments such as scanners will be tested in the future. According to Chang et al. (2005) this commitment to continuous tech advantages is something that is needed to handle flexibility more efficient. The workers have also expressed that they cannot fill in the information whenever they finish a task due to the administrative time would be too great. The scanners should also fill in the right information so that human errors are limited. If all systems were to be digitalized, they could all be monitored at the working station, on a large screen at the daily meeting and online for all concerned actors. For the digitalization to work well, MÍkva et al. (2016) describes that standardization of processes should be implemented. If the workers, as they do not have today, would have a principle to follow when they must document their work the data would become more reliable. With a more reliable data, the Installation hall could even out their working hours and not register all data when the system is done which would enable KPIs measuring.

The Installation hall has the prerequisites for agile linkage, but they should continue the work on visualizing and continuously updating. The dilemma with them being in the end of the production chain is difficult to deal with, but not much to do other than planning the material and sequencing. What the Installation hall should focus their resources on is their own linkage with visual management and digitalizing so that other departments such as the project office and management can have better data and more reliable KPIs.

5.2.5 Core capability

The core capability is the production systems capability to produce new and change between old products without making any investments, thus being flexible and yet cost-efficient (Hallgren and Olhager, 2009). In the analysis model, the core capability is related to new product flexibility and product mix flexibility which determine the production systems flexibility.

The new product and product mix flexibility in the Installation hall differs greatly regarding routing and planning, but not at all regarding routines and standards. Both old and new systems have a routing with belonging work packages telling the workers what to perform. The new systems also have systems responsible, even though no one has yet become experts. However, since there have not been any systems assembled before, the routing and the planned time for each activity will most likely not agree. The first system will have the same quality as the second but could take double the time to produce.

Activities as testing and review cannot be simplified and they most often take more time to perform during the first time which makes the material supply and the assembly process idling. The production engineer is though very much engaged in the process of a new system to support as much as possible so that documentation for the next production will be improved and correspond better to the updated routing. The production of a new system is relatively good compared to the old systems, yet some more can be done concerning the routing. The routing seems always to be too optimistic regarding the belief in material supply and how long the testing will take. If there were a few buffers in the schedule for both time and resources, the throughput time would not be longer, and the routing would correspond better to practice.

For the products which are in the mix assortment, the routing and work packages should be up to date and thereafter work fluently. The packages are designed and structured in the same way which makes it easier to learn new systems for the workers. Tools and aids are following the workers in the systems on their own computers and if there is something missing, they could ask a supervisor or the production engineer. To provide the multi-skilled workforce to be proactive in knowledge, job-rotation is built in the way of working which is on the sufficient level of flexibility according to Narain et al. (2000). There have however been some cases of few operators being experts in one system which later came vulnerable for the production since they left. Consequently, there could be improvements concerning the rotation. To avoid this situation, the Installation hall could either have a minimum of number of workers which should know a system or have a certain time to transmit before leaving.

The Installation hall does fulfill the core capability in many aspects regarding the two types of flexibility. They work on manufacturing involvement with sequencing the material and preparing tools, however, the storage of the material needs to be better arranged in order to become sufficient flexible according to Narain et al. (2000). The work with multi-skilled workforce and tech advantages is also proactive towards aligning the activities for faster learning and more visibility. The work packages and the routing are being developed further with digitizing which should be done in order to have more reliable and continuous measurements. The Installation hall is also being provided with resources to work proactive and flexible, which is a requirement according to Chang et al. (2005).

6. ANALYSIS OF TRANSFERABLE ABILITIES

This chapter aims towards answering the third research question ("*What of TCC's current operational methods and standards that support agile manufacturing are transferable between the production sections and what are the conditions to transfer and adapt the useful standards?*"). Chapter 6 is an internal benchmark between the two production sections where they are compared to see what areas of improvements has been discovered and what areas are possible to transfer and adapt. The answer for the third research question will also be provided in brief in chapter 7.1, discussion of findings.

This chapter presents various abilities which can be found in one of the production sections which support a flexible production and could be adapted within the other section. However, to implement the change, some changes may need to be done in order to generate a feasible implementation, which depends on the production sections prerequisites earlier presented in the study. This chapter therefore only presents methods and way of working which can be assumed to give a positive output and striving towards an agile manufacturing strategy according to the literature framework. The analysis is structured around the issue and the improvement, and if it is possible to adapt to the other section and if there are any changes needed to be done in order to do the implementation.

The already functioning methods found in the current state and analyzed in chapter 5.1 and 5.2 were either in both sections and just in the Installation hall. This means that the adaptation of methods that has proven to give good results only is analyzed from the perspectives of Installation hall towards the Trafo production. Therefore, the following four areas of improvement has been found in the Installation hall and is further analyzed of how they can be adapted towards Trafo and what the conditions are.

6.1 Creating a multi-skilled workforce with job-rotation

One of the dimensions to increase the product flexibility and product mix flexibility presented by Chang et al. (2005) is the commitment to continuous multi-skilled workforce development. This type of dimension can be found in the Installation hall and how they proactively work to reach it. The job-rotation increases the assembler's knowledge and it also reduce the risk of create single competence within the area. If compared to the Trafo production, this is not developed in the same way and the risk for single competence is high. However, the prerequisites for the various production areas are completely different where the Installation hall use the work packages which is created in order for any assembler to be able to perform the task and the Trafo production is based on the knowledge of the operator. If the multi-skilled workforce should be pushed in the Trafo production, both the documentation of the processes and how to produce a product need to be improved. Such improvements can be implemented, but it will require resources from supporting functions such as the production engineer in order to improve and standardize documentation.

The job-rotation within the Trafo production would require skills for various types of processes compared with the Installation hall which rather have a variety of products. However, even if the structure of job-rotation is a bit different, it would still support the striving towards multi-skilled workforce by Chang et al. (2005). For the Installation hall, the rotation between systems occurs when a system is done which can take months to achieve. However, due to the large variety of work tasks for each system in the Installation hall, it could still be seen as job-rotation which will foster the multi-skilled workforce. For the Trafo production, the job-rotation could be one day each week. Nevertheless, the documentation for the processes needs to be improved in order to succeed at all with such implementation. Furthermore, some guidelines need to be set on how to use the job-rotation as it otherwise is likely to fall back to old habits. Such guidelines could be when job-rotation should be used, e.g. only when there is no backlog.

One of the main differences in order to fulfill the multi-skilled workforce is the difference in strategy within the production sections where the Installation hall have an expressed strategy to generate a high level of multi-skilled workforce. In order to implement it successfully within the Trafo production, a similar strategy will probably be needed to be set by the production manager. The existing use of the two teams within the Trafo production is in line with developing a multi-skilled workforce, but as they are still acting as experts on each process, there is a high level of single competence. However, the issue with single competence can also be seen within the Installation hall for some critical process steps which would indicate how they need to further develop the multi-skilled workforce strategy.

6.2 Developing a systematical training framework for new employees

The training for the operators is one aspect of the development of the multi-skilled workforce. Both production sections have started to develop methods in order to define when an operator can work independently, but none of them are yet fully developed. There are however some differences between them where the framework for the Trafo production concerning a basic level of knowledge within the section and the framework within the Installation hall is planned to be on four levels depending on the skills of the assembler. Both production sections have the prerequisites to use a systematically framework within the learning process even though their processes are not similar. As the strategy within the Installation hall is structured around the job-rotation, the training framework will be in line with the striving towards multi-skilled workforce. For the Trafo production, there is a risk of not matching the training according to the striving towards multi-skilled workforce if it is not stated in the strategy.

Three different aspects of creating flexible manufacturing is according to Chang et al. (2005) to commit significant resources to the training, encouragement to learn more as well as design the training according to a job-rotation. The Installation hall commits to all these three aspects as of today without the training framework, but the framework would simplify the definition of working independently. The Trafo production somewhat missing on all three aspects and needs therefore to adapt them into the development of the training framework. One additional aspect of creating a flexible manufacturing is according to Jonsson and Mattsson (2016, p. 235) to reward workers which striving towards learning multiple processes by giving them financial incentives. This aspect could be applied to both production sections as single competence should be avoided in order to generate a more flexible manufacturing. However, this is a hinder needed to be worked around on a company management level as it is a matter between the union and TCC to reward single workers.

It will be difficult to achieve a training similar to the Installation hall with the given conditions for Trafo. One reason is that Trafo only consist of five workers which makes it difficult to only have one teacher which is highly specialized in some processes. Trafo could however adapt the scale of how much a worker knows a process from 1-4 which could be designed towards finding a teacher for all processes. Thus, Trafo should focus on their job-rotation to achieve a multi-skilled workforce described above. New employees could start working within a team but successfully rotate to learn more.

6.3 Standardizing and visual management

Standardization of processes is important to ensure quality of the products and the time to produce. Visual management is important in order to make the needed work more accessible and understandable for all the workers. Standardization of tools and processes and visual management cohere, and synergies can be drawn from implementing both in the same way as implementing only one will not be as powerful. In the Installation hall, the routing is functioning as a visual management tool and the work packages are the standards. The standards within the work packages are functioning well to ensure the quality of the assembly no matter which worker is performing the work. The routing is also functioning well but can be further developed with the digitalization of boards for each station as well as being integrated more into every workers computer.

Routing and work packages

Due to the systems throughput time in the Installation hall, the routing with the work packages is a very beneficial structure to follow. The routing plans the whole assembly process in months ahead and can only be delayed if there is material shortage, unless unlikely events. However, since the products in Trafo have a throughput time of weeks instead, the same structure cannot be followed. The frozen plan could be functioning as a routing on a holistic level but there is also need for a more detailed planning that prohibit the workers to choose what and when to produce.

There are some conditions for Trafo to plan their tools and fixtures ahead since the ERP-system will alert them when old products enter as orders. But even if there are tools, the documentation could be limited or sometimes the tools are in the production area but cannot be found. The condition that is missing is once again documentation as well as physical structure in the manufacturing area.

However, if there were documentation, the routing and work packages could be adapted towards a similar principle working as an order- and operation planning function. The principle could start from the analog order board already existing where the products are moved between processes and workers. If the board could be digitalized and function more as a schedule and documentation hub, the progress could be much more efficient planned and be followed up in real time by the managers and by the workers. But by adding digitalization in the equation, the need for another condition in form of computer for all workers adds. However, since they are only five workers it should not be the main obstacle.

The documentations would be as the work packages are for the Installation hall but be developed towards a product and not an assembly procedure. To develop the documentation and dedicate resources would most likely be the main obstacle. It will take time and it must be performed in parallel to the manufacturing due to the issue of the slow-moving assortment that can be visualized in figure 4.1. However, it is a necessary need in order to achieve a well-functioning standard.

6.4 Improved collaboration between the production engineers and the workers

The production sections have various types of setup regarding the production engineers for their respectively areas. The Installation hall always have a production engineer within the production section which have a close collaboration with the assemblers. If questions occur by the assemblers, it is stated to be easy to communicate with the production engineer in order to solve the issue right away. If compared to the Trafo production, this type of communication is stated to be a matter of improvement as the operators perceive the physical distance between them and the production engineer as a problem. However, one major difference between the production areas are how much each production engineer is allocated for each area. For the Installation hall, the allocation of the production engineer is of full time compared to the Trafo production which only have a part of his time allocated to the area.

A closer collaboration between the production engineer and the operators within the Trafo production would benefit aspects such as improved documentation and help with creating tools and fixtures and would increase the value adding time for the operators within the Trafo production. Due to the backlog the Trafo production have and have had for a long time, increased proportion of value adding time for the operators would be beneficial. The solution could be to move the production engineer from the office area to the space where the line manager and production planner works, which is in close distance to the production area. Another solution is if orders and production status are visualized and digitalized so that the production engineer can follow in real time.

One issue needed to be solved in order to make such organizational transformation is the budget as TCC works with internal billing. Increased collaboration between the Trafo production and the production engineer would generate a higher cost for the Trafo production and there will be a need for the line manager to request for an increased budget. However, the benefits can be assumed to overcome the cost for the change. The benefits would be an increased value adding time for the operators and easier to perform job-rotation and training for the workers as documentation and tools are up to date.

7. DISCUSSION AND RECOMMENDATION

In the following chapter, a discussion of the finding to the research questions as well as a discussion of the realization of the findings is presented. The discussion is meant to provide brief answers to the research questions of the report and give a chance for the authors to discuss the findings and what challenges lies within a possible implementation. Within the chapter, a recommendation will be given to TCC of what they should focus on and which areas of improvements they should prioritize. There is also be a brief recommendation of future research for the reader to understand what aspects of the report would be interesting to further investigate.

7.1 Discussion of findings

In the discussion of finding will the three research questions of the report be answered. Each question will have a clear answer and a smaller discussion meant for the authors to imply on the findings discovered in the analysis.

RQ 1) What are the performance outcomes of the current operational strategy at TCC regarding the production flow, and what type of operational strategy is used?

What could be discovered in the chapter 4 is that the production sections do not have any distinct strategy of what their production should aim towards. This is rooted in that their earlier lean-based strategy where focus has been on resource utilization which is not suitable in an HVLV environment. Yet, TCC's production is performing rather well, since they rely on other structures. The frozen plan is a structure which all production sections follows and provides an aim for the performance outcome. The frozen plan is a three-week production plan which all sections make a list of all the products/activities they promise to produce. However, to ensure the performance outcome when a unit is struggling, the method is adding more resources or overtime and not making efforts to solve the root cause. If the sales volume keeps raising, TCC cannot proceed to adjust with quick fixes. In addition, not focusing on the root cause will decrease the performance outcome and lead to higher WIP and longer throughput times which will make it more difficult to ensure delivery times.

In conclusion, TCC has a production strategy but it has not permeated the organization. The performance outcome is currently adequate but cannot be improved if the focus does not change from resource usage to flow efficiency and fixing root causes. Regarding the measuring of the throughput time, the focus should be moved from looking at planned versus consumed hours and instead to reduce the total throughput time. The total time include administrative lead time and idling which is the main cause of unnecessary time consumption.

RQ 2) How can flexibility be achieved in an HVLV environment with agile manufacturing and what theoretical working standards should be implemented at TCC?

Flexibility has been defined in this report after the core capability which is the ability to produce new and change between old products without making any investments, thus being flexible and yet cost-efficient. To achieve this core capability, actions on improving activities that support the four base capabilities, (strategy, process linkage and people) should be focused on or be implemented which has been analyzed in chapter 5. As discovered in the literature and further analyzed in chapter 5, a multi-skilled workforce is the capability of which TCC should focus on. A broader competence with the workers will create an easier planning and internal flexibility to focus resources where the need is. It is however important for the people capability to be a part of the strategy so that it can permeate the organization. This proves that all capabilities associate with each other and improving one will mean improvement for another. Therefore, all capabilities are needed in order to achieve flexibility.

To achieve a multi-skilled workforce, activities as job-rotation, standardized training and work with documentation must be pushed and well structured. These activities are performed at TCC but not everywhere, and not well enough. Training of new and old employees to become more competent is important and needs a structured job-rotation and documentation so that the same level of quality can be reached by every worker in the same production section.

The four capabilities will take much time and resources to improve and, in the meantime, TCC could improve their conditions. The three lean tools presented in this report (5S, visual management and standardization of tools and processes) would help the production to become more agile or at least provide better prerequisites to reduce administrative lead times. These lean tools are already in place in some sections but needs still to be improved and spread to all sections.

RQ 3) What of TCC's current operational methods and standards that support agile manufacturing are transferable between the production sections and what are the conditions to transfer and adapt the useful standards?

The last research question was answered in chapter 6 where the following four main areas was analyzed:

- Creating a multi-skilled workforce with job-rotation
- Developing a systematical training framework for new employees
- Standardizing and visual management
- Improved collaboration between the production engineers and the workers

These four areas are subjects that the Installation hall already has implemented and what would be possible and be good for Trafo to adapt to support agile manufacturing. The four areas did correspond to what was found in the literature in many ways and with the addition to how it could look like in practice. The adaption can be possible for all areas but with a few adjustments as well as some further fulfilled conditions. To make the workforce more multi-skilled, there is a need for job-rotation which could be in terms of working with other activities some hours per week. However, both rotating experienced workers to new activities and training new will need far better documentation. The last two areas are also possible to adapt for Trafo and the need for them is equally important for the workers. The conditions could be somewhat easier to fulfill since they are more resource driven. The conditions include computers, structure in the production and more time from e.g. production engineers.

What is important to consider is that some methods and standards have synergies which would help all areas simultaneously. Documentation is one of the conditions that would help Trafo in many aspects including training new and experienced workers and provide better working standards. A work of developing a way of handling and developing documenting is needed.

7.2 Discussion of realization

In order to create a successful implementation of flexibility to support the agile manufacturing, it is important to investigate the capabilities and dimensions and how they could be adapted for each production section. A generic transformation would probably not be successful and could be rather contradictory. The areas earlier presented in terms of creating a multi-skilled workforce by using job-rotation, improve the documentation, standardized work and so forth have all various barriers to overcome in order to achieve an improvement and not just a change.

It is important to highlight the amount of work the shift towards the agile manufacturing will be needed from TCC. Some of the areas will need a lot of time to change, such as the work with improving documentation in the Trafo production. Furthermore, tradeoffs will be required as it will not be possible, or financial justified, to change all documentation. The issue will be regarding which documentation that are needed to be updated in order to create sufficient support for the production. However, sufficient level is hard to define which may need further investigation. Other aspects of supporting the production and facilitate the training for new workers are the implementation of 5S. As some of the problems presented in this study occur due to low level of structure within the production areas, it may seem obvious to implement such tool. However, it is important to emphasize the difficulties such as the time required to implement it.

Two important aspects for all these areas are enabling sufficient resources for the development as well as always consider the people and how they would be affected for each transformation. Regarding the resources, it could be in terms of investments in various tools such as monitors within the production area, or it could be enabling more resources from supporting departments to continuously improve the production. Furthermore, it could also be purely monetary resources such as financial incentives for multi-skilled employees. The other aspect is to always consider the affected personnel when implementing the improvements. It is important to not focusing on exploiting the workers in order to change the outcome of the production. If the implementation would be realized, the union in TCC play a crucial part and their approval is necessary for incentive programs and job-rotations.

If TCC should be able to shift towards agile manufacturing, it is important to include the manufacturing strategy within the overall business strategy. However, one important aspect is to not only have an aggregated manufacturing strategy and assume it will fit the production sections. It is of importance to break down the overall manufacturing strategy and adapt it for the various prerequisites each production section has. This would not be as difficult to realize since all sections has their own line- and production manager which are fully dedicated towards performance. Furthermore, with the shift of manufacturing strategy, it is important for TCC to analyze the investments of resources on a holistic level for the company.

7.3 Recommendations for TCC

The recommendation for TCC will be based on the three different levels of flexibility: necessary, sufficient and competitive flexibility. When operating within HVLV environments, the necessary flexibility is a must in order to be profitable. Furthermore, the three different levels of flexibility should be the priority of improvements for TCC and can be used as the timeline for the improvements. The necessary improvements should be a direct matter of issue while the competitive may need to be included in a strategic plan covering multiple year ahead. The areas of improvement founded in the analysis with the respective type of flexibility is presented in Appendix C.

The recommendation can be divided into two directions. They are not contradictory and should therefore not be opposite alternatives. However, they differ regarding needed time for implementation and realization of results. The first recommendation focusses on the necessary flexibilities needed to strive towards an agile manufacturing. Such recommendations will therefore be regarding improvement of the documentation as well as avoiding single competence. However, avoiding single competence will need sufficient flexibilities such as job-rotation and standardized training for new workers which probably will take some time to implement. Thus, this approach may take time to develop successfully. Focusing on the necessary flexibility dimension at TCC will have an effective output for the HVLV environment which they are active in.

The other recommendation is to start with 5S and visual management as they will take shorter time to implement yet be very effective to strive towards an agile manufacturing. In addition, the Installation hall has already implemented these methods in some extent, and they have proven to be of great assistance. Furthermore, this recommendation less affecting organizational and behavioral change compared to the first recommendation which will decrease the time needed for achieving the intended change. However, this recommendation can be applied/further developed within the two production sections used in the study but the effect it could generate on other production sections is not investigated.

The analysis revealed the issue of not being able to work with 5S and job-rotation as a result of lack of time. However, as this has created a vicious circle where the lack of structure of tools as well as single competence is two main causes for delays. To cross the circle, it is important to assign the needed resources to create the change. It may generate some short-term setbacks, but it will have a positive long-term impact.

7.4 Future research

The study was only based on a single company which enabled the analysis to go in depth in the area of investigation. It would have given a good insight to have performed a benchmark on another case company which is in the same type of industry, unfortunately there is a strong limitation of such companies. However, to have the same question but in all production section at TCC would give an extensive coverage.

Another suggestion to future research is to investigate what type of incentives works best for enabling a multi-skilled workforce. A discussed challenge is to motivate the workers to learn more than they, according to their contracts, must. This future research could go beyond the specific industry sector and would therefore most likely provide a good feedback to how to create e.g. job-rotation. A future research or an extended project based on this study could therefore be how the implementation process should look like.

8. CONCLUSION

The aim of this thesis was to evaluate and analyze the potential performance outcomes and what type of production capabilities are needed for using a more agile operational strategy. The aim was directed towards two production sections which also were compared to each other. The aim was investigated in these two sections, but the recommendations was not to be limited to the two and instead include the production at TCC in large. The type of production capabilities that are needed was discovered in the literature by Brown and Bessant (2003) and Hallgren and Olhager (2009). The capabilities were strategy, people, process, linkage and the final core capability which was an outcome of the other four. These capabilities were later used as the foundation of the analysis and was further the base for the performance outcomes. The performance outcomes of using a more agile strategy for a production section was what Chang et al. (2005) mentioned as various types of flexibility (new product-, product mix- and volume flexibility). The report limited the three types into just two (new product- and product mix flexibility) due to that TCC does not require the third (volume flexibility). In conclusion, the potential performance outcomes which an agile strategy could reach are various types of flexibility in the production to manufacture more efficiently and to settle the customer need. To reach a higher flexibility, TCC should focus their resources on improving and advancing the mentioned capabilities in the production starting with people.

The aim of this thesis was to aspire ideas for TCC of what they should focus their resources on as well as what they are currently doing that is aligned with agile manufacturing and which they should keep and spread between production sections. The ideas were developed in chapter 5 and 6 where the current state was analyzed through the agile capabilities and flexibility. The ideas were answers to research question two and three which was answered more concrete in the discussion. The content of the result is that TCC has areas in the production which needs improvements however, some improvements could be transferred internally. Further, the improvements are in form of operational methods and tools as visualizing orders and training personnel, and not operational strategy which TCC needs to develop and adjust to each production section.

The depth of the report could be further investigated in terms of more production sections at TCC or other companies which are also in the defense industry. However, the result for TCC is trustworthy since it is the same organization in the same facility that share operational control and are within the same HVLV environment. The frameworks which was discovered in the literature were deemed to be applicable for TCC since they were in the context of agile manufacturing in an HVLV environment. The result needed some practical modifications and is therefore not creditable in general for other companies, even in the same industry.

REFERENCES

Brown, S., & Bessant, J. (2003). The manufacturing strategy-capabilities links in mass customisation and agile manufacturing–an exploratory study. *International Journal of Operations & Production Management, 23*(7), 707-730. doi:10.1108/01443570310481522

Bryman, A., & Bell, E. (2011). *Business research methods (3rd ed.)*. Glasgow: Bell & Bain Ltd.

Chang, S. C., Lin, R. J., Chen, J. H., & Huang, L. H. (2005). Manufacturing flexibility and manufacturing proactiveness: Empirical evidence from the motherboard industry. *Industrial Management & Data Systems*. 105(8), 1115-1132. doi:10.1108/02635570510624482

Chau, T., Maurer, F., & Melnik, G. (2003). Knowledge sharing: Agile methods vs. tayloristic methods. *In WET ICE 2003. Proceedings. Twelfth IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises,* 302-307. doi:10.1109/enabl.2003.1231427

Christopher, M. (2000). The agile supply chain: competing in volatile markets. *Industrial marketing management*, 29(1), 37-44. doi:10.1016/S0019-8501(99)00110-8

Conway, R., Maxwell, W., McClain, J. O., & Thomas, L. J. (1988). The role of work-in-process inventory in serial production lines. *Operations research*, *36*(2), 229-241, doi:10.1287/opre.36.2.229

De Toni, A., & Tonchia, S. (1996). Lean organization, management by process and performance measurement. *International Journal of Operations & Production Management, 16*(2), 221-236. doi:10.1108/01443579610109947

Duguay, C. R., Landry, S., & Pasin, F. (1997). From mass production to flexible/agile production. *International Journal of Operations & Production Management, 17*(2), 1183-1195. doi:10.1108/01443579710182936

Ghalayini, A. M., & Noble, J. S. (1996). The changing basis of performance measurement. *International Journal of Operations & Production Management, 16*(8), 63-80. doi:10.1108/01443579610125787

Guan, Z., Peng, Y., Ma, L., Zhang, C., & Li, P. (2008). Operation and control of flow manufacturing based on constraints management for high-mix/low-volume production. *Frontiers of Mechanical Engineering in China*, *3*(4), 454-461. doi:10.1007/s11465-008-0083-5

Gunasekaran, A. (1998). Agile manufacturing: enablers and an implementation framework. *International journal of production research*, *36*(5), 1223-1247. doi: 10.1080/002075498193291

Gödri, I., Kardos, C., Pfeiffer, A., & Váncza, J. (2019). Data analytics-based decision support workflow for high-mix low-volume production systems. *CIRP Annals - Manufacturing Technology*, *68*(1), 471-474. doi:10.1016/j.cirp.2019.04.001

Halldórsson, Á., & Aastrup, J. (2003). Quality criteria for qualitative inquiries in logistics. *European Journal of Operational Research, 144*(2), 321-332. doi:10.1016/s0377-2217(02)00397-1

Hallgren, M., & Olhager, J. (2009). Lean and agile manufacturing: external and internal drivers and performance outcomes. *International Journal of Operations & Production Management, 29*(10), 976-999. doi:10.1108/01443570910993456

Hayes, R. and Pisano, G. (1994), Beyond world-class: the new manufacturing strategy. *Harvard Business Review, 72*(1), 77-86.

Irani, S. (2011). Choosing what works. *Industrial Engineer*, *43*(8), 42-47.

Jina, J., Bhattacharya, A. K., & Walton, A. D. (1997). Applying lean principles for high product variety and low volumes: some issues and propositions. *Logistics Information Management, 10*(1), 5-13. doi:10.1108/09576059710159655

Jonsson, P., & Mattsson, S.-A. (2016). *Logistik: läran om effektiva materialflöden*. (3rd ed). Lund: Studentlitteratur.

Khan, S., & Van Wynsberghe, R. (2008). Cultivating the under-mined: Cross-case analysis as knowledge mobilization. *Qualitative social research, 9*(1). doi:10.17169/fqs-9.1.334

Košťál, P., Mudriková, A., & Sobrino, D. R. D. (2010). Material flow in flexible production systems. *Proceedings in Manufacturing Systems, 5*(4), 213-216.

Kulkarni, S. V., & Khaparde, S. A. (2013). *Transformer engineering: design, technology, and diagnostics (2nd ed.)*. Boca Raton: CRC Press.

Leitch, R. A. (2001). Effect of stochasticity, capacity and lead time cost drivers on WIP and throughput in a pull production environment. *Management Accounting Research*, *12*(2), 167-196. doi:10.1006/mare.2001.0161

Little, J. D. (1961). A proof for the queuing formula: L= λ W. *Operations research*, *9*(3), 383-387. doi: 10.1287/opre.9.3.383

McCarthy, I., & Tsinopoulos, C. (2003). Strategies for agility: an evolutionary and configurational approach. *Integrated Manufacturing Systems, 14*(2), 103-113. Doi: 10.1108/09576060310459401

MĺÍkva, M., Prajová, V., Yakimovich, B., Korshunov, A., & Tyurin, I. (2016). Standardization - one of the tools of continuous improvement. *Procedia Engineering*, *149*, 329-332. doi:10.1016/j.proeng.2016.06.674

Modig, N. & Åhlström, P. (2015). *Detta är Lean – Lösningen på effektivitetsparadoxen.* Stockholm: Rheologica publishing.

Narain, R., Yadav, R. C., Sarkis, J., & Cordeiro, J. J. (2000). The strategic implications of flexibility in manufacturing systems. *International Journal of Agile Management Systems, 2*(3) 202-213. doi:10.1108/14654650010356112

Petersson, P., Olsson, B., Lundström, T., Johansson, O., Broman, M., Blücher, D., & Alsterman, H., (2015). *Lean: Gör avvikelser till framgång!* Bromma: Part Media.

Sassani, F. (2016). *Industrial Engineering Foundations: Bridging the Gap between Engineering and Management.* Dulles: Mercury Learning and Information

Silva, A. L. & Cardoza, E. (2010). Critical analysis of layout concepts: Functional layout, cell layout, product layout, modular layout, fractal layout, small factory layout. Proceedings of international conference on industrial engineering and operations management. 12-15 October 2010, São Carlos, Brazil

Stump, B., & Badurdeen, F. (2012). Integrating lean and other strategies for mass customization manufacturing: a case study. *Journal of Intelligent manufacturing*, *23*(1), 109-124. doi:10.1007/s10845-009-0289-3

Tay, H. L., Singh, P. J., Bhakoo, V., & Al-Balushi, S. (2017). Contextual factors: assessing their influence on flow or resource efficiency orientations in healthcare lean projects. *Operations Management Research*, *10*(3-4), 118-136. Doi:10.1007/s12063-017-0126-3

Tezel, B. A., Koskela, L. J., & Tzortzopoulos, P. (2009). The functions of visual management. *International research symposium.* 2009, Salford, UK

Tseng, M. M., & Jiao, J. (2001). Mass customization. *Handbook of industrial engineering*, *3*, 684-709. doi:10.1007/978-3-642-35950

Williams, K., Cutler, T., Williams, J., & Haslam, C. (1987). The end of mass production?. *Economy and Society*, *16*(3), 405-439. doi:10.1080/03085148700000020

Yusuf, Y. Y., Sarhadi, M., & Gunasekaran, A. (1999). Agile manufacturing: The drivers, concepts and attributes. *International Journal of Production Economics, 62*(1-2), 33-43. doi: 10.1016/s0925-5273(98)00219-9

Zohrabi, M. (2013). Mixed Method Research: Instruments, Validity, Reliability and Reporting Findings. *Theory & practice in language studies*, *3*(2). doi:10.4304/tpls.3.2.254-262

APPENDIX A – List of interviews

Titel	Structure	Content of the interview	Time	Date
Production manager Laser/ Project manager	Unstructured	What agile manufacturing is for TCC and how it could be realized	20 min	2020-02-14
Production manager	Semi structured	What is agile manufacturing, and how has lean been a part of the production. Data over the production was also given and discussed.	40 min	2020-02-24
Production engineer	Unstructured	Review of Trafo. How they work and which processes Trafo contain.	75 min	2020-02-26
Production planner	Semi structured	What work includes in a production planner and what can be done better.	30 min	2020-03-03
Line manager Trafo	Semi structured	Measuring and controlling of the Installation hall and their way of working and how it can be improved.	45 min	2020-03-05
Manager product- and project planning	Semi structured	How does project- and product planning work and how does it	40 min	2020-03-09

		affect the production sections.		
Operator	Semi structured	The operators view on the production, strength and weaknesses.	20 min	2020-03-12
Design manager	Semi structured	How is the design department work with the production.	20 min	2020-03-16
Designer	Semi structured	How is the cooperation between the design and production units.	20 min	2020-03-17
Manager product- and project planning	Semi structured	How does project- and product planning work and how does it affect the production sections.	30 min	2020-03-18
Production Engineer	Unstructured	How is the work performed and planned in the Installation hall and how does the routing work.	90 min	2020-03-25
Production Engineer	Unstructured	Explaining and reviewing the routing and work packages.	30 min	2020-03-26

Line manager Installation hall	Semi structured	Measuring and controlling of the Installation hall and their way of working and how it can be improved.	45 min	2020-03-28
Production manager Installation hall	Semi structured	Measuring and controlling of the Installation hall and their way of working and how it can be improved.	60 min	2020-04-03

APPENDIX B – Interview questions

Interview questions for production manager Trafo

1) Can you describe the production section of Trafo?
2) What type of processes does the Trafo production have?
3) What type of products are produced and in which volumes?
4) How many operators does the production section have?
5) What type of operational control is used?
6) How is the layout structured?
7) Does the Trafo production have any inventory or buffers?
8) What type of disruptions may occur in the Trafo production?
9) Do you have any suggestion on what to improve?

Interview questions for production managers

1) What is the expressed strategy to control the production, both overall and certain areas within the production?
2) Do you, as a production manager, want your personnel to know all processes? If not, why or how much?
3) How do you want the production engineer and line managers work to look like?
4) Is there any work concerning a skill matrix?
5) How do you consider the risk of single competence and if the competence is with the workers instead of in the system?
6) Do you consider the number of workers is right in the perspective orders?
7) Analog routing versus digital, what are the differences and how does the future work look like? What are the potentials?
8) What are the bottlenecks in the respective production areas regarding machines/tools, time, space and competence?
9) What do you see as areas of improvements?
10) What do you measure on the production?
11) Do you consider the KPIs provides a good overview of the situation or do you believe that something is missing/overflowing?
12) What would you want to measure in addition?
13) Do you measure total throughput time or only planned versus consumed?
14) Are there any administrative tools that you believe is missing?

Interview questions for production planner

1) Describe your work tasks related to the Trafo production.
2) Do you plan the production for other sections than the Trafo production? If so, is there any differences between them?
3) On what level do you plan? Products, processes, people?
4) What is the difference between product- and production planner?
5) Can you describe the frozen plan used?
6) What type of prioritization is used?
7) Do material shortages occur?
8) What happens if products cannot be produced on time?
9) Do you use any KPIs regarding the performance of the Trafo production?
10) What is your perception about the way of working between you as a production planner and the operators?
11) Do you have any input regarding improvements for the Trafo production?

Interview questions for line managers

1) The operators have become specialized on different processes. Is this an expressed strategy?
2) Is there any strategy for the Trafo production/Installation hall?
3) Do you want that every operator should be able to do all types of processes?
4) Is it possible to define when a new operator can be defined as fully trained?
5) Is there any job-rotation?
6) Do you believe that the number of operators is right?
7) Can you describe the visual board used in production?
8) Would the control of the orders be different if every operator were able to perform each process step?
9) What are the bottlenecks in the production section?
10) Do all products pass all process steps in the production section?
11) What types of KPIs are used? Do they give a good overview of the performance of the production?
12) Do you measure throughput time or is it rather planned versus consumed time?
13) When an operator looking for a tool, is such time registered in any way?
14) Is there any tools or systematic methods missing within the production section?

Interview questions for managers of product- and project planning

1) What is product- and project planning? What are the assignments for respectively function?
2) What do you do as a manager for product- and project planning and in what way does your work affect Trafo?
3) Differences in work tasks between product planners versus production planners?
4) How close is the collaboration between the project- and product planning to the production?
5) Do you see any differences regarding performance for the different production sections?
6) Do you have any suggestions regarding improvements for the Trafo production?

Interview questions for operators

1) Can you describe the different processes and production steps within the Trafo production?
2) Describe the movement of products within Trafo.
3) Describe how you work with the order board?
4) Does the system with the board work well? Can it be improved?
5) Do you want to see any other information visually?
6) Can you describe how you work within the Trafo production with the new structure of two different teams?
7) Is it possible to learn all different production steps?
8) If it was possible, would you want to learn all process steps?
9) Do you have any suggestion of changes regarding the production flow within Trafo?

Interview questions for mechanical design department

1) Can you describe how the mechanical design department work?
2) Describe how the collaboration between the mechanical design department and production unit works.
3) How should the collaboration between the mechanical design department and the Industrialization team be according to you?
4) In what stage is the producibility introduced when a new product is developed?
5) What advantages do you perceive with the collaboration with the operators?
6) What is your though about the large number of different components the operators should be able to produce?
7) Are there any ongoing projects regarding minimizing the number of unique products?

APPENDIX C – Priority of flexibility

Necessary	Sufficient	Competitive
• Avoid single competence • Documentation	• Standardized work and training • Job-rotation • Modularity • 5S • Manufacturing involvement • Visual management • Routing • Material handling	• Strategy • Flexible layout

DEPARTMENT OF TECHNOLOGY MANAGEMEN AND ECONOMIC
DIVISION OF SUPPLY AND OPERATIONS MANAGEMENT
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

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