JÖNKÖPING UNIVERSITY
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Critical Factors for Production Ramp-up in High Technology Companies

A case study at an aerospace company

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Abstract

Purpose - A research gap was identified in relation to the production related factors during ramp-up. Therefore, the purpose of the study was to *“simplify production ramp-up by defining how measures could be prioritised in high technology company.”*

Method – The study used a single-case study method with a qualitative and explorative approach. This method was used to gain in-depth knowledge of the case. The study was conducted at Saab, a high technology company within the aerospace industry.

Findings – The findings included a list of critical factors for ramp-up control and two additional critical factors that are relevant to high technology companies, along with five additional measures. From the case the main critical factors were related to personnel, education and experience.

Implications – The study has contributed with a simplified ramp-up control method with implications for high technology industries. The new method will contribute to a more effective time to volume phase relevant for both practitioners and researchers.

Limitations - As the study uses a new ramp-up control method it has only been applied to one case. The complete data from the case cannot be showcased due to secrecy.

Keywords: Production Ramp-up, High Technology Company, Lean Manufacturing, Assembly and Aerospace.

Summary

Production ramp-up is considered as a very complex phase for any company, therefore it is important to identify the challenges and weak spots of the company to tackle this kind of situation.

The purpose of this study was to *simplify production ramp-up in high technology companies*. This as ramp-up is a very complex phase for any company to go through and in addition that the situation may vary in high technology companies compared to companies with lower degrees of technology. Therefore, three research questions were formulated:

1. What are the critical factors that challenge the production during ramp-up in an aerospace assembly?
2. What measures can be taken to handle the challenges during production ramp-up in an aerospace assembly?
3. How can measures be prioritised to meet the desired output during production ramp-up in an aerospace assembly?

The method used for the study was a case study with a qualitative and explorative approach that aimed to build on existing theory of ramp-up and at the same time develop new theory in ramp-up in relation to high technology companies. The study was conducted at Saab, an aerospace company, to answer the research questions. The case study included interviews, observation, a documentary analysis and a questionnaire based on the so called "ramp-up control method" by Schuh, Gartzen and Wagner (2015).

The findings firstly include an extension of the original control method, with focus on high technology companies. Two additional critical factors and five measures to tackle these have been added based on findings from the case study. The control method has hence been simplified to increase understanding for both researchers and practitioners to apply to their specific case. The findings also include that most of the critical factors are related to personnel, education and experience, which are all heavily emphasised as important for high technology companies. The research questions helped identify critical factors related to these, measures to tackle the critical factors and a method for prioritising the measures to be implemented.

The study has contributed with a simplified ramp-up control method with implications for high technology industries. The new method will contribute to a more effective time to volume phase relevant for both practitioners and researchers. Practitioners should be able to use the control method on their own, however a complementary case study is advised by the authors of this paper to identify further measures and critical factors.

As the study uses a new ramp-up control method it has only been verified by one case. Therefore, further research is suggested by the authors to strengthen the method. The complete data from this case cannot be showcased due to secrecy, hence some information may be missing for a complete understanding of the case.

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1 Introduction

The chapter presents a background to the study, together with the related problem of ramp-up in a high technology company. Further, the purpose and research questions of the study are presented along with the scope and delimitations. The chapter is ended with a description of the study's disposition.

1.1 Background

The pressure on companies is ever-growing and has drastically increased mainly due to globalisation in recent years. Hence, they must find ways to achieve competitive advantage in terms of competitive priorities such as cost, quality, delivery, flexibility, service, innovation and environment (Sansone et al., 2017). For production systems that are constrained by high production costs and quality of products, the productivity is crucial for gaining competitive advantage (Blais, 2003). Companies in industrialized countries are trying to increase efficiency and the same time reducing operating cost while labour costs are increasing (Chowdhury, Shahriar, hossen, & Mahmud, 2016). This includes high technology companies who trying to create competitive advantage by investing in knowledge, intellectual capital and innovations. This combined with an uncertainty from the market gives high technology companies an even more complex situation to manage than a traditional company (Zakrzewska-Bielawska, 2010).

An industry characterised as a high technology industry is the aerospace industry. As the aerospace industry is characterized by swift developments and emphasis put on research developments, it serves a unique purpose in the development of innovative technologies. Despite lengthy projects, innovations are continuously implemented to follow current development. Processes with high quality, resource efficiency and increasing productivity are main goals for the industry, regarding both product and production processes (Denkena, 2014). As the aerospace industry therefore has the pressure of product development, it is natural that the production ramp-up results in difficulties. Production ramp-up is defined as "The period between the end of product development and full capacity production" (Terwiesch and Bohn, 2001). Production ramp-up is a very complex process today as production systems are also very complex and specifically engineered to the specific company in many cases. The mix of implementation of new technologies and responding to market product innovations leads to a unique process which is difficult to plan (Doltsinis et.al, 2013). The ramp-up phase is a topic gaining momentum in recent years by the research community and has been noted to have a large potential for improvement (Ceglarek et al., 2004, Fjällström et al., 2009, Haller et al., 2003, Terwiesch and Bohn, 2001, Terwiesch and Xu, 2004).

1.2 Problem Formulation

As ramp-up is a very complex process, there is a need to simplify this process in many companies. A ramp-up phase is characterised by unplanned changes, errors and delays, making it a very difficult task for management to handle (Nau, Roderburg, & Klocke, 2011). Due to the complexity a systematic approach is required to move from prototype to serial production (Schuh, Gartzen, & Wagner, 2015). However, existing research on ramp-up mainly focus on product launches while production, processes and systems are neglected (Schuh, Kampker, Gartzen, & Wesch, 2010). Thus, a research gap is identified in the area. Ramp-up has gained interest from researchers in past decades, but focus has not been on production, which has been forced to take the impact. No research has been done in the area of production ramp up in the aerospace industry to the authors' knowledge. Therefore, literature on both ramp-up from a production and an aerospace perspective has been identified as a gap. Production systems and processes are complex areas during a ramp-up and measures for improvement need to be identified during such a phase. A common way to simplify processes is by applying the Lean concept. The Lean concept has according to Dillon and Shingo (1989) proved to improve quality as inventory decreases. Quality problems were detected earlier in the process.

1.3 Purpose and Research Questions

In accordance with the background and problem description stated, there is a need for companies in industrialized countries to improve their efficiency in production. The aerospace industry is facing difficulties in the production ramp-up due to advanced products and production systems. There is limited research to be found on how the aerospace industry should handle the production ramp up. Therefore, this study will explore how a company within the aerospace industry can overcome the difficulties during production ramp-up.
The purpose of this study is:

To simplify production ramp-up in high technology companies.

The purpose will be fulfilled by three research questions. The first research question (RQ) is concerned with limitations in production flow. The production flow is the binding force and can provide an overarching picture of the current state. Therefore, the first research question is:

1. *What are the critical factors that challenge the production during ramp-up in an aerospace assembly?*

The second research question specifies measures to be taken to improve the production system. Based on results from the limitations of the production, an analysis can be made to specify these improvements. Hence, the second research question is:

2. *What measures can be taken to handle the challenges during production ramp-up in an aerospace assembly?*

The third research question relates to what measures should be prioritised among the suggested improvements from RQ2. To specify the most urgent problems and their measures will help to improve the production more effectively. Therefore, the third research question is:

3. *How should measures be prioritised to meet the desired output during production ramp-up in an aerospace assembly?*

To answer the research questions and reach the purpose, a single-case study will be conducted at a company in the aerospace industry. Figure 1 describes the connection between research questions, the purpose and the delimitations. The research questions will be answered to in chronological order. When the RQ's have answered the purpose will be fulfilled. The fourth step in Figure 1 includes the delimitations of the study and will be carried out by the case company after this study.

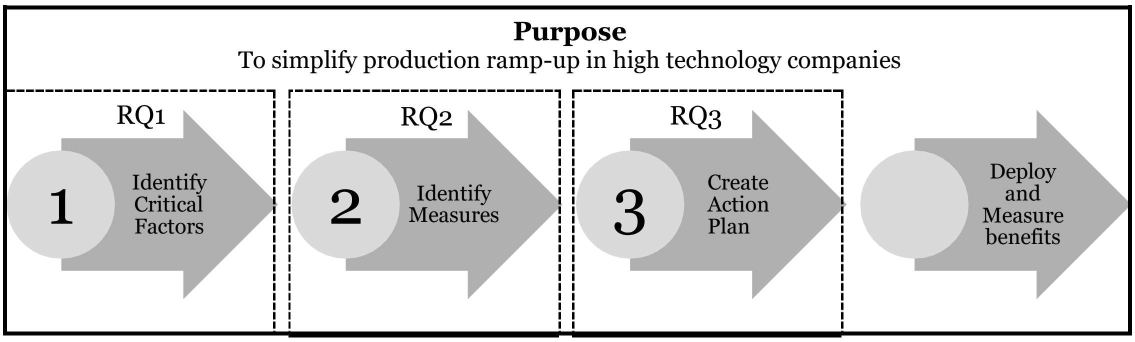

Figure 1 Describes the connection between research questions and the purpose

1.4 Scope and Delimitations

The scope of the study will include a single-case company in the aerospace industry. The focus of the study will be the assembly of the product in-house and related critical factors to ramp-up. Figure 2 visualises this scope and how it is separated from other processes in the supply chain. The study will also be delimited to the production flow in-house between the storage, where separate parts arrive, and final testing, where finished products are quality checked in various ways. The thesis uses the term "production ramp-up" in order to stay consistent with literature, yet the focus is on the assembly of the product. A delimitation is to not include customers, suppliers and earlier processes as it would make the analysis too complex for the authors' level of study.

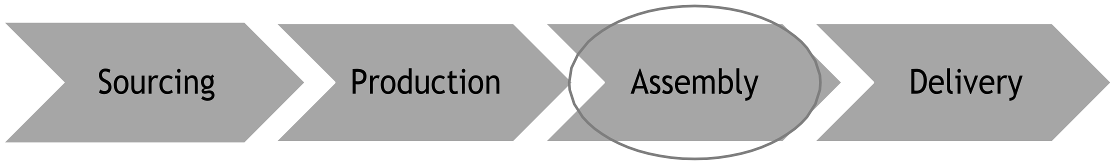

Figure 2 The scope of the study in relation to the production flow

1.5 Outline

The study will consist of six main chapters which are presented below. The first chapter is the introduction where a background of the study describes the current state of the research about production ramp-up. The second chapter is the theoretical background which explains the different theories which are required to carry out this study. The third chapter is the method and implementation, where the working process of the study is presented. This chapter also includes the authors' research approach as well as the design of the study. The fourth chapter is the empirical findings which includes a current state analysis at the case company as well as results from the ramp-up control method. The chapter also includes a description of the case company. The fifth chapter is the analysis which include findings from the case company and the theoretical framework presented. These findings are merged to answer the research questions. The sixth chapter is discussion and conclusion which presents the contribution of the study to practitioner, researchers and the community. An improved model for production ramp-up is stated to achieve the purpose of the study. Lastly references and appendices are listed.

2 Theoretical Background

The chapter formulates a theoretical foundation of the topics of ramp-up, Lean manufacturing and philosophy, together with a description of the characteristics of a high technology industry. One of the main pillars, the ramp-up control method, is also presented with alterations to fit the study.

2.1 Connection Between Research Questions and Theory

The study will include theories regarding production ramp-up, Lean manufacturing and the characteristics of a high technology company. The theories will be involved in all three research questions, however with different approaches. Figure 3 presents the connections.

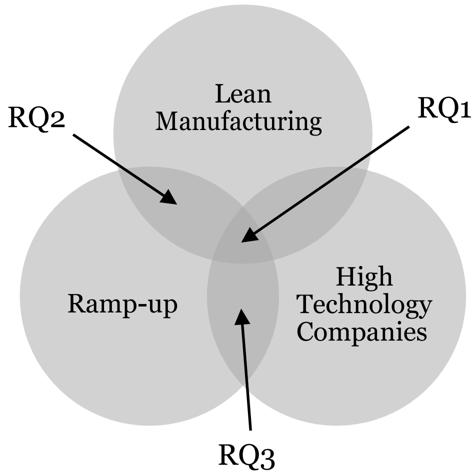

Figure 3 Connection between the research questions and theory

Theory for the first research question, "*What are the critical factors that challenge the production during ramp-up in an aerospace assembly*", will mainly include the topics of "Lean manufacturing", "production ramp-up" and "high technology company". Lean manufacturing has been chosen to describe the current state of the production system at the case company with the help of value stream mapping, a common Lean tool. Lean can also help in the critical thinking of the authors by questioning all activities. Production ramp-up theory will mainly come from earlier case studies like this study. The ramp-up control method (Schuh, Gartzen, & Wagner, 2015) will also be used and modified for identification of factors. Implications from these studies will help the study to focus on common problems and characteristics previously seen in similar situations. Characteristics of high technology companies will also be taken into consideration to tailor the case and compare the aerospace industry with general characteristics of high technology companies. The characteristics will also be used to analyse identified factors in regard to its context.

Theory for the second research question, "*What measures can be taken to handle the challenges during production ramp-up in an aerospace assembly*?", will include "Lean manufacturing", "Production ramp-up" and the characteristics of high technology companies. Lean theories will be used to aid the authors with tools that can pinpoint measures for improvement. From production ramp-up theory, case study results will aid with potential measures and ideas for modified measures together with the ramp-up control method.

Theory for the third research question, "*How should measures be prioritised to meet the desired output during production ramp-up in an aerospace assembly*?", will include theory in relation to the ramp-up control method regarding prioritisation. The theory of the prioritisation will aid the authors create an implementation plan for the case company. With considerations to high technology companies, these characteristics will be used to add to the control method and in turn the prioritisation. The recommended implementation plan can in turn act as inspiration for other high technology companies.

2.2 Production Ramp-up

Production ramp-up is defined as "The period between the end of product development and full capacity production" (Terwiesch and Bohn, 2001) Due to the complexity of the ramp-up phase, an alternative and more simple definition can be: "An increasing volume over time" (Fjällström et al., 2009, Terwiesch et al., 2001). Hence this is a process every manufacturing company will go through to a larger or smaller extent. A visual representation of the ramp-up phase is presented in Figure 4 and can be linked to the first definition by Terweiesch and Bohn, (2001).

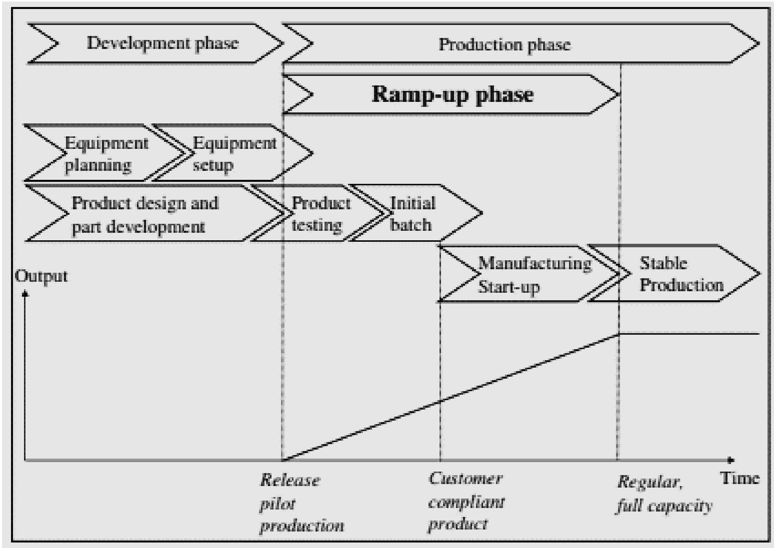

Figure 4 The production Ramp-up phase
(Glock & Grosse, 2015)

The topic has gained momentum during the past twenty years and is being highlighted by the research community as one of the production phases with the highest potential for improvement (Fjällström et al., 2009, Terwiesch and Bohn, 2001, Terwiesch and Xu, 2004). Four main areas that affect the overall performance of the ramp-up phase have been identified as time, cost, complexity, uncertainty (Alpan et al., 2013). Time is important, as the first entrants on the market may profit from less competition and thereby take advantage of premium pricing for example (Fleischer, Spath, and Lanza 2003, Terwiesch and Yi 2004, Carrillo and Franza 2006). Cost is important as many industries are forced to focus on fast profitability due to shorter product life cycles (Almgren 1999, Bohn and Terwiesch 2001) and more expensive production equipment (Bohn and Terwiesch 2001) New products are also a major source of income, where 49% of sales in top performing companies come from new products (Di Benedetto 1999). Complexit*y* is important due to extensive and strong outsourcing (Apilo 2003) as well as advancements and growing complexity in product technology (Terwiesch, Bohn, and Chea 2001 Apilo 2003). These critical factors put pressure on the whole supply chain as well as the production system, meaning that the performance of these are put in focus (Alpan, Blanco & Surbier 2013). Uncertainty is important as (potentially) the supply chain and production system are new and have been redesigned according to estimations (Meier and Homuth, 2006).

Similar to this study, several case studies have been carried out to map typical problems faced during the ramp-up phase (Simola et al. 1998, Bohn and Terwiesch 2001, Fleischer, Spath, and Lanza 2003). Terwiesch and Bohn (2001) highlight the importance and struggles of the learning process in connection to production processes. Continuous learning is an important aspect as each production system and company acts differently. There are also drawbacks to learning, for example time consuming experiments that take time from actual production time. Therefore, the trade-off between learning and production is highlighted, but also the process of learning as companies try to take shortcuts in the learning process as time and cost increases. Alpan, Blanco & Surbier (2013) highlight in their literature review a few characteristics of a company facing the ramp-up phase:

- Low knowledge of the product and processes surrounding it.
- A low production output.
- Higher cycle times
- A low production capacity as a result of the increasing demand.
- A high demand
- A lack of reliability in planning
- Disturbances in quality in the supply chain, product and production processes.

These characteristics result from the challenges faced during the ramp-up phase. Challenges of the ramp-up phase have been pinpointed by researchers by conducting case studies in various companies (Simola et al. 1998, Bohn and Terwiesch 2001, Kuhn et al. 2002, Fleischer, Spath, and Lanza 2003, Haller Peikert, and Thoma 2003, Carrillo and Franza 2006). From these case studies the following problems have been highlighted:

Logistics: As a ramp-up involves the introduction of a new product, the whole supply chain is affected. Long-term and trusted suppliers may still face similar problems as the final manufacturer as new parts can be necessary to produce the final product. Quality and availability at external suppliers were therefore an issue in the cases.

Quality: Due to the complexity of introducing a new product into the production system, quality problems are difficult to avoid as a result of inexperience. Rework and scrap are the resulting wastes that can occur at both the company itself as well as in the supply chain.

Product: Miscommunication regarding product specs, design changes or product maturity can result in insecurity and misunderstandings in the production. Therefore, the match between product and production system is important to consider.

Cooperation/Communication: Ramp-up is a phase concerning many departments with communication between mainly research and development, and supply chain and production departments. To retrieve relevant and accurate information between departments about the product is important to build on the ongoing work at all departments. Information loss and a lack of trust for the information could be seen in the cases.

Personnel: These problems are mainly concerned with know-how. An uneducated work force regarding both internal and external training can result in difficulties, as well as skewness of work distribution.

Technical processes: That the processes involved in the ramp-up are mature is an essential aspect to successfully implement a new product. Unforeseen bottlenecks, time consuming set-ups and fit between product design and production system are typically seen.

Management tools and methods: With a lack of knowledge from management, tools and methods used during the ramp-up phase are not fit for the purpose. This as tools and methods used are often the same as the ones used in mature production, leading to gaps in resource planning for example.

2.3 Lean Manufacturing

Lean Manufacturing is a concept that originates from the post second world war era in Japan. As the state bank was empty after the war, pressure was put on industries as they had no possibilities for investments in ruined facilities. Toyota was one of these companies that focused on keeping inventory, investment, human effort and defects low to stay competitive by keeping a high product variety. Thus, the Lean concept was born. The characteristics of automotive markets today focus widely on customisable products. Lean offered a solution to be responsive to customer demand and thereby reduce waste. Reduction of waste is the main pillar of Lean, where operations should be judged as value-added[1], non-value added or necessary. Lean could in short be described as doing "just enough" in terms of satisfying customer demands at the

[1] The definition of value-added activities is an "Activity that transforms material or information and that the customer is willing to pay for" (Myerson, 2012).

lowest cost by minimising non-value-added operations (Bhamu & Sangwan, 2014). There are several definitions of Lean Manufacturing which have been debated by scholars throughout history. The definition the authors would like to use is the one by Taj & Morosan (2011) which states that Lean Manufacturing is:

> *“A multi-dimensional approach that consists of production with minimum amount of waste […], continuous and uninterrupted flow […], well-maintained equipment […], and well-trained and empowered work force […] that has positive impact on operations/competitive performance (quality, cost, fast response and flexibility).”*

2.3.1 The 14 principles of Lean

The concept of Lean originates from Japan and more specifically the automotive company Toyota. The term “Toyota Production System” was initially introduced in an internal training document and soon became popularised by the book “The Toyota Way“(Liker, 2004). The publication highlights 14 guiding principles for Lean manufacturing at Toyota. These were classified in four categories which can be seen in Figure 5 below (Shang & Sui Pheng, 2013).

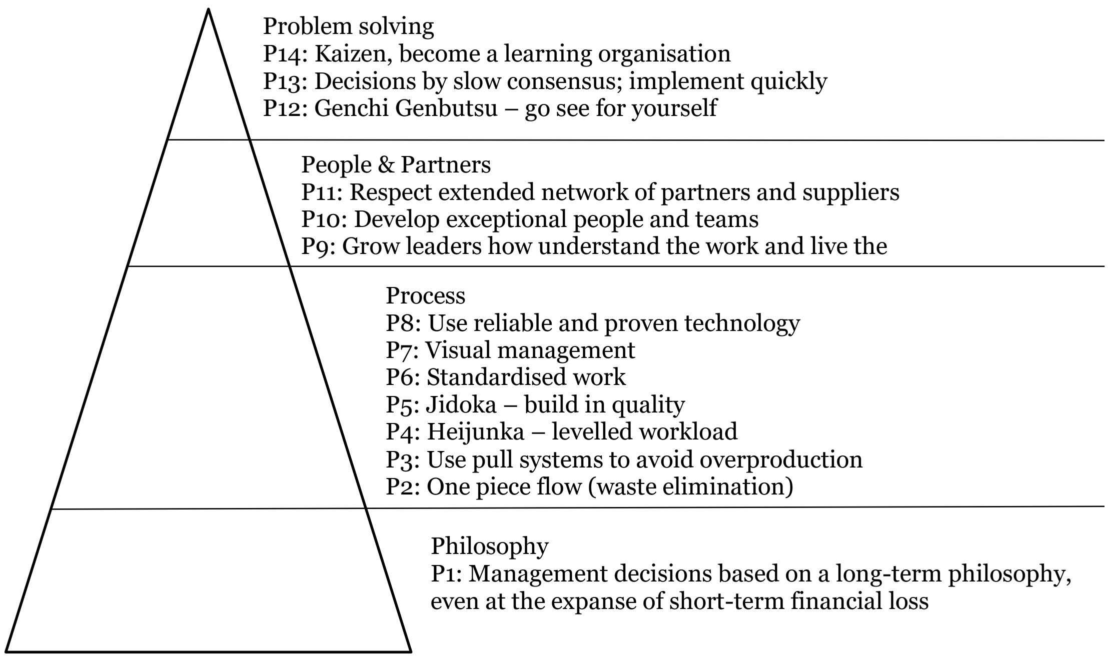

Figure 5 The 14 guiding principles of Toyota Production System (adapted from Liker, 2004)

The authors have chosen to only further explain the process and philosophy related principles in some depth as they are the most relevant to the study. However, the other two categories of principles will be shortly described for context.

Philosophy oriented principles: Base management decisions on long-term goals, even at the expense of short-term losses. This principle is the foundation of the Lean thinking, where sustainable growth and performance is in focus. The principle can further be categorised in four parts, “constant purpose”, “customer focus”, “self-reliance and responsibility” and “long-term perspective”, which describe the core values of the principle.

Process oriented principles: The bulk of principles are process related. The Lean way of process thinking involves having a spread out and even way of working physically, while also having standardised work to rely on. The core of the process is the one-piece flow, which means that an even flow of products is present in the production. This is based on a so-called pull system, which pull the product up-stream as the next operation in line is free. To have this pull system, the work needs to be levelled so that the one-piece flow does not add inventory in between operations. The other four process related principles involve using standardised work practices that have quality built into them, thereby minimising the risk of quality losses. This is also reinforced by only using reliable and proven technology in the processes. Finally, visual management is a cornerstone to be clear in the processes to minimise quality loss. A popular tool is the 5S method which assign a specific location to each tool.

People and partner-oriented principles: These principles address the importance of respecting your extended network as your suppliers and customers are an extension of your company that market your supply chain just as much. They also highlight the internal employees where exceptional teams and people together with knowledgeable leaders form the foundation for better work. To spend time on your employees to keep them stimulated is a cornerstone of Lean.

Problem solving principles: These principles involve basing decisions on facts, where managers should go see for themselves what is happening instead of only reading reports. Managers should also thoroughly consider possible changes with the use of consensus and once a decision has been made, implement quickly. Another cornerstone of Lean is Kaizen, which is continuous improvements. By always improving in small steps, the competitive future of the company can be largely secured.

2.3.2 The 7+1 Wastes

The goal of Lean is to reduce waste, but what is waste? Toyota stated in their “Toyota Production System” that there are 7 kinds of wastes (Myerson, 2012). These can be abbreviated into the acronym TIM WOOD which can be seen in Table 1.

Table 1 Description of the seven wastes
(adapted from Myerson, 2012)

Wastes	Description
Transportation	Relates to unnecessary movement of products.
Inventory	Concerned with costs related to unnecessary inventory.
Motion	Described as unnecessary movement by humans.
Waiting	Concerned with waiting for information, supplies or people.
Overproduction	Defined as processing something before it is needed.
Over-processing	Concerned with putting more effort or time into the processing the product than the customer requires.
Defect	Refers to scrapping, repairing and reworking of products.

Some argue for an eighth waste to be added, namely “behavioural waste”. Employees make up a majority of a company and therefore need to be engaged to the operations. If employees stay creative and passionate, it will be easier to reduce the other seven wastes stated above. These seven (or eight) wastes are the main targets to reduce by using the Lean concept, making the operations do just enough, just right and at just the right cost (Myerson, 2012, pp 19-25).

2.3.3 Value Stream Mapping

Value stream mapping (VSM) is a tool used in Lean practices to identify value-added and non-value-added activities in a value stream. The mapping then consists of a sketch of processes and whether they add value or not, starting from raw material to final customer. The value stream mapping used in this study will only focus on the value stream between storage at the manufacturing company to the final testing, however. The goal of a value stream map is to identify and thereby find solutions to eliminate waste, both regarding physical operations and information flows (Shook & Rother, 1999). A value stream map is made up of a sketch involving a set of standardised icons to clearly signal what type of operation or flow that is being referred to (Abdulmalek & Rajgopal, 2007). An image of the most common icons can be seen below.

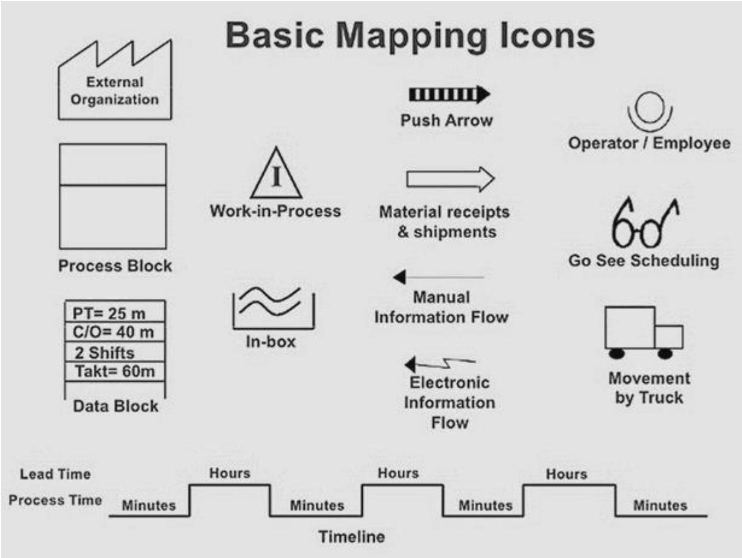

Figure 6 Basic Mapping Icons
(Karen Martin and Associates, 2010)

The first step in the process is to map the current state of the value stream, dealing with the identification of wastes. When the wastes have been pinpointed, an analysis is made to identify what measures that need to be taken to improve the flow. Once this is made, a future state map is sketched, showing what the flow ideally should look like in the future (Abdulmalek & Rajgopal, 2007). A future state map can easily be composed, but it is still only a static map of how the future state could look like. It is almost impossible to predict for example future inventory levels with only a future state map since it will not take any variations in to consideration (Mcdonald, Van Aken, & Rentes, 2002). Relevant process data should be collected to be able to perform a VSM. Some relevant process data according to Myerson, (2012) is stated in Table 2 with the authors' explanation.

Table 2 Description of process data
(adapted from Myerson, 2012)

Process data	Description
Process time	The time between the start and the end of a process.
Available time	Is idle time plus productive time.
Setup time	The time needed to prepare the upcoming work.
Lead time/turnaround time	The time it takes for the object to pass through a flow of processes.
Typical batch size	The amount of object in a batch.
Complete and accurate information	The percentage of failure free output from a process.
Rework	The percentage of the output that will need rework.
Number of people involved	The number of people working with a specific process.
Reliability	The probability of failure free performance during a specified timeframe.
Inventory	Raw material, work in process (WIP) or finished goods that are in waiting.

Many companies have difficulties in finding the right arguments to get the management's commitment required to implement lean manufacturing. It is hard to predict what types of benefits the improvements will have on the organisation since the manufacturing system is so complex. Changes within the system might affect inventory management, raw material procurement, employee management and production control. This results in an insufficient way for managers to make decisions and it comes down to the managers own belief in lean manufacturing (Detty & Yingling, 2000). Using a future state map of the production is one way of creating some evidence to justify suggested improvements.

2.4 Characteristics of the Aerospace Industry

The aerospace industry is an industry characterised as a high technology industry with many complicated processes involved. A high technology industry is hard to define due to its character of being between traditional industries and crossing to new kinds of technology. It is however characterised by effectively using knowledge to spark innovation and inventions (Zakrzewska-Bielawska, 2010). A table highlighting the differing characteristics between a traditional and a high technology industry can be seen in appendix 1. The characteristics were divided into five categories:

Objectives and strategy: A high technology industry will focus on the long term and be aggressive with investment with high risk of return. Decisions are made based on knowledge from own capabilities.

Production and technology: Many patents involved with new inventions and a focus of having variable process plants to be ready for new technology to be implemented if available.

People: The focus of employment lie in development and in creating teams that can act in a mobile way to aid creativity and problem-solving abilities. Continuous training is also important to develop qualifications and being able to learn from mistakes.

Organisational structure: Hierarchy is not important; the processes and self-managed entities are instead the focus. Flexibility, decentralisation and informal communication are also central parts of the organisational structure.

Management: Management decisions are based on empirical data, stereotypes are negated to allow for high autonomy, and acceptance of uncertainty and change is central.

In short, a high technology industry is significantly different in various ways in comparison to a traditional industry. It is therefore required to take these differences into consideration when conducting research and analysing a company in such an industry.

2.5 Ramp-up Control Method

A framework for identifying potential and current problems faced during a ramp-up and accompanying measures to tackle these problems was introduced by Schuh, Gartzen and Wagner (2015) The framework will be used and developed by the authors to match the case at hand and thereby extend the framework. Shortly described, the original framework aims to identify critical factors in an assembly based on a predetermined set of critical factors that are given gradings and weightings based on the criticality of the complexity to the company. These critical factors are based on the categories: “product”, “process”, “network”, “organisation” and “people”. From the grading, a set of predetermined measures can be identified which are prioritised based on the values assigned to the critical factors. In turn an implementation plan with KPI’s to measure the implemented measures are identified, used and controlled. For a full description of the original control method, please refer (Schuh, Gartzen, & Wagner, 2015). The authors have chosen to focus on the process related critical factors as the case company has passed the product development stage and are entering the production and ramp-up phase according to Figure 4. An explanation of the method used in this case will follow.

The method used is divided into seven steps, contrary to six steps in the original method. Steps six and seven will not be included in this study but will be defined to fully cover the original method.

The first step of the method involves filling out a questionnaire of critical factors, specifying which predefined critical factors that are present in the current production system. This form should be filled out in a joint effort between experts in the case company and the researchers to avoid bias in the answers. The critical factors, 37 in total, are valued 1-4 based on how complex they are (see Appendix 2). As complexity in this form does not necessarily imply problems to the company, a weighting scaled 1-5 is also applied to each complexity. If the complexity is considered to have a major impact on the operations it is graded high, otherwise low. The complexity value and the weights are multiplied giving a final grade (1-20), yielding the result of step one

The second step involves ranking the critical factors from highest scoring to lowest scoring. A significance limit is then applied to remove critical factors that are not deemed relevant to the case. A significance limit of three was used in the original method as well as in this study. This indicates that at least one value given was higher than two, hence leaning towards a complex side of at least one scale. The only exception is if both are graded with 2. The result from the second step is hence a list of relevant critical factors.

The third step involves consulting the list of relevant critical factors (see appendix 3), to find suggested measures to tackle the critical factors. The critical factors in the columns are matched with the measures in the rows. Suggested measures are then analysed and excluded if not relevant or kept if deemed relevant to the production system. The result from the third step is hence a list of relevant suggested measures.

The fourth step involves matching suggested measure to the specific case. Measures from the control method are rather general, hence they can be specified by the researcher conducting the method. An example being a suggested measure, “rework stations”, which is specified to “rework station at soldering station nr2”. The result of the fourth step is a list of specified, relevant suggested measures.

The fifth step involves prioritising the identified measures. This is made by consulting the table of ranked critical factors gained from the second step and composing a table with the relevant specific measures gained from the fourth step. The table will plot critical factors in falling order based on value from left to right on the X-axis, with corresponding measures plotted on the Y-axis. This results in an overview of an implementation plan, where measures furthest to the left in the table should be prioritised. The measures should then be implemented from left to right. This step results in an implementation order or prioritisation of the measures and is the final step used in the case of this thesis.

The sixth step involves implementation of the measures after the prioritisation has been made. To be able to properly follow up the improvements from the implemented measures, relevant key figures specific to the measures must be identified. These key figures will be case specific to monitor the progress of ramp-up improvements. The original method suggests that overall equipment effectiveness should act as an overall figure for monitoring, with more specific key figures for each measure. The result from this step is hence a plan for monitoring the progress of measures and then implementing them.

The seventh and final step involves controlling the implemented measures. By reaching a desirable level with the key figures, the measures can then be deemed as finished and the next measure can be implemented. Thereby the method repeats steps six and seven until desirable results have been extracted from the method.

The modified ramp-up control method will contribute to the potential findings a traditional case study would not identify, thereby act as a complement where additional critical factors and measures have been identified from the case. Table 3 below specify the steps of the control method in a summarising manner.

Table 3 Step-by-step guide for the modified ramp-up control method

Phase	Step
Identify Critical factors	1. Fill in critical factor Questionnaire 2. Rank critical factors and apply significance limit.
Identify Measures	3. Consult table for potential measures, exclude irrelevant ones. 4. Specify measures for the case.
Create Action Plan	5. Create action plan based on criticality score.
Deploy and measure benefits	6. Identify key figures for monitoring, implement measures 7. Measure and control.

3 Method and Implementation

This chapter presents an overarching description of the working process of the study, together with the research approach of induction and design of single case study. In addition, the study's data collection techniques and analysis of qualitative nature are explained. The chapter is ended with a discussion regarding the quality of the study.

3.1 Connection Between Research Questions and Method

A research method is defined as "provides a design for undertaking research, which is underpinned by theoretical explanation of its value and use" (Williamson, 2002, p. 11). There are various kinds of methods that can be used in research, case study, action research and experimental research design to name a few. For this study, the method of case study was chosen. A case study is defined as an empirical enquiry that investigates a phenomenon in its context. Especically when boundaries between context and phenomenon cannot be clearly distinguished (Yin, 1994).

Case studies can be either single- or multiple case. Single cases are appropriate when the case is critical, it explores a unique setting or when the research is exploratory (Yin, 1994). This study is a single case, since ramp-up in the aerospace industry is a rare topic that rarely can be closely observed. As the aerospace industry is a complex high technology industry (Denkena, 2014). A single-case study is appropriate.

To conduct a single-case study, various research techniques need to be used to collect data. A research technique is a technique for gathering data. Techniques related to case studies include observations, interviews, questionnaires, document analysis (Williamson, 2002).The authors will use all four mentioned techniques in the study. The connection between the chosen techniques and research questions can be seen in Table 4 below.

Table 4 Connection between research questions and research techniques

RQ	Research Question	Case Study			
		Interviews	**Observation**	**Document Analysis**	**Questionnaire (Control method)**
1	What are the critical factors that challenge the production during ramp-up in an aerospace assembly?	X	X	X	X
2	What measures can be taken to handle the challenges during production ramp-up in an aerospace assembly?	X	X	X	
3	How should measures be prioritised to meet the desired output during production ramp-up in an aerospace assembly?	X	X		

To answer the first research question, a variety of techniques such as interviews, observations and a document analysis acted as an explorative foundation for research question one, together with a structured questionnaire to gather data regarding the case company's critical factors. The structured questionnaire was based on the complexity forms from the control method. The second research question analysed the gathered data to gain more specific knowledge of the flows, to better understand potential measures and their impact. To achieve this, further documents were reviewed, and interviews with experienced managers were carried out. Moreover, a value stream map was drawn to identify wastes. With the third research question the authors aimed to prioritise the measures that are more relevant to implement in the near future. Data collection was made via unstructured interviews with managers and observations to gain understanding of the reasoning within the company.

3.2 The Working Process

The working process of the study can be seen in Table 5. A pre-study was conducted to specify the problem formulation at the case company combined with identification of the literature gap, thereby understanding the view of the company before going further into theory. Next the planning of the case study was made to clarify what techniques where to be used and when. This aided the authors to focus on the right things when going into the case. The planning was made simultaneously with the literature review (for the theoretical framework) to modify the research according to theories identified, thereby, keeping the study agile to changes which is important in explorative research. Data collection was initiated after the planning was complete to have a full action plan ready once data collection began. Data analysis and conclusions followed in separate stages to fully focus on the sections. This enabled the analysis to remain unaffected by outside factors.

Table 5 Gantt-chart of the working process

	January	February	March	April	May	June
Pre-study						
Problem formulation						
Planning of case study						
Literature review						
Data collection						
Data analysis						
Discussion and Conclusion						

3.3 Research Approach

Research has two major traditions in thinking, interpretivism and positivism. Interpretivism is strongly related to qualitative research, while positivism is related to quantitative research. Qualitative research has a purpose of studying phenomena and try to gain an understanding of it (Williamson, 2002). Therefore, this approach is suited to this study. Qualitative research is mainly associated with the inductive research approach. An inductive approach is "reasoning that begins with particular instances and concludes with general statements or principles." (Williamson, 2002, p. 26). This meant that observations, interviews and specific data collection methods were used to gain in-depth understanding of the case. The approach used was inductive since the thesis would contribute to theory or by adding to previous theory in relation to ramp-up. Data collection included both structured data and semi/non-structured data. Interviews, observations and document analysis were less structured in nature, while structured data came from the value stream mapping.

3.4 Design

The research method case study is used to understand a phenomenon in its natural environment (Yin, 1994). The goal with this case study was to generate new knowledge in an unexplored area, production ramp-up in the aerospace industry. According to the definition by Yin (1983), the design of the study was a single case. The case company was chosen based on two criteria, the company had to be a manufacturing company and it had to act as a high technology company. When these criteria were met the companies were ranked based on distance from Jönköping University. Saab will act as the case and the aerospace industry, the context. Saab is a manufacturing company within the aerospace industry and fit this study since they are facing difficulties in ramping up their production output as well being a high technology company. The purpose of the study was to simplify the production ramp-up for high technology companies which means that the production ramp-up needs to be studied in its context. This strengthens the authors' choice of using a single case study with a holistic viewpoint.

3.5 Literature Review

To form an initial understanding of the topic to further build on with empirical material, a literature review was conducted. The goal of the literature review was to identify current trends within the chosen topic and the methods/theories used for analysis and understanding. The review started with the formulation of keywords, which in turn were put into an academic database called Scopus. Scopus was chosen as the main database for the study as all publications in the data base are peer-reviewed and the tools for delimiting the searches were deemed best from the authors' perspectives. From the hits generated in the data base (see appendix 3), the title was first analysed to identify relevance. If the title was deemed relevant, the abstract/summary was read. If in turn the abstract/summary was deemed relevant, the full introduction and conclusions was studied and analysed. Finally, the full article was studied given that the introduction and conclusion were relevant to the study. In addition to the search terms mentioned, a snowball technique based on these articles was made. Snowballing is defined as a technique where articles cited in the articles found in the literature search are reviewed in addition to identify further insights in the topic (Williamson, 2002).

3.6 Data Collection

The data collection in a case study is critical due to its complexity. Different methodologies and a formal procedure are needed to control the quality of the data collection. The goal is to make the data collection process as transparent as possible so that the collected data can be trustworthy for further analysis (Yin, 2018). The authors´ have collected both primary and secondary data by using different techniques to ensure a wider spectrum of knowledge in the area of the study. Observations, interviews and a questionnaire were used to collect primary data while a document analysis was used to collect secondary data.

3.6.1 Interviews

Interviews can be structured in three different ways. Unstructured interviews are useful for exploring a subject and for building questions based on answers given. Semi-structured interviews are use a standard list of questions but is open for follow-up questions from the interviewee. Structured interviews follow a fixed set of questions and could be described as a questionnaire administered by interview (Williamson, 2002). Interviews for data collection were not formal in nature as the topic was not well researched in the company, meaning limited knowledge for specific questions from both authors and employees. As a degree of "free creative thinking" was needed, the authors would like to argue that fully structured interviews would trap the interviewee in their existing frame of thinking. The authors were also asked to form their own understanding of the production, hence informal interviews were carried out in the initial stages of the study to create a clear view and form a foundation to build on further interviews and observations. Informal interviews or on-site discussions were acting as a complement to observations where observed phenomena would raise questions for the discussions. These were carried out with a variety of workers, mainly operators and production managers. The questions asked during these two interviews can be seen in appendix 4. Based on the informal interviews, an individual view of the problem could be formed, and two semi-structured and one structured interview were carried out according to Table 6.

Table 6 List of interviews

Date	Time	Purpose	Place	Position	Structure
2019-03-27	10.00-11.00	Defining production flow	Saab	Workshop Manager	Semi-structured
2019-03-28	13.00-14.00	Defining planning process	Saab	Production Planner	Semi-structured
2019-04-15	14.30-15.00	Filling out control method form	Saab	Workshop Manager	Structured

3.6.2 Observations

Observations is a useful technique for understanding of a specific setting and behaviours surrounding it. There are four main forms of observations, "ad libitum", "focal", "scan" and "behaviour". Ad libitum will be the form used in this study as it involves being impressionistic and non-structured to gain insight in a new setting or situation (Williamson, 2002). This means that exploratory observations were carried out to understand the production and the processes surrounding it. As previously stated, observations and on-site discussions are intertwined to gain insight as questions arise. All observations were unstructured in nature. A table of conducted observations can be seen in Table 7.

Table 7 List of observations

Date	Time	Place	Observation object
2019-02-25	08.30-09.15	Warehouse, Saab	The workflow
2019-02-28	10.00-10.15	Workshop, Saab	The workflow
2019-03-14	13.30-13.45	Workshop, Saab	The workflow
2019-03-21	14.00-14.30	Workshop, Saab	The workflow
2019-04-08	13.30-13.45	Workshop, Saab	Internal planning

3.6.3 Document analysis

Document analysis was a minor method used for the case study to understand the current state of the product and the production. A document analysis is an analysis of official documents from the company or setting. Documents can be related to company policies, product specifications, external correspondence etc. and can help researchers gain valuable insight to a company (Williamson, 2002).Documents reviewed in the study involved operational descriptions, planning documents, product specifications and blueprints of the physical setting. These where retrieved from the company´s ERP system. A complete list of the analysed documents can be seen in Table 8.

Table 8 List of analysed documents

Date	Document type	Purpose
2019-03-06	Operations description	Understanding of work and production flow
2019-03-14	Production Layout	Understanding the physical setting
2019-03-14	Operations planning	Analysing the structure of planning

3.6.4 Questionnaire

A questionnaire was used according to the ramp-up control method defined by the authors in the theoretical framework. The method uses a questionnaire to identify critical factors and their impact on the current ramp-up situation faced by the company. The questionnaire was filled out in a joint effort between the workshop manager and the authors, to result in a clarified situation. The questionnaires touch upon areas such as processes, organisational preconditions and culture to pinpoint sources of critical factors which later could be analysed and be assigned measures to. Appendix 2 shows the questionnaires with grading for reference. Please refer section 2 and Schuh et al. (2015) for further details on the method.

3.7 Data Analysis

According to Strauss (1987), qualitative researchers are encouraged to analyse data while gathering data. This thinking has been used by the authors to collect relevant and sufficient data. Analysis was also inspired by Williamson (2002). The field notes, which acted as the raw data, where first categorised as recommended to keep an overview of each piece of information. Following the categorisation, an ad hoc brainstorming (playing with ideas) was made to enable depth of the analysis. This enabled the authors to think outside the box and further identify pieces of information that could be linked to the case, both via other findings and theory. An organisation of the categories was then made to understand connections between the categories. As production ramp-up is a topic covering the whole organisation, linkages were important to study in order to grasp the situation. Mainly based on empirical data analysis, this resulted in the final discussion and conclusions. This method was cross-functional for interviews, observations and the document analysis in order to connect different findings and validate through triangulation. With this method the understanding of the case was continuously growing and thereby enabled the data collection to be suited for further analysis. This was seen by authors as a suitable analysis method for a qualitative and explorative study. Transcriptions could add possibilities for other methods of analysis but could not be made due to secrecy, therefore field notes acted as the raw data for the analysis. Figure 7 Visualises the process of analysis.

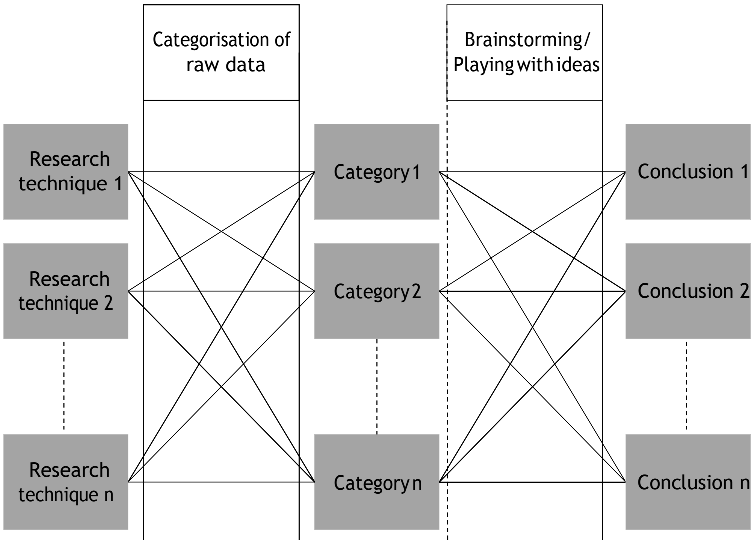

Figure 7 Visualisation of the data analysis process

3.8 Quality of the study

There are four different tests to determine the quality of a study according to Lincoln and Guba (1985). The quality is important to increase trustworthiness and is argued for in the categories: credibility, transferability, dependability and confirmability. This approach to research quality was chosen as it especially fits with an inductive and explorative approach.

Credibility was checked with the use of prolonged engagement as the authors have previously worked with the case company and has done so for seven months in total. Triangulation in the form of data collection techniques was also used, as well as peer debriefing with colleagues at the case company and at the university to ensure unbiased results.

Transferability was ensured by not solely focusing on the aerospace industry, but by categorising it as a high technology industry. The results should therefore act broader to be able to apply to similar settings both within the aerospace industry and other high technology industries. However, the transferability can be questioned since it is the only study of its kind and the results have not been validated by other studies.

Dependability of the study was relatively strong. However, a case study enables various interpretations. The interviews, document analysis and the control method are dependable with the use of the methods vividly described in this chapter. The majority of the study should have the ability to be remade with similar results gathered.

Confirmability does not have a significant impact on the study as much of the data collected was specific to the case and can thereby not be significantly altered by the authors. Previous experience in the company was not sufficient for creating a fully biased view, therefore the confirmability is high.

Additionally, all respondents that have been involved in the data collection were informed of how it will be used by the authors. Thereby taking ethical considerations towards people involved and their identities, which were anonymised to ensure integrity.

4 Empirical findings

The chapter presents an overarching description of the empirical findings gained from the case study and the control method. A problem description in relation to the case company is also presented.

The empirical data gathered in the study will follow two paths which in the end will conclude in a common analysis. On one end, the modified framework based on Schuh, Gartzen and Wagner (2015) will be used for data collection. On the other, a traditional case study approach with interviews and observations. Together these paths should contribute to each other and fill potential gaps which a single path of reasoning would result in.

4.1 Saab

To answer the research questions, a case company was chosen as described in section 3.4. The Swedish company Saab was chosen which serves within the aerospace and military defence sector and "*serves the global market with world-leading products, services and solutions from military defence to civil security. With operations on every continent, Saab continuously develops, adapts and improves new technology to meet customers' changing needs*." (Saab group, 2019). The aerospace sector of Saab, which the scope of the study lies in, is mainly covered by the business area "Industrial Products and Services" (IPS).

> "*IPS support leading aircraft industries in making aviation more efficient, provide leading technology for traffic management and public safety. IPS also support industry, defence and public sectors with services such as, Cyber Security, Digitalization and R&D*." (Saab group, 2019)

Saab IPS is currently concerned with penetration of the civil market, as opposed to the previous military focus. This has led to increased volumes that require attention to production to a higher extent than before (Production Manager, personal communication, December 4, 2018).

4.1.1 Problem description

The authors have based on the overarching challenge been given a problem description of the current situation faced by Saab, where ramp-up is the central theme. Over a longer period, the production's future at Saab has faced uncertainties. This has led to a halt of new employment of production personnel, even as retirements have increased in number and a lessened need for personnel has occurred. The need for a large-scale production has not been self-evident to the company, hence equipment and production system have not been updated towards a new takt time. The demand for Saab products has increased during recent years due to new business opportunities arising due to changes in laws, and mainly the exploration of the civil market. Together with an aging personnel force, small facilities and a need for new recruitment there is a need for development of the production system. Saab thereby stand before one of their biggest challenges yet, involving a new production layout and a need for improvements in efficiency and delivery. As a part of this challenge, the three workshops at the chosen Saab site need a thorough analysis. The workshop that will have the largest impact from this demand increase is the hydraulics workshop. The hydraulics workshop is the part of the organisation where final assembly and testing of servo actuators is conducted. To meet customer demands, a yearly output of 18 ship-sets [2] is needed, which should be achieved by 2022. This takt will be continuously increased until 2022. (Production Manager, personal communication, December 4, 2018). Based on this problem description, the hydraulics workshop was chosen as the case for the study as the ramp-up would be most substantial in this workshop.

4.2 Current State

To carry out an analysis at the case company, some delimitations needed to be stated in direct relation to the case. Firstly, the company has very long cycle times for their products, meaning that a complete current state could only be defined by following a specific product with the available time frame. Secondly, as the study only had time to gather data for one product, the value stream analysis had to be made up-stream contrary to the norm of down-stream due to

[2] A ship-set is defined as a complete set of products needed for delivery to the customer.

the inability of gathering data from several products of the same kind. Thirdly, the ramp-up products will be pilot tested with this production, therefore no previous data can be used for data collection of the specific product. With these delimitations in mind, a product needed to be chosen for analysis. The product chosen is one of seven servo-actuators used for a ship-set. Due to secrecy, the specific type of product will not be mentioned in the thesis. The product was however chosen for analysis by the authors as it is a very complex product that goes through almost all operations in the workshop, therefore the gathered results from this specific product is best suited for generalisation for the whole production among the product catalogue. An important factor to bear in mind throughout the findings and analysis is that this is the first time the company has faced a significant ramp-up, hence experience is very limited.

4.3 Value stream mapping

Based on the current state of the production gained from the scheduling documents, observations and interviews, a value stream map could be drawn as a representation of the current state. Figure 8 describes the current state and will be explained in detail in the sections below.

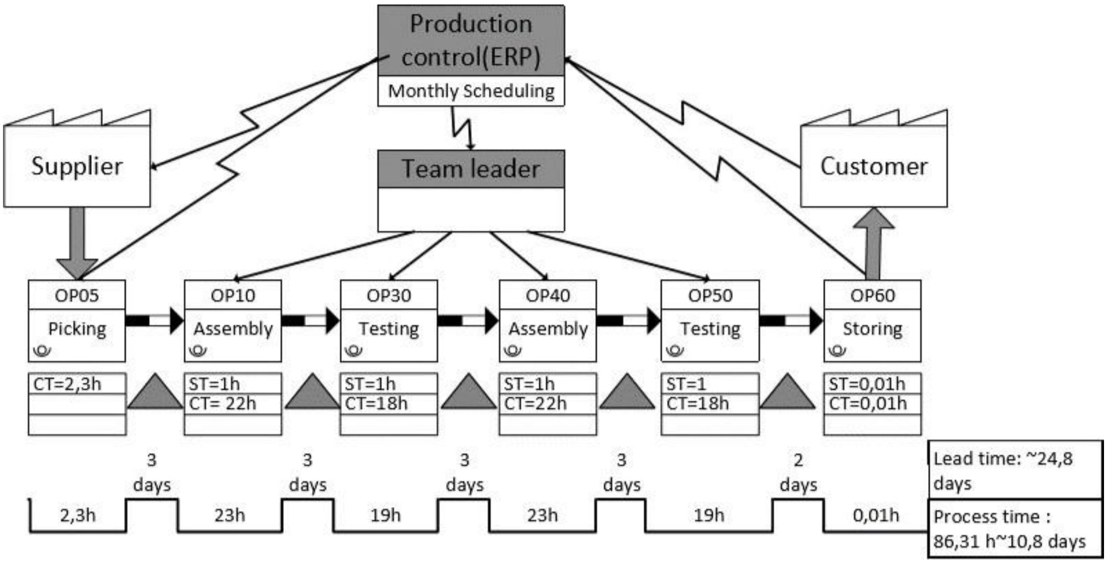

Figure 8 Value stream map of the chosen product

In the mapping above, certain assumptions are made due to the situation being a pilot production. Availability is assumed to 100% as well as a 0% scrap rate, hence a non-interrupted flow. The reason for this is the wait times in between operations which hide problems in documentation, which will be further explained in the following sections. The data regarding production flow is gathered to perform the value stream mapping and is explained below.

4.3.1 Production Flow

The production flow is planned using monthly scheduling in the ERP system. The monthly scheduling is pushing operation 05 and 60 to start the operations at set times, while the team leader is scheduling the work for the assembly and testing. The team leader is using a weekly updated printed version of the monthly schedule. The team leader thereafter sorts the operations after the start date and delegates the operations that should be prioritised.

The production layout is designed with eight separate workstations for the assembly and five testing chambers. Each one of the six employees have their own workstation and the other two workstations are currently allocated to specific operations which are not included in the study. Each one of the six workstations are flexible, and the employee collects all the tools needed to perform a specific operation. After each operation is completed the product is placed in various locations within the workshop to wait for the upcoming operation. The five testing chambers are also flexible and can be combined with different setups in order to test every type of product. A major problem seen in the ramp-up from production management is how the layout should fit in the areas assigned for production. As mentioned, six employees are currently working in the workshop with limited space to work in. In a few years' time, the personnel force will have more than doubled, meaning that space will be even more limited for production. At the interview with the workshop manager, a preliminary layout was presented and argued for. Due to secrecy, this layout cannot be presented in the thesis.

The studied product is one of the products needed for a complete ship-set. Each product has its own production operations as the work varies between the products. According to the operations planning document, which was part of the document analysis, the product's operations list consists of operations described in Table 9. The order of the operations can be seen in rising order in Figure 8, but due to similarities some of the operations share the same description.

Table 9 Operations list for the chosen product

Operation number	Operation description
5	**Picking**: All the parts needed to perform the upcoming operations is picked from the warehouse in a standardised way.
10/40	**Assembly**: A totally manual assembly consisting of different steps stated in a standardised work description.
30/50	**Testing**: A machine-based test observed manually to test functions and variations.
60	**Storing**: The final product is packaged to be stored.

As the operations are lengthy, specific descriptions of them cannot be described in this study. The parts needed to assemble the module (Op 5) is first picked from the warehouse in an external building and put in a box together with necessary documents. The parts are then taken to the workshop where two repetitions of assembly and testing are made (Op 10-30 and 40-50) and is then taken back to the warehouse for packaging and storing (Op60). The operations are described in general but are very complex and lengthy in nature both content- and timewise. In between these operations there are scheduled wait times, which are used as a slack in production planning to enable flexibility for returns and more urgent products. These waiting times vary between two and five working days depending on the length of the operation and whether the planned time is interrupted by non-working days. The case company only operates the production Monday-Friday, hence weekend interruptions. The reason for these wait times is according to the production planner to stay flexible in production. As a start of a product means that an operator could be unavailable for up to four days, it is necessary to have this slack. However, operations can be interrupted and thus forcing the operator to put aside the current work and set up a new. This is often the case with product returns, where small changes need to be made quickly to send back to a waiting customer. From the observations the operators explained that these interruptions are not a major concern for them, but rather a source of irritation as it sometimes means extra cleaning and setup time. The operations are characterised by manual work in varying degrees. Assembly operations are fully manual, where operators assemble parts by hand or with handheld tools. The work can therefore mainly be considered as man-hours, where an increase in demand will require more personnel. The operators themselves do not see any specific problems in the work content wise. Tests are made with the help of machines which are currently manually controlled. Management have recently been looking into the possibility of having automated test chambers. This has also partially been implemented which in turn can free operators to focus on assembly instead. Due to high demands on quality, assembly operations and tests are very standardised with work descriptions and specifications to aid the operators in their work as observed in the document analysis.

4.4 Ramp-up Control Method

Based on the method by Schuh, Gartzen and Wagner (2015) parameter values valued 1-4 were given based on the current situation at the case company. These were given following discussions of each parameter (seen in appendix 2), together with production management. A weighting valued 1-5 was then given to each parameter to highlight parameters that has or will have a significant impact on the processes and organisation. Table 10 presents the results gathered from the discussion.

Table 10 Result of critical factors from the second step of the method

	Critical factors	Criticality
Critical factors above significance limit	Ramp-up experience	20
	Acceptance of flexible schedules	20
	Number of assembly steps	16
	Ramp-up organisation	16
	Number of linkages	12
	Professional experience	8
	Contentual process variety	4
	Information availability	4
	Language and communication skills	4
	Assembly automation	3
	Associate qualifications	3
Critical factors below significance limit	Technological process variety	2
	Number of work stations	2
	Motivation	2
	Willingness to work in unknown areas	2
	Willingness for further training	2
	Originality of equipment	1
	Originality of assembly processes	1
	Material staging automation	1
	Willingness to take over responsibility	1

A significance limit of three was given for the critical factors to highlight the critical factors that were most relevant for the results. A significance limit of three was used by Schuh, Gartzen and Wagner (2015) and was used in this study as it implies that at least one value given (either the weighting or the parameter value) was higher than two (except 2x2), hence leaning towards a more complex side. As seen in Table 10, eleven critical factors were deemed relevant after the significance limit had been applied. Measures and critical factors are shown in Table 11 and only include the ones that were deemed relevant according to the significance limit, please refer appendix 3 for the complete tables. The measures gained from the control method are meant to act as a guideline for more specific measures to be adapted to a specific case. These specific measures will be identified and discussed in section 5.

Table 11 Result of Ramp-up measures from the third step of the method (Schuh, Gartzen and Wagner, 2015)

Ramp-up measures \ Critical factors	Ramp-up organisation	Information availability	Associate qualifications	Professional experience	Ramp-up experience	Language and communication skills	Acceptance of flexible schedules	Contentual process variety	Number of linkages	Assembly automation	Number of assembly steps	Potential costs
Data integration		x										P,I
Ramp-up room		x										S
Restructuring of the ramp-up organisation	x											P,I
Integration of experienced employees				x	x							P
Ramp-up teams with experienced and new employees			x	x	x	x						P
Integration of equipment suppliers		x	x	x	x							P
Floaters			x	x	x							P
Multiplicators			x	x	x							P
Mentoring			x	x	x	x						P
Process training			x									P
Soft skill training						x						P
Language courses						x						P
Intercultural training						x						P
Workshop for integration of suppliers						x						P
Kick-off event							x					P
Ramp-up based incentive system							x					P
System segmentation by buffers								x	x		x	S,C,I
Redundant processes								x		x		S,I,P
Partially autonomous work groups								x			x	
Manual back-up										x		S,I
Stepwise automation										x		S,I
Adaptive Kanban cycle								x			x	
Adaptive production test								x	x			P

Legend; P: Personnel costs, S: Space, I: Investment, C: Carrying costs

5 Analysis

The chapter answers the research questions of the study by processing collected empirical material from the case study and control method, with theoretical framework in relation to ramp-up, Lean and high technology companies.

5.1 Identify Critical Factors

The first research question was stated as:

> *What are the critical factors that limit the production during ramp-up in an aerospace assembly?*

As specified in the theoretical framework, there are a few problems that a company generally faces during a ramp-up. Based on the problem areas, a connection with literature can be linked to this study. The control method and case study will contribute to highlight the critical factors.

5.1.1 Existing critical factors

The critical factors identified from the existing control method questionnaire generated eleven results which are presented in Table 12 below. These results are based on appendix 2. The critical factors have also been matched with the problem areas identified in the theoretical framework to identify themes and connections. To streamline the analysis, only the six top scoring critical factors have been analysed in depth for the thesis.

Table 12 Connection between critical factors and critical ramp-up problem areas

Critical factors	Ramp-up problem areas
Ramp-up experience	All departments
Acceptance of flexible schedules	Personnel
Ramp-up organisation	Personnel, Management tools and methods, Cooperation/communication,
Number of assembly steps	Product, Technical processes
Number of linkages	Cooperation/communication
Professional experience	Personnel,
Language and communication skills	Cooperation/communication, Personnel
Information availability	Cooperation/communication
Contentual process variety	Technical processes
Associate qualifications	Personnel
Assembly automation	Technical processes

Ramp-up experience was the highest scoring complexity in the control method, which is understandable considering that this is the first time that the case company has faced this kind of situation. It is therefore important to underpin the importance of understanding the situation, the critical factors and the challenges ahead. This complexity is overarching and hence influences all other critical factors to some extent.

Flexible schedules are a very sensitive question in the company where the current workforce is reluctant to that sort of change. As space and time is limited, a second work-shift could potentially solve some of the problems faced. However, this complexity is critical to the company as the resistance is big. With the existing problem of finding qualified workers to employ, it will be important to hold on to the workers they have and the ones that are about to be employed.

A ramp-up organisation is non-existing according to the workshop manager and therefore one of the largest problems faced during the ramp-up. As it is a new situation, a qualified group of people would be preferable for follow up and analysis of the ramp-up. The lack of such an organisation could result in additional uncertainties in the years to come, as well as an inability to learn from the ramp-up phase as emphasised by Terwiesch, Bohn and Chea (2001).

The number of assembly steps was identified as a complexity during the interview with the workshop manager due to the long operations list with more than 50 assembly steps in each assembly operation. The number of assembly steps affects the process time of each operation, which for the studied product is more than a workday. Even if the work descriptions are detailed, the number of assembly steps makes it harder for new personnel to learn the operations.

Number of linkages is loose because of the complexity of the products being assembled in the workshop. The workshop tries to solve most of the problems by themselves but if they need expertise from other departments they can always ask for help. Production engineering have a rigid linkage while other departments such as production planning, purchasing, quality and testing have a loose linkage to the production, leading to less understanding throughout the organisation.

The professional experience is according to the workshop manager high now since two out of six employees have been working at the same position for more than 20 years. The professional experience is however expected to decrease over the coming years due to hiring. The workforce in the workshop is planned to more than double in strength, while experienced staff retire within the ramp up period. This will create a lack of experienced personnel and is a therefore a complexity for the workshop.

In relation to the ramp-up problem areas identified in the theoretical framework, there is a clear correlation between these and the identified critical factors. The problem areas of personnel and cooperation/communication recur in many of the critical factors and can be identified as central to the case.

5.1.2 Additional identified critical factors

Additional, case specific, critical factors were identified via the classical case study approach. As a foundation for the analysis, the value stream map was drawn to identify wastes in the production based on the data from the studied product. The main finding from this analysis was that there are planned wait times between operations and the role of the team leader in planning. These contribute to increased work in process (WIP) between the operations, which is considered a Lean waste (Myerson, 2012). The consequences of having these wait times is according to the authors that problems related to production are hidden within these wait times. The case company defends this kind of production planning to enable flexibility in production by for example moving work between employees if there is an urgent need for work on another product. There are however drawbacks, mainly due to lack of documentation. Work is reported by a start and stop time, meaning that abrupted work is not documented and hence hidden in the wait times. The abrupted work will due to these wait times not affect planning unless it is delayed by more than the assigned wait times. This is a major problem that in turn lead to several other problems. Documentation, longer lead times and properly measured KPI's are examples of created problems due to the wait times. Another reason for increased WIP is the information flow in connection to planning. As there is a first-hand planning that is made by the production planner and a secondary made by the team leader, a risk of mismatching is present. This is due to that the overarching planning has a lot of slack and have different start times that should be followed by operators. The overarching planning is made for every operation, while the team leader can only see the next operation in line for the shop order. Therefore, the team leader's weekly planning is not able to see the full picture to plan for. For example, OP10 and OP40 are very similar in nature and are therefore simultaneously planned by the team leader. This can have the effect that a product at OP40 can be halted by another product in OP10 even though the first product has come longer in production, hence interrupting the flow. This can be connected to the Lean waste of over-processing, where too much effort is put into planning that does not flow as planned (Myerson, 2012).

The characteristics of the case company in comparison to a high technology company as described by Zakrzewska-Bielawska (2010) were identified as closely connected. The description of the five categories "objectives and strategy", "production and technology", "people", "organisational structure" and "management" were a perfect match as seen from a pre-ramp-up perspective. In the future, as a result from the ramp-up, the characteristics of the case company may change due to the impact of the ramp-up. Based on the authors' perception, the only category that will change is the "people" category. This as focus need to shift from development to production to a higher extent than before. That kind of shift is not natural for a high technology company and is therefore identified as a critical factor for the ramp-up.

Based on this analysis, two critical factors have been identified by the authors. These have been given values and a weighting according to the method, which can be seen in appendix 6. The critical factors identified are:

Focus shift, specifying the characteristics of a high technology company that will need to partially change towards a serial production mentality.

Planning strategy, where new planning strategies may be needed for serial production in relation to prototype production.

With the additional two critical factors, Table 13 specifies the relation of the critical factors to the identified ramp-up problem areas.

Table 13 Additional critical factors

Critical factors	Ramp-up problem areas
Planning strategy	Management tools and methods, Cooperation/communication,
Focus shift	Cooperation/communication, personnel, Management tools and methods

5.1.3 Critical factors for ramp-up

To answer the first research question, Table 14 has been composed to list the critical factors sorted by their criticality score. Additionally, the ramp-up problem areas are stated.

Table 14 List of critical factors above the significance limit

Critical Factor	Method of Finding	Ramp-up problem areas	Criticality Score
Ramp-up experience	Control method	All departments	20
Acceptance of flexible schedules	Control method	Personnel	20
Ramp-up organisation	Control method	Personnel, Management tools and methods, Cooperation/communication,	16
Planning strategy	Case study	Management tools and methods, Cooperation/communication,	16
Number of assembly steps	Control method	Product, Technical processes	16
Focus shift	Case study	Cooperation/communication, personnel, Management tools and methods	15
Number of linkages	Control method	Cooperation/communication	12
Professional experience	Control method	Personnel	8
Language and communication skills	Control method	Cooperation/communication, Personnel	4
Information availability	Control method	Cooperation/communication	4
Contentual process variety	Control method	Technical processes	4
Associate qualifications	Control method	Personnel	3
Assembly automation	Control method	Technical processes	3

5.2 Identify measures

The second research question was stated as:

> *What measures can be taken to improve the production system during ramp-up in an aerospace assembly?*

To analyse the question the result gained from RQ1 will be used to identify measures based on the control method and the case study. From the case study, two major critical factors were identified. The authors have in turn identified five measures to these critical factors, which can be seen in Table 15 marked with an asterisk (*). These measures are based on the empirical material gathered and are argued for in the analysis of all the measures. Based on the control method, Table 15 depicts the measures suggested by Schuh, Gartzen, & Wagner, (2015) to solve the critical factors, together with the ones identified by the authors. To not go fully into detail on every identified critical factor, the six highest scoring will be analysed and assigned measures to in this study based on the ones identified both from the case study and control method. The critical factors identified both by the control method and case study in RQ1 will be used for analysis. Measures based on the critical factors identified by the case study are the result from the analysis following the table.

Table 15 List of critical factors and measures for the case company

Critical factors for ramp-up / **Ramp-up measures**	**Ramp-up experience**	**Acceptance of flexible schedules**	**Ramp-up organisation**	**Planning strategy**	**Number of assembly steps**	**Focus shift**	**Potential costs**
Adaptive Kanban cycle					x		
Partially autonomous work groups				x	x		
Data integration				x		x	P,I
Restructuring of the ramp-up organisation			x				P,I
Integration of experienced employees	x					x	P
Ramp-up teams with experienced and new employees	x						P
Floaters	x			x			P
Multiplicators	x					x	P
Mentoring	x						P
Process training						x	P
Ramp-up based incentive system		x					P
Lean and production education*				x		x	P
Selection of relevant KPI's*				x		x	
Restructuring of planning strategy*				x			P, I
Cluster or divide assembly steps*					x		P
External ramp-up inspiration*	x		x	x		x	I

Legend; P: Personnel costs, S: Space, I: Investment, C: Carrying costs

Ramp-up experience gave six measures from the control method. In the current state, mentoring and external ramp-up inspiration will be important to carry the project forward. Mentoring as many new employees will be introduced to the company, and the importance of quickly integrating them in the work is critical. A mentor can also act as a floater where his/her role would be to assist new employees by both teaching and sharing workload. Levelling out the workload is also a Lean principle where floaters can help prevent inventory from stacking up between operations. The floater in this case would be an experienced worker that should understand the work and the Lean philosophy according to the principle, and thereby also uphold the Lean thinking. Experienced employees are hard to find in the field; therefore, this measure will be hard to implement. However, external ramp-up inspiration is needed as ramp-up experience is quite low. Some managers have previously worked with higher volume companies. However, experience is needed on all levels of the organisation. By for example inviting a production manager from a company that has faced ramp-up, valuable lessons could be learnt for all employees of the company.

Acceptance of flexible schedules is as mentioned a sensitive subject to the operators at the case company. An incentive system is suggested by the control model, which could be an effective solution. However, a preliminary production layout has been drawn which can host the approximated number of employees. Quality problems could also occur as the handover between operators could be cumbersome. Hence, even though effective, there is no need currently to introduce a second work shift and potentially stir up negative emotions.

Ramp-up organisation is also non-existing, meaning that a suggested restructuring of the organisation is a good measure to implement. The authors would suggest the case company to put together a competent, diverse group of experienced employees to monitor the progress of the ramp-up. As the preparations for a ramp-up have been lacking, setting up a proper organisation for the task is needed to proceed with success.

The planning strategy was the first critical factor that was identified via the case study. Changing the planning is necessary to gain full control of the production, where relevant KPI's should be chosen and monitored to manage the future production. The KPI's should follow the work conducted, which in the past has been poorly documented. If the wait times were to be taken away and planning would be more flow based, the ability to monitor and document would be significantly easier for the company. Seven different measures were identified from the control method, where autonomous work groups also could play an important role in the planning process for the future. As there currently only is one production line with a flexible functional layout, the planning and flow is very complex. If a division of the work force could be made to have separate production lines depending on the type of product, planning would be simplified as the planning schedule would be split and hence enable specialisation from the operators. Another important measure would be to allow products further upstream to be prioritised. As described, operations are very similar in nature and therefore require the same planning, operators and work space. This leads to potential stops of products upstream in favour of a product going into production. To have a better flow and possibilities of documentation, the product upstream should be allowed to move through its operations and thereby increase traceability and decrease lead time and WIP. For the organisation to understand the importance of these suggestions, education about Lean and higher volume production is key.

The number of assembly steps is a problem mainly connected to education. As the assembly steps are many and complex, it takes years between an operator being introduced to being fully aware of all processes. This must not be the vision in the workshop however as a carefully planned competence matrix can enable planning to distribute work among workers. A part of this could be made by having partly autonomous work groups. This could work in two ways:

- By dividing the full assembly to have specialised groups of workers that are experts in a certain type of assembly steps. The advantage would then be that the steps would always be made by an assigned expert and thereby increase quality. The downside would be that it in many cases would involve handovers of work, which potentially could result in more WIP and quality losses.

- The other alternative would be to have work groups that specialise in certain products that are similar in assembly. This would enable workers to become experts and increase quality. No handovers would be needed, but close to all types of operations would still be needed to learn.

The focus shift from development to production is perhaps the most defining complexity of high technology companies during ramp-up. As high technology companies have a lot of focus on product development and the product in general (Zakrzewska-Bielawska, 2010) they may lack knowledge of full-scale production. This is the case with the case company and therefore a variety of measures can be taken. Three categories of measures can be seen related to education, documentation and external inspiration. Education has been mentioned in earlier critical factors, where internal process training and external production and Lean education is needed to deal with rapidly increasing volumes. Experienced employees will play a key role as well as multiplicators that can bring forth the best in future employees to swiftly learn processes. Ideally, new employees should come from companies with slightly higher volumes and Lean thinking. Documentation will be important to follow work, where data is currently lacking. The authors believe that current KPI's are not measured properly and therefore not showing what they are supposed to show. By documenting better and identifying new KPI's, management of the production will be eased as implemented measures can be monitored to follow progress. External inspiration will be needed to get new thoughts into the company to tackle the new production situation. Lectures from external managers or managers in other Saab companies could prove useful for understanding of higher volume production. New employees can also play an important role if taken from companies with higher volumes, that in turn bring in new ideas. The focus shift will be enabled by a major shift in thinking within the company, which will need external influence and an ability from current employees to change according to needs.

5.3 Create Action plan

The third research question was stated as:

> *How should measures be prioritised to meet the desired production output during ramp-up in an aerospace assembly?*

The prioritising of measures is made by tackling the highest scoring critical factors found in research question 1 and merging them with the measures identified in research question 2. No method for prioritising the specific measures for each critical factor is presented as the requirements varies depending on the case company. Each critical factor is assigned with an action plan of measures to be prioritised based on relevance to the company. Table 16 presents a structured planning of company specific measures for each critical factor, which should be implemented from left to right in the table. Please note that all critical factors above the significance limit have been reintroduced to create a complete action plan.

Table 16 has shown company specific measures which build on the analysis in RQ2. It is clearly shown from the priority that experience of ramp-up is the main critical factor, which has resulted in measures mainly concerned with capabilities, education and organisational factors. This is also reflected by the potential costs which in many of the measures involve personnel costs. The case company is in need of major measures to be able to handle the ramp-up phase and hence this action plan can help the organisation conduct a project to improve the assembly at hand. Also, as the critical factors and measures are to a high extent very similar, some critical factors may be solved simultaneously before it is time for implementation of the coming measures. This has advantages that the case company has problems related to a few, but big, categories of critical factors when it comes to implementation and the time span for improvements

Table 16 Prioritisation of measures gained from the fourth and fifth step

Critical factors / Ramp-up measures	Ramp-up experience	Acceptance of flexible schedules		Number of assembly steps	Ramp-up organisation	Focus shift	Number of linkages	Professional experience	Language and communication skills	Information availability	Contentual process variety	Associate qualifications	Assembly automation	Potential costs
Criticality	**20**	**20**	**16**	**16**	**16**	**15**	**12**	**8**	**4**	**4**	**4**	**3**	**3**	
Integration of experienced employees	x					x		x						P
Ramp-up teams with experienced and new employees	x							x	x			x		P
Floaters	x		x					x				x		P
Multiplicators	x					x		x				x		P
Mentoring	x							x	x			x		P
External ramp-up inspiration	x		x		x	x								I
Ramp-up based incentive system		x												P
Partially autonomous work groups to create separate lines			x	x							x			
Data integration to improve documentation			x			x				x				P,I
Lean and production education			x			x						x		P
Selection of relevant KPI's			x			x				x				
Restructuring of planning strategy			x											P, I
Adaptive Kanban cycle				x							x			
Cluster or divide assembly steps to increase flexibility				x										P
Creation of ramp-up organisation					x									P,I
Process training						x						x		P
Ramp-up board										x				S
Redundant processes by education of personnel											x		x	S,I,P
Stepwise automation of testing													x	S,I

Legend; P: Personnel costs, S: Space, I: Investment, C: Carrying costs

6 Discussion and Conclusions

The chapter gives a summarizing description of the results and insights from the control method. Further, the study's implications and limitations in relation to researchers, practitioners and management are described. In addition, the study's conclusions and recommendations for both case company and research community is described. The chapter is ended with suggestions of further research.

6.1 Results

The answer to research question 1, "What are the critical factors that challenge the production during ramp-up in an aerospace assembly?" was presented in Table 14. 13 critical factors were identified in total after the significance limit had been applied. These were mainly related to personnel, education and experience. Thus, they are clearly linked to the characteristics of a high technology company. The results from this question are valid as the critical factors could be identified to a large extent both via the original control method and the case study, thereby yielding reasonable results.

The answer to research question 2, "What measures can be taken to handle the challenges during production ramp-up in an aerospace assembly?" was presented in Table 15. 19 relevant measures were identified for the case based on the critical factors. 14 of these came from the original control method, while five were added based on the case study. This result is valid as measures have been identified and validated both by the authors and employees at the case company. Thereby, both parties agree that the results are reasonable.

The answer to research question 3, "How should measures be prioritised to meet the desired output during production ramp-up in an aerospace assembly?" was presented in Table 16. An ideal implementation plan was proposed based on the criticality scores of the critical factors and their corresponding measures. The result is valid as the score of the critical factors are based on empirical findings, thereby suited to the case company. The prioritisation is however not fully clear with each critical factor as measures for each critical factor does not include an internal prioritisation. Therefore, each case should firstly implement the suggested measures based on the critical factor, but secondly based on relevance to the case.

6.2 Implications

For the case company to implement the suggested measures according to the prioritising made in Table 16, the measures should bring them in the right direction during the ramp-up process. For other practitioners within a high technology company assembly, the prioritising in Table 16 can still be applicable. However, if that is not the case the same method as stated in the theoretical background can be used to identify specific measures for that case since the model is rather flexible in that manner. For researchers the theoretical contribution is a built on the existing theory about ramp-up. Currently, there is limited research to be found on ramp-up in relation to physical production, hence the contribution is the testing and development of one of the few existing ramp-up methodologies. The study showed that most of the measures in the ramp-up control method were relevant for the case but did according to the authors lack some connection to Lean. The original ramp-up control method was also too complex according to the authors and was therefore simplified in the study. This study has contributed to a simplified ramp-up method for production systems with five additional measures and two critical factors. For managers, the simplified control method can be used in a standardised manner to identify critical factors and measures to decrease time-to-volume. Also, by simplifying production ramp-up, companies will be able to stay competitive in their native country, thus reducing the need for off-shoring and act sustainably based on all three pillars.

Furthermore, sustainability is an important aspect to consider in any operation of a supply chain as highlighted by the authors' programs. In relation to the knowledge gained during the education, sustainable aspects could be taken into consideration to gain deeper understanding of the topic. By simplifying production ramp-up, less waste will occur in the production and thereby streamline further down in the supply chain. Suppliers and customers are as much affected by a ramp-up as the focal company, therefore the topic of the thesis was relevant and valuable to the authors' work and learning. Based on the three pillars of sustainability the thesis has contributed to all three, economic, social and environmental pillars. Economic as a simplified production ramp-up will result in greater efficiency and thereby reduce costs. Social as the greater efficiency may create new work opportunities and contribute to the social well-being of the community which the company lies. Environmental as an increased understanding of a company's operations will result in less waste and thereby reduce energy consumption and unnecessary use of raw materials. The sustainable aspects of ramp-up is hence very central to the topic and should be closely considered in future research.

6.3 Limitations

The choice of conducting a single case study was necessary for the authors and gave the authors the possibility to study the case in depth. This was necessary to do in order to generate new critical factors and measures. Using a single case study did affect the transferability of the study in a negative way. A multiple case study could increase the transferability and verify the results from this study. Replicating the study should however be easy since the result of the study includes a standardised method, but the result will differ between companies. The data collection had more to ask even if triangulation has been made with data collection techniques to receive data from different sources. The authors did not record nor transcribe any of the collected data. Transcription of the data could have improved the credibility since the authors did only take notes during observations and interviews due to secrecy. Some interviews were unstructured where the interviewed did not have time to prepare anything before answering the authors questions. This affected the quality of the interviewee's answers. The authors did not have the possibility to book a separate meeting every time the authors had any questions for the employees at the case company since the study was exploratory and questions appeared frequently. This affects the dependability of the study since the answers could have differed if the interviewees had more time to formulate their answers.

Another limitation to discuss is the control method which was further developed by the authors. To the authors' knowledge, the original method has not been verified by further application, thereby the development made by the authors are not well grounded for implementation. The method has however proved useful for identifying critical factors and measures during production ramp-up. However, the authors do not believe that neither the original method nor the developed one should be used on its own. As part of a case study, the method was able to identify many relevant factors but lacked in some areas, which were filled with the results from this case study. This enabled the method to be tailored to the case and the authors recommend that researchers conduct a case study in direct link with the control method. For practitioners the insight to the situation may not require further research, therefore the control method could be used on its own in these cases

6.4 Conclusions and Recommendations

The conclusions of the study can be divided into two areas, one concerning the theoretical contribution with the control method and another with the practical contributions to the case company. From the literature review and the case, the authors have fully grasped the complexity of production ramp-up as a subject. The subject reaches across all departments of a company and it was hence difficult to limit the analysis to the physical production. Organisational factors were pinpointed via critical factors in the control method and were perceived as most relevant and urgent in the case company, therefore the first conclusion drawn from the study is:

> Production ramp-up is one of the most difficult challenges a manufacturing company can face.

After studying the characteristics of a high technology company and the critical factors at the case company, the authors could see a pattern why those critical factors appeared at the case company. Therefore, the second conclusion drawn from the study is:

> Ramp-up in high technology companies is mainly restrained by critical factors related to personnel, education and experience.

The characteristics of a high technology company and its complexities hinders the implementation of Lean since the structure and the thinking within the organisation is distant from being Lean. This makes it harder for the organisation to start making changes towards a more Lean-organisation. Therefore, the third conclusion drawn from the study is:

> Lean practises can be useful during a ramp-up, however the mind-set of manufacturing in high technology companies hinders these practises from being self-evidently implemented.

Based on the conclusions, the authors have extracted three recommendations for high technology companies. Firstly, a clear vision and action plan must be communicated throughout the whole organisation in order to tackle the ramp-up phase. Neither the case company nor the literature review could present such an overarching strategy. Therefore, the first recommendation is to:

> Have a standardised method for production ramp-up for identifying critical factors and measures.

Secondly, as the ramp-up phase in high technology companies is mainly restrained by the critical factors related to personnel, education and experience, companies must share competences and not rely on a few persons with all the knowledge. This can be done by strategically planning and developing the personnel so they can perform different operations which will increase the flexibility in the production system. Therefore, the second recommendation is to:

> Have a well-structured competence development plan before entering the ramp-up phase.

Thirdly, moving towards a more Lean-organisation is one way of remaining competitive but everyone has to see the benefits with Lean in order to steer the organisation in this direction. Therefore, the third recommendation is to:

> To promote Lean education and the use of the process related Lean principles in all levels of the organisation.

The recommendations are general to fit high technology companies in their effort to simplify and plan for production ramp-up. These are formulated from a perspective where there is time to act before the ramp-up begins, therefore they are not completely linkable to the case company since they have already begun their ramp-up phase. However, the use of Lean practices, a standardised method for identifying measures and an effort to educate the workforce is also recommended to the case company.

6.5 Further Research Suggestions

Companies are struggling with creating a strategy to handle the ramp-up phase and only uses bits and pieces of measures to keep up with the demand. The managers in charge of the production ramp-up feel overwhelmed because they cannot get the situation under control. Therefore, this study opens paths for further research about production ramp up in relation to the physical production should be organised during production ramp-up, since current research about the subject is limited. The developed ramp up control method in the study is limited to an assembly production and the critical factors might change in another type of production. Therefore, an overall method of how to handle different production ramp-up situations, which is also an important path for future research. The new critical factors and measures generated from this study have not been implemented in a production system. Therefore, a comparison of pre- and post-implementation of ramp-up measures need further research.

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Appendices

Appendix 1 – High technology company versus traditional industrial company

Appendix 2 – Critical factor questionnaire

Appendix 3 - Measures for critical factors

Appendix 4 – Literature search terms

Appendix 5 – Interview questions

Appendix 6 - Additional critical factor questionnaire

Appendix 1 - High technology company versus traditional industrial company

	Traditional industrial company	A high technology (HT) company
Objectives and strategy	Gaining profits	Return of expenses in a very short time due to dynamic changes in technology
	Often passive or reactive strategy versus change environment	Proactive, anticipating changes in environment, especially opportunities and chances
	The lack or rare cooperation with other organisations, focus on producing material goods	Intense, strategic domestic and international cooperation, especially with R&D centres
	Building competitive advantage on the basis of capital and financial assets	Building competitive advantage on the basis of knowledge, intellectual capital and innovations
	Investing mainly in tangible assets	Investing in tangible and intangible assets with high risk factor
Production and technology	Mass and large series production of goods for mass consumers, long production batches, few patents, rare inventions	Production of goods involving resources of modern science and technology for an intelligent customer, short production batches, numerous patents and licences, continuous innovativeness
	Large capital demand	Large scientific input demand
	Specialised plants	Variable processes plants
	Long changeover time of machines and technical equipment	High level of rotation of technical equipment; replacing with more modern and innovative devices
	Limited integration of production process (focus on partial processes)	High integration of production process (focus on making an innovative product)
People	High employment of production personnel	High employment of science and technical personnel as well as persons with knowledge
	Individual work or in permanently organised teams	Teamwork with much mobility and diversity as well as temporary participation
	Low creativity of personnel, heteronomy and frequent lack of independence in problem solving	High creativity of personnel, ability of creative thinking and autonomy; independent problem solving
	Little training and skills improvement	Continuous training, improving qualifications and development of personnel; team learning
	Disciplinary measures for mistakes	Learning from mistakes
Organisational structure	Traditional, focused on the functions of a company	Cooperation networks of self-managing entities, focused on processes
	Hierarchy, monolithic, developed	Weaker hierarchy links, domination of horizontal connections with virtual features
	Fixed and structured organisation	High dynamics of change and flexible organisation
	High centralisation	High decentralisation
	Formalised, mainly vertical communication	Communication by means of advanced information technologies, vertical and horizontal, often informal
Management	“Control-focused” management	“Support-focused” management
	Holding on to stereotypes	Negating stereotypes
	Making decisions frequently on the basis of intuition or within fixed procedures	Making decisions on the basis of empirical data
	High position of managers	Large autonomy of employees, based Management on competences
	Avoiding uncertainty	Acceptance of uncertainty and permanent change

Appendix 2, part 1 – Critical factor questionnaire

Level 1	Level 2	Level 3	Low complexity (1)	(2)	(3)	High complexity (4)	Weighting
Process	Process variety	Contentual process variety	Widely standardized work process	Work processes with partly different contents	Work processes with many different contents	Large variety of different contents	2
		Technological process variety	One process	Few processes	Many processes	Countless processes	1
		Number of linkages	No linkage	Loose linkage	Elastic linkage	Rigid linkage	4
	Process originality	Originality of assembly processes	Only well-known processes	Few new processes	Many new processes	Entirely new processes	1
		Originality of equipment	No new equipment	Some new equipment	Much new equipment	Entirely new equipment	1
	Degree of automation	Assembly automation	Completely manual process	Partially automated process	Mostly automated process	Entirely automated processes	3
		Material staging automation	Manual material staging by assembly operator	Material staging by logistics staff	Material staging by automated guided vehicle system	Material staging by conveyor	1
	Size of assembly system	Number of assembly steps	One assembly step	Few assembly steps	Many assembly steps	Countless assembly steps	4
		Number of work stations	One workstation	Few work stations	Many work stations	Countless work stations	2

Appendix 2, part 2 – Critical factor questionnaire

Level 1	Level 2	Level 3	High complexity (1)	(2)	(3)	Low complexity (4)	Weighting
Organization	Organizational preconditions	Ramp-up organization	Fixed ramp-up team lead by ramp-up manager	Temporary ramp-up team supported by advisory staff	Ramp-up team temporarily released from line tasks	Employees face ramp-up parallel to series production	4
Organization	Organizational preconditions	Information availability	IT-supported data system (no waiting for information)	High availability of information (e.g. production data acquisition, drawings available)	Low availability of information (e.g. drawings rarely missing)	Very low availability of information (e.g. drawings often missing)	2
People	Associate potential	Associate qualification	High qualification	Rather high qualification	Rather low qualification	Low qualification	3
People	Associate potential	Professional experience	Long work experience	Medium work experience	Rather low work experience	No work experience	4
People	Associate potential	Ramp-up experience	Many ramp-ups completed	Multiple ramp-ups completed	Few ramp-ups completed	No ramp-up experience	5
People	Associate potential	Motivation	Very high motivation	High motivation	Rather low motivation	Low motivation	1
People	Associate potential	Language and communication skills	High communication skills	Communication uncomplicated	Communication difficulties	Distinct communication difficulties	2
People	Culture	Willingness to take over responsibility	High	Rather high	Low	None	1
People	Culture	Willingness to work in unknown areas of expertise	High	Rather high	Low	None	1
People	Culture	Willingness for further training	High	Rather high	Low	None	1
People	Culture	Acceptance of flexible work schedules	High	Rather high	Low	None	5

Appendix 3, part 1 - Measures for critical factors

Critical Factor / Ramp-up Measure	Contentual process variety	Technological process variety	Number of linkages	Originality of assembly processes	Originality of equipment	Assembly automation	Material staging automation	Number of assembly steps	Number of work stations	Potential costs
Cardboard engineering				x	x					P,S,I
System segmentation by buffers	x	x	x	x	x			x	x	S,C,I
Opening of station limits (drifting)				x						P,I
Redundant processes	x	x		x	x	x	x			S,I,P
Rework stations				x	x					S,I,P
Disassembly stations				x	x					S,I,P
Additional test stations				x	x					S,I,P
Partially autonomous work groups	x	x						x	x	
Manual back-up					x	x	x			S,I
Stepwise automation						x	x			S,I
Adaptive Kanban cycle	x	x						x	x	
Adaptive production test	x	x	x	x	x					P

Legend; P: Personnel costs, S: Space, I: Investment, C: Carrying costs

Appendix 3, part 2 - Measures for critical factors

Critical Factor / **Ramp-up Measures**	**Ramp-up organisation**	**Information availability**	**Associate qualifications**	**Professional experience**	**Ramp-up experience**	**Motivation**	**Language and communication skills**	**Willingness to take responsibility**	**Will to work in unknown areas**	**Willingness for further training**	**Acceptance of flexible schedules**	**Potential costs**
Data integration		x										P,I
Ramp-up room		x										S
Restructuring of the ramp-up organisation	x											P,I
Integration of experienced employees				x	x							P
Ramp-up teams with experienced and new employees			x	x	x	x	x					P
Integration of equipment suppliers		x	x	x	x							P
Floaters			x	x	x							P
Multiplicators			x	x	x	x						P
Mentoring			x	x	x	x	x					P
Process training			x			x						P
Soft skill training						x	x					P
Language courses							x					P
Intercultural training						x	x					P
Workshop for integration of suppliers						x	x					P
Kick-off event						x		x	x	x	x	P
Ramp-up based incentive system						x		x	x	x	x	P

Legend; P: Personnel costs, S: Space, I: Investment, C: Carrying costs

Appendix 4 – Literature Search terms

Database	Search terms	Search Field	Delimitations	NR. of Hits	Hits Used
Scopus	"Production" AND "Ramp-up"	Article title, Abstract, Keywords	Year: 2012-2019 Subject area: Engineering Sorting: Cited by (Highest)	254	4
Scopus	"Lean Manufacturing" AND "Literature Review"	Article title, Abstract, Keywords	Year: 2012-2019 Sorting: Cited by Highest	138	2
Scopus	"Lean Manufacturing" AND "Literature Review"	Article title, Abstract, Keywords	Year: 2012-2019 Sorting: Newest	138	1
Scopus	"ramp-up" AND "assembly"	Article title, Abstract, Keywords	Year: 2012-2019 Sorting: Cited by highest	81	1
Scopus	"Lean Manufacturing"	Article title, Abstract, Keywords	Sorting: Cited by highest	3936	1
Google scholar	"High Technology Company" AND "Characteristics"			2820	1

Appendix 5 - Interview Questions

Questions for Production Planner

How do products prioritize?
Who decides what to produce and when?
Who decides on which returns should be taken into production?
Why do three working days wait time between operations in planning?
Why aren't all operations running in one go?
Does the product need to wait between operations, especially why?
How often are the times kept in the planning? Is this followed up?

Questions for Workshop Manager

How is production capacity determined at present?
How does production follow-up, productivity etc. take place?
Can everyone carry out any assembly work or are certain operations tied to certain operators?
Is there a competence matrix?
How reliable are the controls? In our case, operations 30 and 50.
How much time is spent on reworking products? How much is discarded due to quality deficiencies?

Appendix 6 - Additional critical factor questionnaire

Complexity	**Low Complexity (1)**	**(2)**	**(3)**	**High Complexity (4)**	**Weighting**
Focus shift	No focus shift from development to production	Some focus shift from development to production	Moderate focus shift from development to production	Significant focus shift from development to production	5
Planning strategy	Flow-based/fixed planning	Moderately fixed planning	Moderately flexible planning	Flexible planning	4