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Improving the Industrialisation Process at an Engineer-to-Order Company

An Analysis of the Interface between Design and Manufacturing

Master's Thesis in the Master's Programmes
Supply Chain Management & Quality and Operations Management

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

Engineer-to-order companies face demand for rapid development of complex products due to a dynamic market. Thus, short lead times and flow efficiency are important to ensure competitiveness. In order to ensure an efficient product development process, a smooth transition between design and manufacturing is required. Therefore the industrialisation process, which is the interface between these two, is of paramount importance. This master thesis studies the industrialisation process at a Defence and Security Company, which includes describing and analysing the product flow from the end of the design phase, via the industrialisation function, to manufactured product. The aim is to improve the performance of the product flow in terms of reduced lead times, without compromising on quality. A current state description with a visualization over the product flow was created based mainly on observations and interviews, including both the product flow of new products as well as previously produced products. This showed that the product flow was iterative and complex due to issues which arise. Parallel to this, an empirical study was conducted on two other companies, as well as the creation of a theoretical framework covering areas such as concurrent engineering, lean production within engineer-to-order environments and social sustainability.

Several areas of friction with a negative impact on the performance were identified based on the current status description, such as non-standardized working procedures, non-value adding activities and low collaboration between the involved functions of the product flow. The areas of friction result in negative effects such as unwanted variation, delays and low motivation, which in turn have a negative impact on the performance of the product flow in terms of increased lead times and inadequate social sustainability. Subsequently, a set of suggested improvements were identified in order to increase collaboration, standardization and transparency, which are three key principles to consider for an improved performance. Some of the suggested improvements are cross-functional teams and meetings, standardized processes, synchronized planning, common goals and utilization of visual management. These positively affect the performance of the product flow in terms of shorter lead times and higher employee motivation. In conclusion, the theoretical contribution of this thesis is an investigation of how the industrialisation process in an ETO environment can be improved utilizing academic principles.

Keywords: industrialisation process, production preparation, engineer-to-order, concurrent engineering, lean production, product development process, high variation environment

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Jonathan Bergström & Louise Persson
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List of Abbreviations

BOM	Bill of materials
DSC	Defence and security company
ETO	Engineer-to-order
HWR	Hardware review
NCR	Non-conformance report

1. Introduction

In this chapter the background of this master thesis is introduced, along with the thesis aim and subsequent research questions. Additionally, the scope, limitations and outcome of the master thesis are presented.

1.1 Background

Performance improvement and focus on efficiency is key in order for manufacturing organizations to remain competitive. Due to aggressive competition, rapid change and constantly shifting prerequisites, continuous improvement is crucial for a company’s long term survival (Ljungberg & Larsson, 2012). This is especially true for engineer-to-order (ETO) companies where each end product is engineered and manufactured according to customer specifications. Due to the unpredictable and dynamic nature of the business environment in which ETO companies operate, along with an ever growing demand for a more rapid development of complex products, requests for changes during product development and need for shorter delivery lead times, the effective management of operations and flow is vital for a firm's survival (Kozjek, Vrabič, Rihtaršič & Butala, 2018). If the organization also operates in a high technological environment, there are additional challenges related to the high rate of change as well as increased complexity of the products (Villamizar, Cobo & Rocha, 2017).

A company that operates an ETO production in a high technological environment is a defence and security company, which in this thesis will be referred to as the DSC. The company has identified a need to improve their production in terms of shorter lead time, greater lead time precision, increased flexibility and decreased cost. The object which will be investigated and analysed in this master thesis is a product flow consisting of several steps, starting with the end stage of product design and ending at finalized manufacturing of the product, with the purpose to optimize the performance of the product flow. More specifically, the product flow for a specific group of manufactured products, which are ingoing components in the end product, will be studied. This group of products will further be defined as Product Group A. The product flow of Product Group A includes three main functions, which are the design function, the industrialisation function and the production function.

As a result of high customization and a broad variety of products every product is developed and produced according to specific customer requirements. This leads to a high variation of products and therefore a complex product flow for Product Group A. Due to the complex and non-linear flow, the product flow is not standardised and an overview over the actual product flow is missing. These problems have initiated this master thesis, with the purpose to increase the performance of the product flow in terms of reduced lead time.

1.2 Aim

The aim of this master thesis is to improve the performance of the product flow for Product Group A through decreased lead times without compromising quality, by identifying principles and guidelines which can be applied on the product flow.

1.3 Scope and Limitations

Due to a broad product portfolio and high product variation, the product flow of only one product group will be covered in this study, specified as Product Group A. This product group involves manufacturing at one site within the company organization, so other productions sites will not be included. The study will due to restriction in time cover the product flow from end of the design phase, through industrialisation to manufactured product in the production phase. The assembly step of the final product, of which Product Group A is a component of, will not be covered and is therefore a limitation in this study.

1.4 Research Questions

To support the thesis aim, three research questions have been formulated. The first question refers to understanding the current status of the product flow. This means that the product flow for Product Group A needs to be investigated by identifying the different processes in the flow, in what order they are completed and the interaction between these. Therefore, the first research question that has to be answered is:

1. *What is the structure of the product flow for Product Group A and how do the different processes interact?*

After establishing a current status description, the focus will be to identify areas of improvement within the product flow. In order to improve the product flow, areas of friction both within and between the different processes in the product flow needs to be identified. Areas of friction are here defined as issues that have a negative impact on the performance of the product flow and can be seen as areas of improvement. Areas of improvement can either stem from the design of the identified product flow, but also from how the processes are applied and how they interact. The second research question thereby becomes:

2. *What areas of friction arise during and between the processes of the product flow of Product Group A and how does this affect the product flow's performance?*

When the product flow has been described and areas of friction have been identified, the overall thesis aim can be addressed. This means that applicable principles and guidelines, which can improve the product flow and its performance, can be identified. Thus, the third research question of this thesis is:

3. *What principles and guidelines can be applied to mitigate the above frictions or their effects in order to increase the performance of the product flow for Product Group A?*

1.5 Outcome

This master thesis is an academic report with three main outcomes. The first is a status description including a process map of the current product flow for Product Group A, including the end phase of design, industrialisation and production. The second outcome is a number of identified problem areas which have a negative effect on the product flow's performance. Based on this, the third outcome covers a number of suggested improvements, which enable increased performance for the product flow. Further, a discussion regarding implementation will be included but no detailed implementation plan will be given for the suggested improvements.

1.6 Report Outline

In this section, an outline of the report is presented, with the purpose to introduce the disposition of this master thesis and support the reader. In the initial chapter, *1. Introduction,* a background to the subject area is given, followed by the aim, scope, limitations, research questions and outcomes of this master thesis. In the second chapter, *2. Theoretical Framework,* relevant academic principles connected to the area of study is presented, which becomes the academic foundation for this thesis. In order to provide an understanding of how this study was conducted, a detailed description about the study procedure is presented in the third chapter, *3. Methodology.* In this third chapter the research strategy is presented, followed by an ingoing description of the data collection methods used and the analysis of collected data. The quality of research is also discussed in terms of validity, reliability and objectivity. In the fourth chapter *4. Current State Description,* a description of the studied product flow with related functions and activities is presented and visualized. After an understanding of the product flow is gained and essential concepts have been introduced, the fifth chapter *5. Empirical Study,* describes the industrialisation processes at two other companies. This is in order to give a broader perspective of the subject area and show how key concepts can be applied. The sixth chapter, *6. Identified Areas of Friction,* presents an analysis of the current state of the product flow in form of identified areas of friction. In the following chapter, *7. Suggested Improvements,* a number of recommended actions in order to mitigate the areas of friction and thereby increase the performance of the product flow are presented. Further, in *8. Discussion,* a critical discussion regarding results and implementation is held and the contributions and generalisability of the study are presented. In addition, suggestions for future research areas are provided. In the final chapter *9. Conclusion,* the three research questions of this master thesis are summarized and the study is concluded.

2. Theoretical Framework

In this chapter, the theoretical framework for this thesis is introduced. The framework is the academic foundation of the thesis and will be utilised both during the analysis of the current state description, as well as for identifying principles and guidelines for improvement of the performance of the flow of Product Group A. The theoretical framework is based on several research areas, where relevant principles are extracted and utilized in tandem and conjunction with each other throughout the thesis. The research areas are visualised in *Figure 1* below.

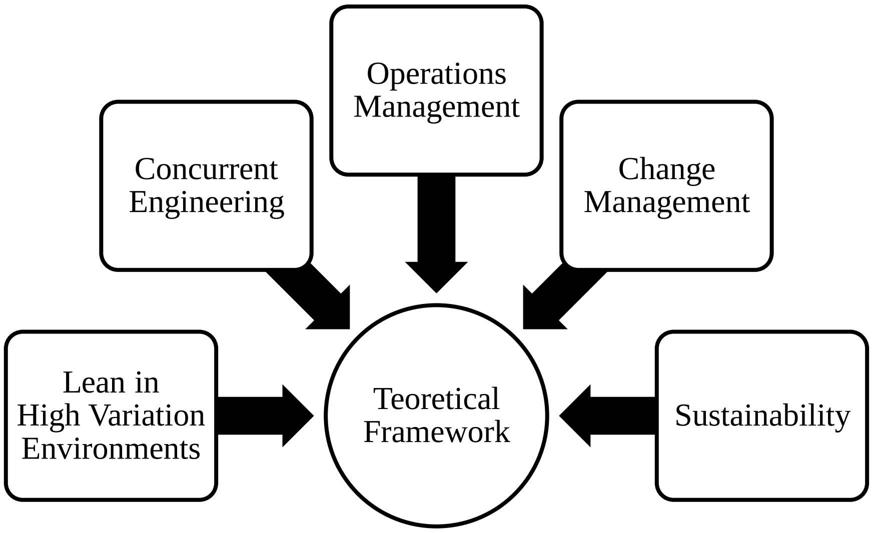

Figure 1. Research areas within the theoretical framework

The research areas have been selected based on the overall thesis aim of improving the flow of Product Group A. The first area Operations Management covers essential principles within organizational and flow efficiency theory. Theory regarding production preparation, interface and barriers between design and manufacturing functions and planning and control of organizations will be presented. The area of production preparation is included as this is a core process of the product flow of Product Group A, while interface and barriers between functions as well as planning and control are essential when managing a flow in a production company. The section also includes an introduction to lean production, which currently is one of the leading research areas within operations strategy and flow efficiency.

A further investigation about lean within high variation environments has been conducted, which is presented in the second section of this chapter. The adaptation of lean principles to ETO manufacturing is presented as well as application of lean within complex socio-technical systems. This areas are investigated due to the complex nature and ETO manufacturing conducted by the company in this master thesis. Due to the substantial dependency between design and production in ETO environments, the principles of concurrent engineering have been studied. Concurrent engineering focuses on the communication and cooperation between design and production and how this affects the performance of a products flow through a production system. Therefore the fundamentals and application of concurrent engineering are presented in the third section of this chapter.

Additionally, change management is included in the theoretical framework. To increase the probability of a successful implementation of the outcomes in this master thesis, knowledge about change management and implementation is important to investigate. This thereby enables the forthcoming discussion regarding implementation of recommendations. Lastly, academic principles regarding social sustainability will be presented. Sustainability is essential for companies to include in their activities to maintain competitive and is therefore a key element to include in the theoretical framework.

2.1 Operations Management

In this section areas and principles within operations management are presented. First production preparation is explained, followed by an introduction to the interface and barriers between design and manufacturing. Subsequently, selected areas of planning and control of organizations is covered, including collaboration, visual control and performance measurements. Lastly, fundamental principles of lean production is presented.

2.1.1 Production Preparation

Production preparation, or manufacturing engineering as it also is known as, is the link between design and production (Bullen, 2013). Managing this interface between the different functions is a challenge in many industrial companies (Dekkers, Chang & Kreutzfeldt, 2013). Bullen (2013) describes that the activities performed in order to achieve synchronization are numerous and varied, due to the fact that the design and production often are isolated from each other because of their different characteristics. These synchronization activities can be divided into two categories, one which is more technical and one which is more administrative. Some of the technical activities included are analysing and defining the needs for new and specific tools, machines, processes and technologies (Bullen, 2013). This further entails calculating the required performance based on design specifications, as well as implementation and validation of these (Blocisz & Hadas, 2019). The administrative parts include a creation of documents such as work instructions as well as time planning (Bullen, 2013).

In order for the relationship between design and production to be effective, Dekkers et al. (2013) have identified four key success factors which should be implemented. The first success factor is that the involved stakeholders need to have the correct skills and capabilities. This knowledge must span the entire product development and production process, from product design, engineering, production planning and manufacturing. The second success factor stresses the importance of both the willingness and ability to collaborate internally as teams. The greater the need for innovation and amount of new knowledge needed, the closer the collaboration needs to be. Related to this, the third success factor highlights the need for knowledge management in the organisation. This enables sharing of knowledge to enhance collaboration, as well as increased possibility for new innovations to arise. The fourth key success factor, top management commitment, is essential if the above is to succeed. Top management not only need to give direction for employees, but they also need to work together in order to ensure that the right knowledge is available in the organisation and enable both collaboration as well as knowledge sharing between the different functions (Dekkers et al., 2013).

2.1.2 Interface and Barriers between Design and Manufacturing

As mentioned above, production preparation is the interface between design and manufacturing. This interface between design and manufacturing as well as the integration between the two functions has been examined by Vandevelde and Van Dierdonck (2003). The authors state that an insufficient integration of the design and manufacturing department can result in lack of respect and understanding for each other's work, tense and weak relationships and a favourable bias towards the own function. This can further have a negative impact on the information sharing and utilization of knowledge within the company.

Vandevelde and Van Dierdonck (2003) presents five barriers to integration of design and manufacturing, which are physical, organizational, language, cultural and personality barriers. Physical barriers is related to the physical location of the functions, which affect the probability of informal communication and interaction between employees. Organizational barriers originates from differentiation of functions with separated objectives and award systems. Also lack of management support, resistance to change and unclear goals, roles and responsibilities induce organizational barriers. Furthermore, language differences between departments can become a barrier, since usage of different language or technical terms can inhibit communication and generate misunderstandings. Cultural barriers can occur due to different employee backgrounds and training, but also due to different organizational focus and goals. Manufacturing is often judged on level of output from a short term perspective, while the design department is judged on development progress from a long term perspective. This occurs even though the overall organizational objectives are equal. Cultural barriers can also occur through an *us versus them* attitude, as Vandevelde and Van Dierdonck (2003) state. The functional differentiation and historically difference in status for design and manufacturing can create this attitude and hence a cultural barrier. Moreover, personality barriers can exist between the functions due to the different needs, motivations, personal goals and perception of stereotypes.

Twigg (2002) introduces some mechanisms for integration between design and manufacturing. The first mechanism is the use of standards throughout the process, so all involved employees act upon the same information. Another mechanism is schedule and plans, which refers to integrating strategies and objectives of different functions prior to projects and additionally having clearly defined requirements and responsibilities. One example of this, that the author states, is a sign-off procedure, which is an occasion where the design can be either accepted or rejected by the manufacturing due to insufficient design, producibility or documentation. Mutual adjustments, which is the third integration mechanism, is that some changes are done in collaboration of several functions. This is enabled by a coordination committee, which synchronizes the work between functions to match downstream resources and operations prior the project start. The last integration mechanism, presented by Twigg (2002), is establishment of cross-functional teams. The author states that usage of cross-functional teams creates an opportunity for manufacturing engineers to be involved early in the development process and continuously give input regarding the product design to ensure manufacturability and suitable process design. Additionally, it gives opportunity for fast problem solving of issues that arise early in production, since design engineers are involved in the production introduction and thereby can correct design issues immediately. Problem solving by cross-functional teams also results in a common solution, that design engineers can consider in future design assignments. If these mechanisms are adapted by an organization, they need to be modified to fit the business environment (Twigg, 2002).

Vandevelde and Van Dierdonck (2003) argue that the transition from design to manufacturing is hindered by the level of the products' complexity and uncertainty. The authors however introduce factors which smoothen the transition. One factor that has a positive effect on the production start-up is empathy from the design function towards production, which more specifically refers to the design function's understanding of the manufacturing and consideration of manufacturability in the design process. It is valuable to involve design engineers in the production start, to receive an understanding and respect of manufacturing, which in turn generates better and more qualitative future designs. Further, formalization also have a positive impact on the transition between design and manufacturing, since formalization through common standards, rules and clear responsibilities integrate the functions (Vandevelde & Van Dierdonck, 2003). This is in line with the mechanisms presented by Twigg (2002) above. According to Vandevelde and Van Dierdonck (2003) formalization also fosters transparency, which is required in combination with completed designs to ensure a smooth transition between design and manufacturing. Additionally, having a project structure and continuous communication between design and manufacturing are important factors which favour the transition between design and manufacturing, according to the authors.

2.1.3 Planning and Control

Production planning and control is essential for manufacturing companies in order to meet customer demands, requirements and expectations in an increasingly competitive environment (Stevenson, Hendry & Kingsman, 2005). Planning and control can be divided up into several activities, including material requirement, capacity and demand planning, as well as the scheduling and sequencing of jobs. Key goals of these processes include reducing the work in progress, shortening throughput and lead times, better responsiveness to changes in demand and ensuring customer service levels (Stevenson, Hendry & Kingsman, 2005).

A characteristic which sets ETO companies apart, related to planning and control, is the relatively low degree of information which is available when an order is received, according to Jonsson and Mattsson

(2009). The authors describe that since exact specifications of the product are unknown at the time of order, it is vital that planning and control methods are selected which can handle the limited amount of knowledge. This means that for early planning and control steps, information and forecasts are often based on estimates stemming from earlier experience, which may lead to planning with a longer planning horizon (Jonsson & Mattsson, 2009).

Furthermore, in ETO companies, an additional part of the planning and control work is the coordination between the engineering and production processes (Konijnendijk, 1994), in order to ensure synchronisation of the processes. This is due to the fact that the engineering and production process contains many specific skills and often include elements of craftsmanship. Combined with this is the fact that orders are seldom repeated, which means that the level of standardisation often is low and therefore coordination is needed. The better the company can coordinate, the better they perform (Konijnendijk, 1994). A lack of coordination also leads to delays between functions, which in turn increases both lead time and cost (Caron & Fiore, 1995). Another effect of decreased coordination is an increased amount of rework and engineering changes required during product development. Engineering changes, when poorly managed, can lead to inefficient manufacturing, missed deliveries and poor quality according to Wänström and Jonsson (2006). The authors explain that the poor management of engineering changes is often the result of poor communication and late identification of problems.

In order to improve and ensure coordination in ETO companies, Mello et al. (2017) suggest a set of principles which should be implemented. One principle is to systemise both internal and external requirements. This not only reduces the uncertainty, but is also a first step towards an implementation of standardisation and modularisation, which is essential in order to reduce rework and avoid delays. Another principle focuses on creating and ensuring a high production capability, though increased staff skill, knowledge, experience and autonomy. This allows identification and elimination of errors which otherwise would lead to rework and delay. A third principle to improve the coordination is to better integrate design and production, with associated production preparation activities. This includes co-located teams, common goals, direct communication and similar organisational culture, which is vital in order to handle engineering changes effectively as well as improving responsiveness and the flow of information.

A fourth principle described by Mello et al. (2017) is to ensure existence of a systematic learning process, which entails collecting knowledge gained in earlier projects and being able to adapt and apply this in future projects. This allows for identifying issues in the early project stages using past experiences, in order to mitigate future problems and avoid subsequent delays. A fifth principle for improving coordination between functions is to enable joint project management. Projects within ETO companies involve multiple stakeholders with high interdependence and their decisions affect each other. It is therefore important that the different stakeholders are represented in the project management team. Not only does this improve understanding and communication between different functions, but it also decreases the risk of conflicts. An effective use of an IT system is the final principle described by Mello et al. (2017). ETO projects are dynamic and often involves data from several different sources. If engineering and production are to be coordinated effectively, the information available to each of them needs to be able to be integrated in the same systems. In addition, an effective IT system also allows for enhanced collaboration and communication between different stakeholders.

Another tool within planning and control for enabling coordination across an organization is visual management. According to Tezel, Koskela and Tzortzopoulos (2016), visual management and information sharing enables overcoming of vertical and horizontal boundaries. This is through better awareness and understanding of the actual work conditions, issues and difficulties in different functions. Visual management in this context is a managerial strategy where visual tools and visual control measures are used, such as signboards, Andon boards, Kanban cards and poka-yoke systems. These tools should not only be implemented in the production function, but rather should be incorporated throughout the organization (Tezel, Koskela & Tzortzopoulos, 2016).

Moreover, in order for coordination and cooperation of different functions to be effective, it is important to have good performance measurements which focus on this collaboration, according to Meyer (1994). The author explains that without proper measurements, which support knowledge sharing and create understanding between different functions, there is a risk of coordination failing and different functions reverting to sub-optimization. This means that focus would shift from working together as a team towards each function improving their own performance measurements instead. Meyer (1994) highlights the following four characteristics of performance measurements, in order to minimize this risk. Initially, the main purpose of the performance measurements should be to enable monitoring of the progress made through collaboration and not individual functions progress. Further, the stakeholders involved in collaboration need to design the performance measurements in cooperation with each other so they have a mutual understanding of the measurements. The performance measurements must also show the progress of the process rather than individual functional outcomes, since the collaborations aim is to complete a certain process. Lastly, the amount of performance measurements should be limited to a handful. However, as Meyer (1994) notes, an organization with focus on collaboration still requires traditional performance measurements which show functional performance as well.

2.1.4 Lean Production

Lean production originates from the production system of Toyota, which many industries have been influenced by (Liker, 2004). Due to lack of resources after World War II, Toyota was forced to focus on doing the right things and not produce products which were not in demand, resulting in a strong focus on both the customer and flow efficiency (Modig & Åhlström, 2015). A pull production system was created where customer orders initiated the production process.

According to Modig and Åhlström (2015) lean is an operation strategy, which focuses on the value creation and continuous improvements within an organisation. The authors describes that lean focuses primarily on flow efficiency rather than the more traditional focus on resource efficiency. Focus on resource efficiency results in a sub-optimized organisation with insufficient integration, according to the authors. A focus on flow efficiency, on the other hand, generates an integrated organisation. This in turn results in better resource efficiency, which is illustrated in *Figure 2*. Furthermore, Rubenowitz (2004) argues that when it comes to design and production engineering, lean advocates minimizing the number of parts in a product and ensuring products are easy to produce in a lean way. To achieve this, Rubenowitz (2004) states that there needs to be a close collaboration between design engineers, production technicians and the production line.

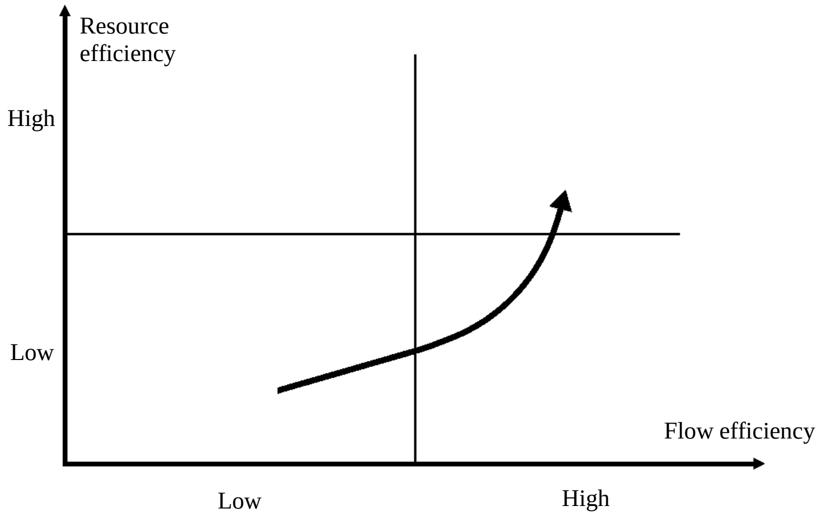

Figure 2. Efficiency matrix which illustrates the efficiency focus within lean production.

Modig and Åhlström (2015) present three laws of process performance, which are Little's law, the law of bottlenecks and the law of variation impact. The laws are universal and explain the difficulty of combining flow efficiency and resource efficiency. Little's law shows that throughput time is equal to work in progress multiplied by cycle time. This means that to decrease throughput time either the cycle time or the number of units in the flow needs to be decreased. It also shows that cycle time is affected negatively by a lack of resources and high utilization (Modig & Åhlström, 2015). The law of bottlenecks states that the throughput time is affected by the process with the longest cycle time, known as the bottleneck (Modig & Åhlström, 2015). The flow capacity will hence be limited to the bottleneck. Bottlenecks can increase the throughput time, since they result in queues of units in the system. This non value adding activity affects the throughput time negatively (Modig & Åhlström, 2015). One reason for bottlenecks appearing is, according to Modig and Åhlström (2015), the presence of variation. This is related to the law of variation impact. The authors explains that variation complicates the combination of flow and resource efficiency and occurs through variation of resources, people, units or external factors. Modig and Åhlström (2015) state that flow efficiency is affected negatively by variation according to Kingsman's equation, which is illustrated in *Figure 3*. Keeping resource utilization constant, the throughput time can be reduced as a result of decreased variation. Hence, variation is important to consider within lean.

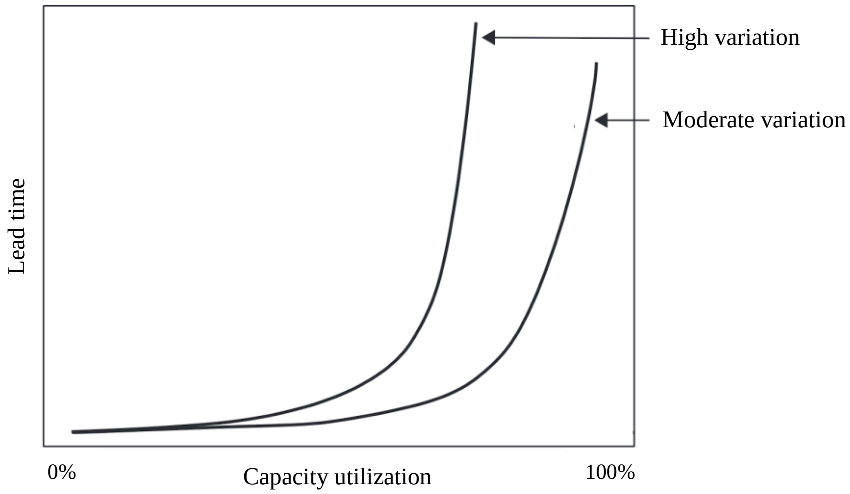

Figure 3. Visualisation over Kingman's equation regarding capacity utilization and variations impact on lead time.

As mentioned, focus has traditionally been on maximizing the utilization of resources within organisations. According to Modig and Åhlström (2015) this generates problems from a customer perspective and as well as increases the need for additional resources to handle problems. The authors mention three sources of inefficiency which are long throughput time, many flow units and many restarts per flow unit. Initially, long throughput time generates delays and excess work. This does not only affect the process performance negatively, but also the motivation of employees in terms of frustration and loss of motivation. A human's inability to work on many thing simultaneously is related to the second source of inefficiency, which according to Modig and Åhlström (2015) is a high number of flow units. A high number of units results in warehousing and buffers, which require facilities and secondary resources in order to manage the abundance. Buffers and a requirement for completing tasks simultaneously can in turn also generate stress and lack of control for employees, hence negatively affect the efficiency within the organisation. The third inefficiency source stated by the authors is many restarts per unit. Restarts require set up time since the affected employee need to receive insight in the situation before undertaking value adding activities. In situations including handovers between operators or processes, frustration and quality issues can result due to the risk of miscommunication. As for both previous inefficiency sources, secondary resource needs are generated by restarts, since problems as a result of restarts needs to be handled and corrected. Subsequently, Liker (2004) presents seven types of waste that originates from Toyota, which are the following: overproduction, waiting, unnecessary transport, over processing, excess inventory, unnecessary movement and defects. These activities are defined as waste, since they are not value adding and therefore processes should be changed in order to eliminate them (Modig & Åhlström, 2015). By creating a continuous process flow without excess inventory, problems do not remain hidden, as the production line stops and in order to continue problems need to be solved immediately (Liker, 2004).

A problem in relation to lean that is raised by Modig and Åhlström (2015), is that when lean is applied by companies it is often seen as a method instead of a goal. Companies imitate Toyota's ways of working instead of understanding why lean methods are used. Rather, they implement lean methods and forget the fundamental reason for the change. The specific methods become the goal instead of the actual goal to develop the organisation. One example Modig and Åhlström (2015) gives is about standardisation. Standardisation is a prerequisite for improvements, since it constitutes a common basis that can be developed. Without a standard, there is nothing to develop. However, according to the authors, standardisation often becomes the goal within companies, even if it should be defined as a method and way to reach a goal. In conclusion, Modig and Åhlström (2015) state that using lean as an operations strategy is about continuously developing the organisation and having a dynamic goal to move towards.

2.2 Lean in High Variation Environments

In this section application of lean principles in ETO manufacturing will be presented. Additionally, lean within socio-technical systems with high complexity is introduced, which covers how complexity can be handled through the use of lean.

2.2.1 Lean within Engineer-to-Order Manufacturing

Engineer-to-order is defined by Gosling and Naim (2009) as a supply chain where customer penetration occurs in the design phase of a product, often associated with complex and large-scale projects. Within ETO organizations a master schedule is often produced in an early phase of a project and updates are not done regularly (Rauch, Dallasega & Matt, 2018). This leads to a push production system, according to Rauch et al. (2018), with subsequent problems such as high levels of work in progress, non-value adding activities and long lead times.

Lean production has successfully been applied in repetitive high-volume and low-mix manufacturing, for example in the automotive industry (Braglia, Gabbrielli & Marrazzini, 2019). For companies working with ETO manufacturing, the application of lean can be challenging and limited, where all tools and methods are not suitable (Braglia et al., 2019). Implementation of lean in an ETO environment entails improving the value flow through identification and elimination of waste creating activities, which is challenging due to the non-repetitive nature of manufacturing (Birkie & Trucco, 2016). High uncertainty is an attribute of ETO environments as a result of dynamism and complexity factors, which further appears as an environment with unpredictability and low homogeneity (Birkie & Trucco, 2016). Due to customized products and non-repetitive processes associated with low volumes and high variety, Powell et al. (2014) reformulated traditional lean principles with the intention to be more suitable for ETO manufacturers. The principles are an extract of the authors' analysis of existing principles in the areas of lean production, lean product development and lean construction. The authors formulated ten principles specifically adjusted for ETO manufacturers, which are presented below.

The first principle is defining stakeholder value, which states that value should be defined from the perspective of all involved stakeholders, not only the customer. Due to the tendency of a complex end product in an ETO environment, the whole process including design, engineering and production needs to have customer engagement, in order to assure quality. By establish internal customers across the process, every function needs to provide the internal customer with the exact needs they have, to be able to accomplish their function and purpose in the process.

The second principle is defined as leadership, people and learning. This refers to a focus on the people within the organization, which is often absent when implementation of lean is not successful. Flexibility is the third principle, which is extracted from lean product development and construction. Traditional principles in lean production are associated with standardisation and repetition to increase performance in terms of flow efficiency. In an ETO environment, flexibility is a requirement due to the characteristics of the manufacturing.

Furthermore, the fourth principle is modularization, which is a concept where the advantages of standardisation and customization can be combined. By using a modular design with standardised interfaces the production flow can be improved. This is done through the use of sub units, or modules, which allow for a standardisation of the production process while maintaining the ability to customize end products. Related to this is principle five, continuous process flow, which is enabled by modularization through standardisation. The subsequent principle six is defined as demand pull. This sixth principle intends to produce more according to a just-in-time approach instead of a more traditionally push production.

Stakeholder and systems integration is the seventh principle, which intends to establish a system view within the organization. To succeed with this a cross-functional integration needs to be present, through a systematic integration including all functions and both internal and external stakeholders. To enable this level of integration the organization needs to be transparent, which is the purpose of the eighth principle, transparency. This can be applied through visual controls and sharing of the performance of the different functions by their performance indicators throughout the organization. Furthermore, the authors refer to the importance of technology, which is the ninth principle. When producing customized products as ETO manufacturers do, the requirements of technology deployment is higher than in more standardised manufacturing. Finally, the last principle is continuous improvement, which according to Powell et al. (2014) is an essential principle when applying lean in all type of environments.

2.2.2 Lean in Socio-Technical Systems with High Complexity

The complexity in ETO industries is usually high, as a result of both complex products and uncertainty in production processes (Rauch et al., 2018). According to Soliman and Saurin (2017) complex systems have some common characteristics, such as a high number of elements, nonlinear dynamics, feedback loops, adaptive behaviour and emergent properties. In a socio-technical system there is a focus on the interaction between people and technology and how this interaction can be utilized in order to deliver an outcome (Soliman, Saurin & Anzanello, 2018). A socio-technical system with high complexity has four main attributes that defines the system, also known as a complex socio-technical system. These attributes are the following: dynamically interaction that occurs between a large number of interdependent elements, wide diversity, unexpected variability and resilience (Saurin & Gonzalez, 2013).

Saurin, Rooke and Koskela (2013) present how lean principles can be applied in complex socio-technical systems in order to handle complexity. The potential impact of lean was related to the four attributes by Saurin and Gonzalez (2013), introduced above. Related to the first attribute regarding many elements interacting in a dynamically manner, Saurin et al. (2013) argues that lean can have the impact of reducing the number of elements by eliminating elements which are not value adding. The number of interactions can also be reduced by dividing the manufacturing into separate lines or cells for specific product families. By either reducing the number of elements or interactions, or both, lean can according to the authors contributes to reduce or eliminate complexity that is not necessary. To handle the wide diversity of elements, which is the second attribute, unnecessary diversity can be eliminated, since lean underline the importance of standardisation. To define the level of necessity for diversity is though difficult according to the authors. The line between waste and value is indistinct in complex socio-technical systems, making them hard to separate (Soliman et al., 2018). However, Saurin et al. (2013) states that diversity that handles and reducing waste is encouraged by lean, for example variation in demand handled by multifunctional teams.

The lean principle of standardisation can also be applied to handle unwanted variability, which is the third attribute. Saurin et al. (2013) describes that standardisation can both assist in identifying unwanted variability and be applied in the form of guidelines, to receive a standardised way of handling unwanted variation within the organization. All variability cannot be eliminated however, as some external and human variability exists. Furthermore, creating a continuous flow, which is a key part of lean, may have a negative impact on complex socio-technical systems, since this kind of flow can result in increased variability. Otherwise, as stated by the authors, lean focuses on eliminating or reducing variability though principles such as continuous improvements, usage of reliable technology and having a culture of stopping production to handle and solve problems. By highlighting problems that arise, unwanted variability can be identified and eliminated, resulting indirectly in reduction of variability in the production process and hence reducing the number of stoppages.

Lean principles such as pull production and visual management both support resilience, which is the fourth and last attribute (Saurin et al., 2013). Through pull production only activities which adds value are performed and hence the system can adapt to variation in both internal and external demand. Usage of visual management aids the organization and employees to receive insight on the performance, which is a prerequisite to know how and when changes needs to be done, in order to configure and increase performance. As mentioned earlier, multifunctional teams can handle variations in demand, which also supports the attribute of resilience. Additionally, a common vision and system view within the organisation, as lean urges, facilitates the consistency of performance adjustments to avoid sub-optimization. Lastly, involving and challenging employees to work with continuous improvements and have a critical mindset regarding the processes and procedures can, according to the authors, enhance performance adjustment and thus supports resilience.

2.3 Concurrent Engineering

A typical product development cycle consists of several processes, including research and development, design, production planning, process planning, planning of manufacturability and manufacturing (Parsaei & Sullivan, 1993). Concurrent engineering is an approach where different processes are completed simultaneously (Parsaei & Sullivan, 1993), and therefore integrates the upstream and downstream product development processes with each other (Curran, Zhao & Verhagen, 2015). One of the first definitions of concurrent engineering was developed by Winner, Pennell, Bertrand and Slusarczuk (1988) at the Institute of Defense Analysis, who define concurrent engineering as:

> *Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including, manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements. (p. 2)*

This definition focuses on the core principle of concurrent engineering, which is the parallel execution of both product and process design steps, and can be applied to both completely new products but also in changes to existing products (Wognum & Trienekens, 2015). In the following sections, the benefits of utilizing concurrent engineering and the key elements needed in order to achieve these benefits will be introduced.

2.3.1 Benefits of Concurrent Engineering

The product design and development process has a significant impact on the performance of a manufacturing company. Not only does the design process stipulate how well customer requirements can be reached, but it also affects the products quality, the efficiency and productivity of manufacturing, as well as life cycle costs of the product (Parsaei & Sullivan, 1993). For example, during the design phase, as much as 80-90% of the total life cycle cost for a product is fixed (Gatenby & Foo, 1990), while Suh (1990) states that the design phase can determine 70-80% of the manufacturing productivity. The reason for this is that early design changes have the largest impact while having the lowest cost and as the design and development process moves forward the more expensive changes become. *Figure 4* below shows that during the design stage a large percentage of the eventual total cost of the product has been committed to or decided, while only a small percentage of the cost has been expended (Creese &

More, 1990). Furthermore, the engineering changes do not only add cost, but each additional engineering change takes time which increases the products time to market (Syan, 1994).

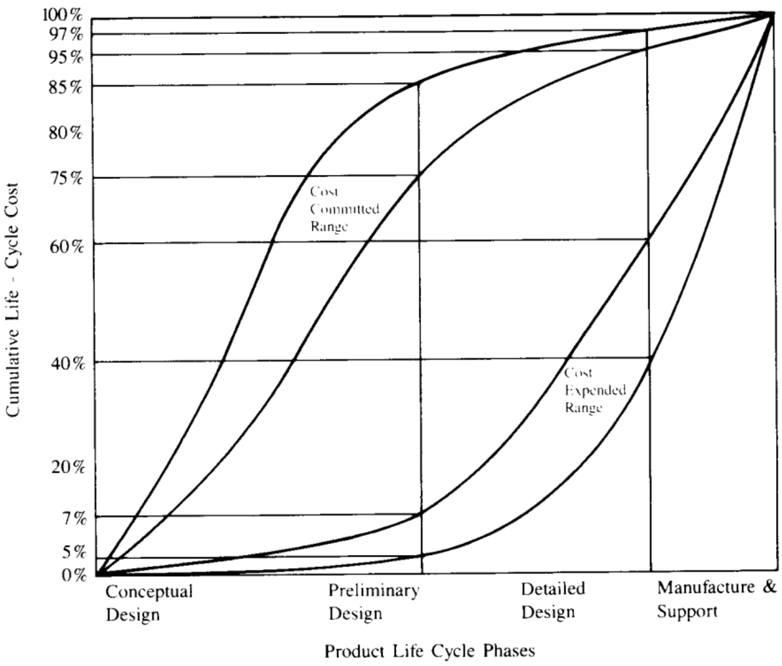

Figure 4. The percentage of committed and expended cost during the product life cycle (Creese & More, 1990).

One main goal of concurrent engineering is to ensure that when the design phase of the product life cycle is complete, no future engineering changes will have to be made, i.e. the design is right the first time (Turino, 1992). Concurrent engineering can therefore lead to several benefits: a shorter time to market, lower product development costs, higher product quality, lower manufacturing costs, lower testing costs, reduced service costs, enhanced competitiveness and improved profit margins (Syan, 1994; Turino, 1992).

Turino (1992) describes the product life cycle as consisting of four main parts: design, building, testing and servicing of the product. The author argues that the design step, which includes production preparation, is the only step that is done once per product type, while the other steps are recurring and are completed at least once per produced product, if not multiple times. This is shown in *Figure 5*. Since each step has a cost associated with it, reducing the cost for each step will have a substantial impact on the total cost during the product life cycle, and the subsequent margin, since the costs increase per product. If more time is spent during the first design phase of the product in order to ensure a design which takes into account performance, manufacturability, testability and serviceability, then less time and money has to be spent in the recurring steps and thereby both the life cycle cost and total time to market for the product will decrease. This also means that there is seldom an advantage to rush the design of a product, as this often leads to required redesigns when issues arise later in the process (Turino, 1992). As Syan (1994) describes it, the philosophy should be one of problem prevention early in the process, rather than continuous problem solving and subsequent redesign.

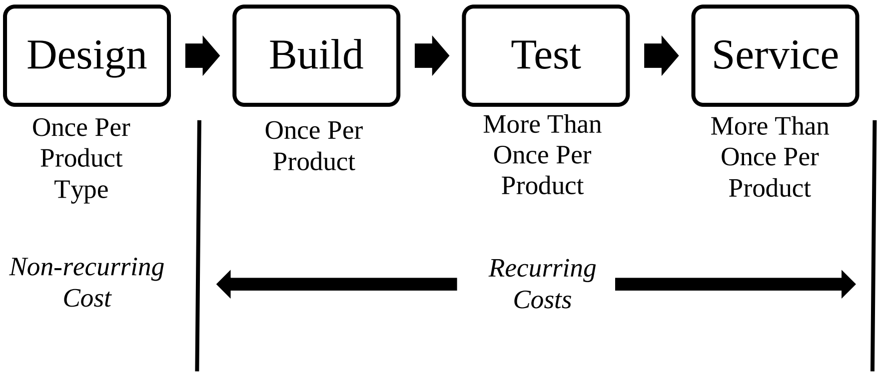

Figure 5. The four main parts of the product life cycle and the associated costs for each (adapted from Turino, 1992).

2.3.2 Elements of Concurrent Engineering

The three key elements of concurrent engineering are early involvement of key participants, a team approach and simultaneous work on different phases of development (Koufteros, Vonderembse & Doll, 2001). An effective implementation of these three key elements is required in order to reap the benefits of concurrent engineering.

Early involvement of key participants entails the involvement of participants from several different functions, such as design, production preparation, manufacturing planning and sourcing, production and marketing (Curran, Zhao & Verhagen, 2015), and is essential in order to achieve reduced lead times and capacity for improved product innovations (Koufteros et al., 2001). According to Koufteros et al. (2001), the early involvement of these participants allows them to bring attention to problems related to their specific function and provide solutions early in the product development process. Thus, potential incompatibilities between the products' characteristics and the manufacturing capabilities can be identified and in turn the need for changes to the products' characteristics later in the process is reduced. This is key, as changes to the product early in the process are easy to handle, while changes which are made later in the product development process have much greater negative effect on both the lead time and cost (Barkan, 1992).

The team approach incorporates four features which together enable the successful implementation of concurrent engineering (Wang, Yan & Ma, 2003). These four features or requirements are: cross-functional teams, team devotion to the project, flexible co-located teams or distributed teams with easy communication and empowered teams which are entitled to make decisions. Cross-functional teams, with team members from different departments, enable and simplify the communication of requirements and constraints from the different stakeholders, as explained by Zirger and Hartley (2002). The authors explain that this communication allows early identification of issues and solving of these. The benefits of this is further enhanced if the team members are located close together or have a convenient way of communicating with each other, as increased communication richness and frequency improves mutual understanding and problem solving capabilities (Rahim & Baksh, 2003; Zirger & Hartley, 2002). Accordingly, the amount of non-value adding time is increased if physically separate functions have a need to communicate (Koufteros et al., 2001). If the team members are dedicated to only one task, it increases the efficiency of the teams as the members spend more of their time on value-adding activities instead of spending time trying to relearn or familiarize themselves again, which often becomes the case when switching between projects (Zirger & Hartley, 2002). Finally, the team needs to be able to make their own decisions and have a certain degree of autonomy. Since the teams consists of stakeholders from a variety of backgrounds and have continuous communication with each other, the team is often in the best position to make decisions regarding the ongoing product development process as they can see the big picture (Gerwin & Moffat, 1997). This can reduce the development time, as no time is wasted waiting for approval (Zirger & Hartley, 2002).

The third element of concurrent engineering is simultaneous progress on different phases in the development process, i.e. a concurrent workflow (Koufteros et al., 2001). The authors explain that, since information is released to the whole team simultaneously it allows for the completion of different phases of the design to occur in parallel. This enables early identification of problems as no phase has to wait for the previous phase to be completed and thus also reduces the amount of needed reworking of the design. This overlap of work also allows for a reduction in the time to market of the product (Loch & Terwiesch, 1998). When the development phases are completed simultaneously, there are other positive effects as well, as explained by Imai, Nonaka and Takeuchi (1985). The team perceives a greater shared responsibility and therefore cooperation is improved, involvement and commitment is stimulated and more focus is placed on problem solving.

The above mentioned elements enable an implementation of concurrent engineering and the subsequent benefits, as Koufteros et al. (2001) states. They provide a possibility for ideas from different functions, such as design, production preparation and manufacturing, to be combined early in the development process and a mutual understanding for issues which arise. They empower all who are affected by the design work of the product and puts the decisions in the hands of the stakeholders with the correct knowledge. Finally, they allow for the early identification and mitigation of issues in for example manufacturability and serviceability which may arise due to the design of a product.

2.4 Change Management

Change management is aimed at ensuring successful implementation of change through supporting and guiding key stakeholders through the process (Davis & Radford, 2014). In order to achieve this Davis and Radford (2014) explain that the change management process needs to consider two main elements, communication and involvement. Two frameworks regarding change management in which these two elements are taken into consideration are the ADKAR model and Kotter’s eight step change model. These two models have both similarities and differences, and can be utilised in conjunction with each other in order to ensure a successful implementation of change. These two frameworks are presented below.

The ADKAR model for change is a framework for implementing change at an individual level with the goal to ensure the success of change implementation and consists of five elements (Hiatt, 2006). An overview of the model is shown in *Figure 6* below. The first element is to create an awareness of the need for change, why the change is necessary. The second element focuses on developing a desire for change, a willingness to support the change through intrinsic motivation. The third element is ensuring that there is enough knowledge, information, training and education available in order for the change to be implemented. The fourth element of the ADKAR model is the ability to implement required skills and behaviours. This refers to actually implementing the change and turning theory into practice. The final element of the ADKAR model is reinforcing the change, through internal and external forces which will sustain the changes made.

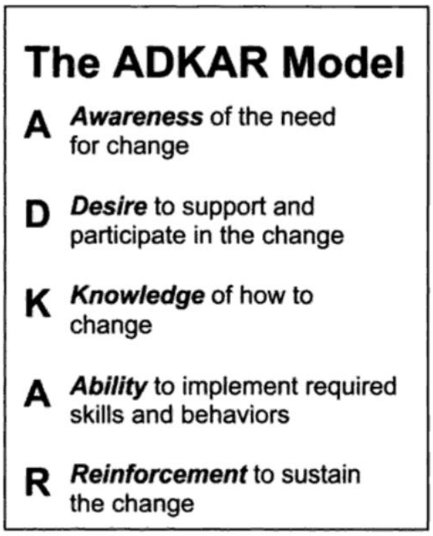

Figure 6. The ADKAR Model for change (Hiatt, 2006).

Kotter (1995) introduces an eight step model for change management, which enables a successful implementation. The first step is to create a sense of urgency, in order to create a willingness to change and cooperation toward a common goal. The second step is to form a powerful guiding coalition, by creating a group who have enough power to implement changes and guide the rest of the organization as well as encourage teamwork. The third step is to create a vision, in order to create a sense of direction and enable creation of strategies to get there. The fourth step is then to communicate this vision, to ensure that everyone is working toward the same goal. The fifth step is to empower action toward the vision, by removing barriers and allowing actual implementation of changes. The sixth step is planning for and creating short term wins, which are improvements which are noticeable and aim to keep motivation and momentum going. The seventh step is to consolidate improvements and continue producing change, which stresses the importance of not giving up once the short term wins are realised but rather to keep going. The eighth and final step is to institutionalize the new approaches, which includes changing corporate culture and structures to ensure that changes made are kept in place.

2.5 Social Sustainability

It is impossible to understate the significance of corporate social responsibility (CSR) for a company, as it not only affects the economic bottom line but also has a number of other benefits which positively correlate to a firm's competitiveness (Vogel, 2005). Social sustainability is a key part of a company's sustainable development, shapes the welfare of both internal and external stakeholders and has become instrumental for ensuring sustainable performance of companies (Awan, Kraslawski & Huiskonen, 2018). Social sustainability is the social component of employees and society which is impacted by and impacts business practices (Schönborn et al., 2019) and is critical in order to create both social and economic change (Awan et al., 2018). According to the Brundtland Commission, social and economic sustainability should be incorporated, since resources spent on social development can generate positive effects on productivity and hence economic development (WCED, 1987).

A good psychosocial work environment is required to gain social sustainable development. Rubenowitz (2004) states five dimensions of a good psychosocial work environment. The first dimension is autonomy, which refers to an individual's ability to some extent control their own work. The second dimension is a positive management relationship between different levels within the organization. The following dimension is that the individual should be stimulated from the work assignments and have opportunity to use prior knowledge and experience. The last two dimensions are a good relationship and connection with colleagues and an optimal workload, both physically and mentally. A good psychosocial work environment not only affects the social development but also positively affects productivity (Rubenowitz, 2004), and therefore has a positive impact on economic development (WCED, 1987).

Employee motivation is also an aspect that affects the productivity and quality of work within a company (Amabile, 1993). Motivation is according to Rubenowitz (2004) defined as the need and desire to reach a goal. Amabile (1993) states that motivation can be divided into extrinsic and intrinsic motivation. Intrinsic motivation is according to the author related to personal challenge, interest and enjoyment in the work, while extrinsic motivation refers to motivation from rewards, deadlines and other external motivators. Amabile (1993) further states that the two types of motivation often appear simultaneously and therefore both aspects are important to consider. Though, according to Rubenowitz (2004) intrinsic motivation is to aim for, from the perspective of both the individual and organisation. Intrinsic motivation is according to Hackman and Oldham (1980) positively affected by five motivation factors, which are skill variety, task identity, task significance, autonomy and feedback. These motivation factors in turn leads to three psychological states for the individual, which are meaningful work, experience responsibility of outcome and knowledge of results. All these states are critical to attain intrinsic motivation according to Hackman and Oldham (1980).

3. Methodology

In this chapter the methodology for this master thesis is presented. First the research strategy is introduced, followed by a more detailed explanation of the data collection and procedure for data analysis. Lastly, this chapter will present a discussion regarding the quality of research in terms of validity, reliability and objectivity.

3.1 Research Strategy

In this section the research strategy is presented, which according to Denscombe (2014) is a designed action plan for reaching a specific goal. The first part of the research strategy was a planning stage, which included working and subsequent reworking of the project's aim, research questions, outcome as well as the scope and limitations of the project. Based on this, the project moved forward to the data collection and a literature review, which gave further support as well as the academic depth needed. The collected data was analysed and connected to the reviewed literature in order for conclusions to be drawn. The main steps of the research strategy, including current status description, literature review, empirical study and data analysis, are explained in greater depth below.

After identifying the purpose, research questions and limitations of the study, a current status description was developed. To collect data about the present situation, observations were performed to receive an understanding of how the product flow is structured and identify the process steps of the product flow for Product Group A. After gaining an initial understanding of the organization and process, interviews were conducted with people in different positions to receive deeper knowledge about areas of interest and identify areas of frictions between the different functions. When data collection through observations and interviews had been performed, group discussion with employees took place to verify findings and receive input on the status description to get both a more valid and more reliable result.

Parallel to the creation of the current status description a literature review was conducted, to establish a theoretical framework for this study. The theoretical framework consists of different principles and frameworks from academic literature, which is related to the subject of flow performance and organizational processes. The literature review was to some extent dependent on the findings in observations and interviews, in order to incorporate an academic perspective on the product flow processes. To receive a broader view of the area of study, an empirical study was conducted. By visiting other companies and studying how product flow and processes related to the industrialisation function were structured, ideas and knowledge was extracted about principles and ways of working. After developing the current status description and conducting a literature review and an empirical study, an analysis was performed with the purpose to identify areas of friction and finally generate suggestions for improvement. Group discussions were held during this phase to enable employee involvement and opportunity for clarification and validation.

3.2 Data Collection

The data collection in this thesis included five different methods; observations, interviews, group discussions, literature review and an empirical study. The different areas of data collection will be presented in this section, followed by the course of action regarding the analysis of collected data.

3.2.1 Observations and Field Notes

The first step in the data collection was to understand the product flow for Product Group A. According to Walshe, Ewing and Griffiths (2012), observations are a useful qualitative data collection method when it comes to understanding roles, actions and behaviours. Therefore, observations was used as a starting point for the mapping of the product flow. However, as Phillips and Stawarski (2008) explain, in order for the observations to be effective, five criteria should be fulfilled. The first criteria is that the observations should be systematic, which means that the observations must be planned out, with individuals being observed understanding the aim of the observations. The second criteria is that the observers should be knowledgeable and therefore be able to interpret the different actions that take place. Following this, the third criteria is that the observer's presence should be minimized so as to decrease the risk of influence. The fourth criteria is that the observers should be selected with care, to balance objectivity and cost. Finally, the fifth criteria is that the observed must be well prepared, and understand the reasoning behind the observations taking place. These criteria were taken into consideration when the observations were conducted for this thesis, through for example prior and continuous communication with production managers, line managers and production operators. Observations were conducted parallel with other activities for about six weeks. In combination with the observations, field notes were taken. As described by Phillippi and Lauderdale (2018), these gave context to the study object and set interview and observation subjects in a wider perspective. The field notes can also be utilised during the analysis in order to give further details (Phillippi & Lauderdale, 2018), which was the case in this thesis.

3.2.2 Interviews

Qualitative data was collected through interviews, after an overall understanding of the product flow for Product Group A was gained through primarily observations. By conducting interviews primary data was collected, which is data collected for the current study (Björklund & Paulsson, 2014). The form of semi-structured interviews was used, where a predefined number of questions and issues are prepared but depending on the interview situation the order of questions can alternate and follow-up questions can be added (Denscombe, 2014). Answers from semi-structured interviews result in a combination of both fixed and open-ended answers (Lantz, 2007), which were required in this study.

Interviews were held with individuals in different roles and functions within the organization, to receive a holistic perspective and avoid bias from a specific function. An interview form was created in advance and revised depending on which role and function the interviewee had, see *Appendix A*. The interviews were conducted by two persons, where one had the lead role as an interviewer and the other took notes. According to Voss, Tsikriktsis and Frohlich (2002) by conducting interviews in pairs, the possibility for consistency throughout the interview process increases. A pilot interview was also held to test and verify interview questions. After the pilot interview, employees from different functions and positions were interviewed. In total 23 interviews were held and the distribution of interviews is shown below in *Table 1*.

Table 1. Number of interviews held per function

Function	Quantity
Design	4
Industrialisation	6
Production	9
Managers	4
Total	**23**

In conjunction with the semi-structured interviews, informal interviews were also held continuously with all functions, including a product planner, to increase knowledge of specific processes in the product flow. An informal interview takes places when the interviewer takes a more active role in a discussion and dialogue with the respondent (Dingwall, 1997), and were held in order to supplement the collected data.

3.2.3 Group Discussions

Once a preliminary status description of the product flow was established, group discussions were used to give further depth to the description as well as act as a check to ensure data accuracy. This is because, as stated by Payne and Payne (2004), group discussions can give information about the participants underlying opinions, as well as an understanding of their views on ideas presented and any concerns regarding these. The groups were composed of individuals with a connection to the product flow, but from several different departments and positions with different perspectives on the product flow, in a similar fashion as the interviews, which according Payne and Payne (2004) allows for a capture of different opinions. Another benefit of utilizing group discussions is that it allows the most important issues from the participants to be identified (Gugglberger, Adamowitsch, Teutsch, Felder-Puig & Dür, 2015). In this way, any eventual misinterpretations or errors could be identified early, as well as ideas regarding the problem identification could be generated.

Related to the current status description, one group discussion was held with team members from the industrialisation team to verify the visualized product flow, which resulted in an iterative communication process until the product flow was deemed completed. Three group discussions regarding identified areas of friction were also held with stakeholders from several functions, with the purpose to receive feedback and ensure that key areas were captured. The areas of friction were presented and a following discussion was held. Furthermore, the group discussions gave insight on how the different problems areas was perceived by employees from different functions as well as thoughts on suggested improvements were captured. To gain a broader perspective on the areas of friction and ensure validity, a survey was created where respondents could evaluate the magnitude of the problems. The survey was sent to 25 employees within the design, industrialisation and production functions and the respondent rate was 56%.

3.2.4 Literature Review

A literature review was conducted in order to create an academic foundation and to establish a theoretical framework for this master thesis. Literature was explored continuously, since the establishment of the theoretical framework was an iterative process. The procedure was to search for literature in several databases, using keywords such as “production preparation”, “process variation”, “lean” and “flow efficiency”, to find relevant literature within the subject of this study. An additionally search strategy was to explore interesting and relevant references of examined literature, to obtain a width and depth in the used literature and also to verify findings. Since collected data through literature reviews is secondary, Björklund and Paulsson (2014) points out the importance to be conscious of the risk for information bias, since the data is produced for a specific purpose. To avoid information bias, several sources within a specific area of research were therefore used in this thesis.

3.2.5 Company Data

Secondary data in terms of existing data from the company was collected from the company’s management systems as well as the company’s ERP system. This data includes for example descriptions of processes, working procedures, roles and methods. The data gave an overview of the organization and current status from the perspective of the company. It was therefore a valuable data source for the current status description in this thesis. Other relevant data from the ERP system such as production times and amount of non-conformance reports was extracted to quantify the current status description. The data was based on statistics from 2019 and specific product sets were used as a sample.

3.2.6 Empirical Study

To receive a broader perspective of the subject of this thesis, an empirical study was conducted. This entailed study visits and interviews at two other companies, which have manufacturing with high variation and customization. During the two study visits the involved companies presented their way of working regarding the interface between design and manufacturing and follow-up questions were asked.

The purpose of an empirical study was to receive inspiration of how manufacturing processes can be structured and also identify best practices within the subject. Findings from the empirical study gave the analysis of this thesis a broader perspective, which has a positive impact of the quality of recommendations.

3.3 Analysis of Data

After all data was collected, an analysis was initiated. According to Björklund and Paulsson (2014) this implies an analysis of the empirical data based on a theoretical framework. When all data was collected, the data was structured, reduced and summarized. Patterns and connections was identified, in order to find any relationships between the data. Findings from the data collection and the empirical study was analysed and connected to frameworks and principles from the established theoretical framework of this thesis. The outcome from the analysis were areas of improvements and suggested improvements connected to appropriate principles, which can be applied in order to increase performance of the product flow.

3.4 Quality of Research

The credibility of a study is affected by its reliability, validity and objectivity (Björklund & Paulsson, 2014) and were therefore factors that needed to be taken into consideration in all stages of this thesis. Reliability is a measurement of stability, meaning that a replication of the study should generate the same result and validity refers to the study's ability to measure the right thing (Björklund & Paulsson, 2014). If reliability is absent, validity is unreachable; however, a high reliability does not assure a high validity (Bell, 2006). Hence, reliability and validity are interconnected and both aspects were therefore essential for this thesis. Objectivity is according to Björklund and Paulsson (2014) the influence and impact of personal values on the result of the study.

To increase the reliability in this study, triangulation was used. Triangulation increases the reliability since a specific phenomenon is investigated from several different perspectives (Björklund & Paulsson, 2014; Voss et al., 2002). In this study both observations, interviews and group discussions are part of the methodology, resulting in a reliable current status description since it was examined from different perspectives. Also, by including all affected functions in relation to the product flow, reliability increases due to the different perspectives on the product flow. Further, triangulation was applied in the literature review, where different sources were examined, resulting in a diversified bibliography. According to Denscombe (2014) this method of triangulation is called theory triangulation. As stated, multiple interviewers was present when conducting interviews, which according to Voss et al. (2002) strengthens the reliability in terms of inter-rater reliability. More specific, inter-rater reliability is defined as the degree of agreement in the interpretation of data (Voss et al. 2002), hence conducting interviews in pairs generated a more valid and reliable data outcome from the interviews in this study. Notes were taken during interviews, but tape-recording was not utilized. This can have a negative effect on the reliability. As objective data was the focus during interviews in this study, taping was not conducted, since the taping benefits are reduced (Voss et al., 2002).

Voss et al. (2002) argue that triangulation also has a positive impact on the validity, hence usage of triangulation strengthens the validity of this thesis. Additionally, to increase validity, concise and explicit question should be used in interviews (Björklund & Paulsson, 2014). Therefore, to strengthen the validity in this study, interview questions were tested and reviewed prior to the interview process through a pilot interview. This was done in order to ensure the understanding of the questions and verify that the questions covered the areas of interest, so that the right data was captured and measured. Furthermore, findings and data were presented and discussed with a team leader at the DSC to verify findings and clarify areas of uncertainty, which according to Denscombe (2014) is termed respondent validation and strengthens the validity of a study.

The objectivity of a study is increased if the different courses of action taken and choices made are motivated as well as clarified (Björklund & Paulsson, 2014). This is ensured in this thesis through a detailed methodology chapter and usage of anchoring literature. Voss et al. (2002) argues that students can have personal bias in relation to subject of study, which can result in observer bias and therefore affect the objectivity in a negative way. A way of counteracting this is usage of multiple interviewers (Voss et al., 2002), which was applied in this thesis. Further, the authors of this master thesis have a diversified background in terms different areas of study, which can have a positive impact on the objectivity and strengthen the total quality of research.

4. Current State Description

In this chapter a current state description of the product flow for Product Group A, consisting of three parts, will be presented. The first part is a description of the three main functions of the product flow; design, industrialisation and production. In addition the function projects and planning is described, since this function is related to the product flow. The second part of this chapter will describe the structure of the flow both within and between the different functions of the product flow, detailing how the processes of each function interact. The third part of this chapter describes planning and control activities which occur between the different functions of the product flow for Product Group A, in order to further describe the interaction of the processes.

4.1 Function Description

In this section the functions within the product flow for Product Group A are examined, which are design, industrialisation, production and projects and planning. The formal organizational structure over involved functions in this thesis is illustrated in *Figure 7*.

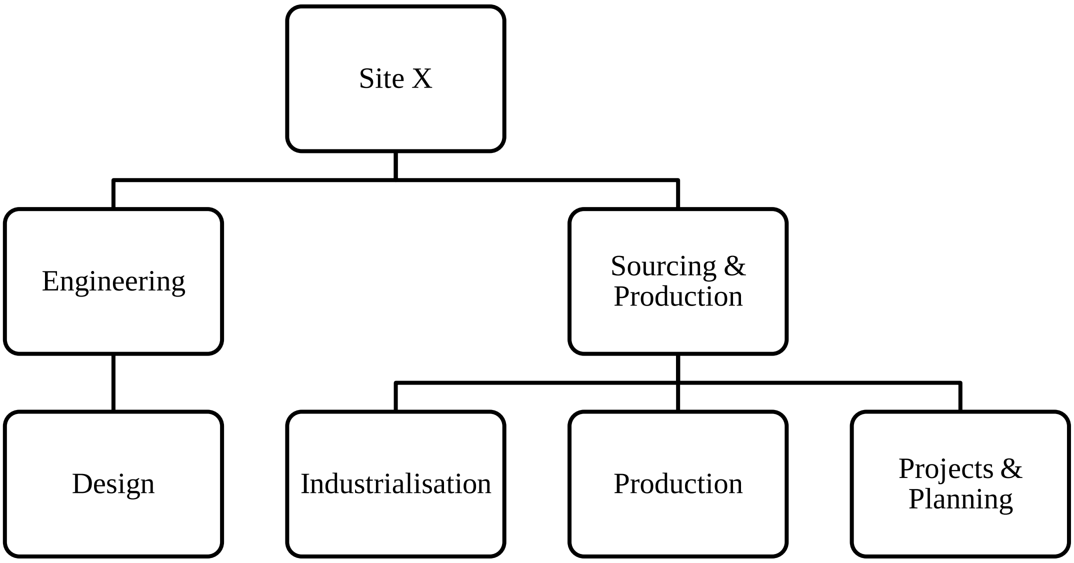

Figure 7. Illustration of the organisational structure.

The industrialisation, production and projects and planning functions are part of the Sourcing & Production Department, while the design function is a part of the Engineering Department, which are separate in the organization. Most of the horizontal communication between the functions occurs directly between employees, however some formal meetings also take place. The different departments are located on different floors at the site, and therefore the communication most often occurs over email, instant messaging or telephone. The goals and purposes of each function are described below.

4.1.1 Design Function

The main purpose of the design function is to convert customer requirements into a product design. This results in design documents from which the product can be produced and delivered to customers. The design function works both with new product development and revisions of current products. The design team divides each product into a specific set of materials. Depending on the degree of complexity of the product a digital visual model may be created as well. The design function is responsible for ensuring that the product meets customers' requirements, with respect to function, materials and quality.

4.1.2 Industrialisation Function

The goals of the industrialisation function is to ensure manufacturability of products, prepare and verify production operations and support production. The industrialisation function has three main categories of assignments, which are defined as projects, production support and continuous improvements.

Assignments within the project category aim to review product designs through a design review and prepare products for full scale production through a production preparation activity. The design review is a first check of the preliminary design documents. The aim is to check that the product can be manufactured based on the preliminary design documents received. In other words, check for manufacturability. Furthermore, this is an opportunity for the industrialisation team to suggest standardized parts and possible modularisation. The production preparation consists of several activities and is done in order to enable production of the product. The bill-of-materials (BOM) for the product is analysed and evaluated so all required material is included, the required time for assembly is defined through routings, labels and markings are prepared and assembly instructions as well as work guidelines for production operators are created if needed. These activities are proactive, as potential problems are identified and eliminated before the product is put into full scale production, in order to minimize the risk of issues arising in later steps.

The support category of the industrialisation function is aimed to ensure that the production processes occur with minimal disturbances. This includes handling of problems that arise during production and support the production operators in their work. The third category of the industrialisation function's assignments, continuous improvement, entails improvement work within the industrialisation team and function. This category exists with the purpose to increase knowledge within the team and to develop and improve the work process with the goal to increase the functions performance. This can for example include developing methods and tools that ease and streamline the teams work or increase knowledge through training and education. The continuous improvement also includes work to continuously improve the production process, by analysing the assembly or production processes in order to identify areas of improvement.

4.1.3 Production Function

The production function is responsible for the manufacturing of Product Group A, where the ingoing material are assembled into a product. The production is a form of craftsmanship, where production operators assemble the products by hand, based on assembly instructions. The operators work is divided into shop orders and the required materials, which are specified in the BOM, arrive in the production pre-picked. Another part of the production function is the quality check, where the assembled product is checked both visually and functionally to ensure that sufficient quality has been achieved.

4.1.4 Projects and Planning Function

The projects and planning function has the responsibility to ensure that all required activities are performed in order to meet project and customer delivery deadlines. A product planner has ownership of specific product sets and handles the transition of product sets between the departments. The product planner has the role of scheduling the industrialisation and production activities for products. The product planner is a part of an overall project team with a project manager.

4.2 Product Flow Description

In the section below the product flow for Product Group A will be described. The products of Product Group A are produced in product sets, containing approximately 20-80 products each. Each product in the product set goes through the flows described individually. The product flow can be categorized in two types, depending on what type of product set is being produced. If the product set is completely new, this results in one type of product flow. The other type occurs when producing a previously produced product set. During the study period for this thesis, the amount of products classified as new was 36% and previously produced products were 64%, shown in *Figure 8*. These two types of product flows have different processes related to their production, and therefore the description of the product flows will be separated into the flow for new products and the flow for previously produced products.

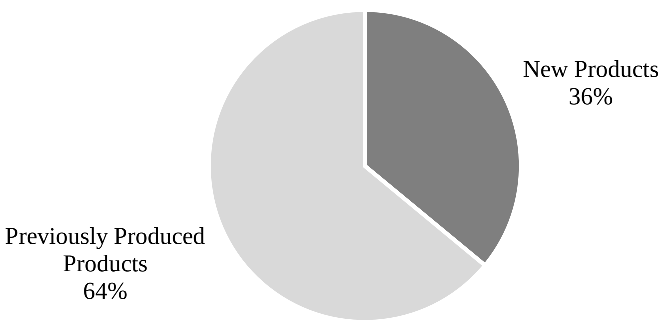

Figure 8. Division of new and previously produced products.

The main difference between the new product flow and the previously produced product flow is that new products go through what is known as a hardware review (HWR) process. This process is done in conjunction with the first production run of a product, to identify and solve problems associated with first time production. As a part of this process an HWR protocol is created for each new product set, which is a joint protocol for design, industrialisation and production functions.

However, there are similarities between the two product flows. For example, both flows pass through the same production area and workstations. Also, the assembly is conducted by the same operators irrespective of product flow type. Another common theme between both types of product flow is that, while seemingly streamlined, they seldom flow smoothly. Rather, the flow is often recursive and goes through the same process at the same function more than once. The product flows are described in depth below and are visualized in *Appendix B* and *Appendix C*.

4.2.1 New Product Flow Description

In this thesis the flow for new products is divided up into two phases, the design review phase and the hardware review phase. The transition between these phases occurs via a product planner, who has the responsibility to plan the production of product sets and reserve required material in order to meet delivery deadlines. The product flow is visualised in *Figure 9*, as well as in *Appendix B* in a larger format.

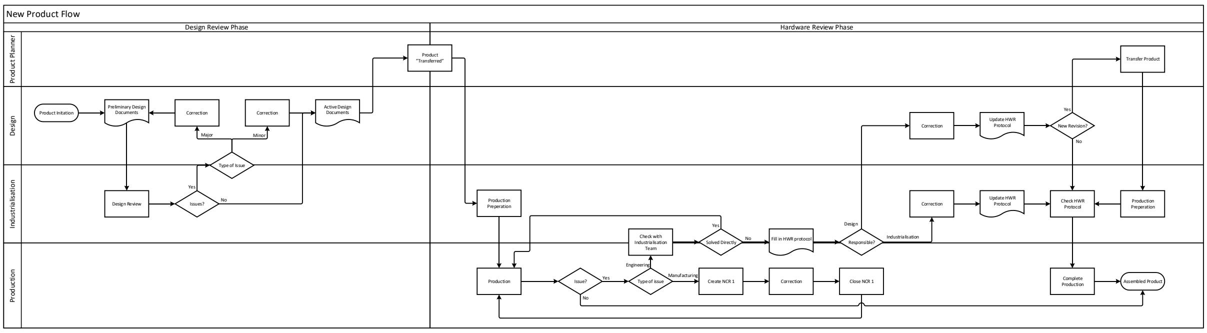

Figure 9. The product flow for new products.

The design review phase starts when the preliminary design documents, including the product BOM, have been created by the design function. These documents define the product design and specifications. Following this, a request for a design review is sent through email to the industrialisation team. The industrialisation team then complete a design review in order to assure manufacturability and look for standardisation opportunities. However, in practice, time is spent mainly on double checking the contents of the BOM instead. If issues are discovered they are sent back by email, along with any eventual recommendations, to the design department. If the issues raised by the industrialisation team are of a more encompassing nature, the preliminary design documents are updated and the process is repeated. If the issues raised are deemed minor, or are non-existent, the product design documents are switched from preliminary to active by the design team, which means that the product planner can start planning for the required material and for production to occur. This marks the end of the design review phase. In tandem with this, and once all products of the product set have passed the design review phase, an HWR protocol is created and an HWR start meeting is held, where responsible stakeholders from design, industrialisation and production meet. The HWR protocol is utilised in the next phase of the product flow, the hardware review phase, in order to collect identified issues which arise during production.

The first step of the hardware review phase is that the product planners sends a request for a production preparation to the industrialisation team via email. This preparation consists of several parts, including nomination of responsible production engineer from the industrialisation team, creation of assembly instructions, preparation of labels and markings and an estimation for the amount of time needed in production. When this preparation is done, the product can be planned into production. Production is initiated through shop orders. The operators select a shop order from the order que and start the assembly process. If no issues arise during the assembly process, the product is manufactured according to the production plan and the product is completed.

If the operator perceives an issue during the production stage, the first step is to classify the issue. The issues which may occur can be divided into two categories, manufacturing issues or engineering issues. Manufacturing issues include two sub-categories, picking errors or installation errors. Picking errors is when material received from stock is incorrect and installation error is when the operator themselves have created the error though a mistake in their work. These manufacturing issues are handled by the operator themselves. The first step is that they create a non-conformance report (NCR), which describes the error. This error is connected to the shop order which the operator is working on and is known as NCR 1. The operator then solves the issue, for example by ordering a replacement part from stock. This action is recorded in the NCR 1, and once this is done the NCR 1 can be closed. The NCR 1 has to be closed before the order can be completed, in order to ensure that no defective products are delivered.

If an issue is not a manufacturing issue it is classified as an engineering issue. Engineering issues cover a much wider spectrum of issues, but can generally be divided into two main categories; production preparation error, where the preparation done before production is incomplete or incorrect, and design error, where the design work done on the product is incomplete or incorrect. If during the assembly process, the operator encounters what they believe to be an engineering issue, they should contact the industrialisation team. A joint decision is then taken regarding if the issue can be mitigated easily and directly, or if it should be entered into the previously mentioned HWR protocol. The issues entered into the protocol can include for example incorrect amount of material in the BOM, incorrect assembly instructions or insufficient work guidelines. Based on company data, approximate 40% of the products in a product set suffer from an engineering issue during the first production run which requires corrective action. For these products the throughput time through the flow is tripled, on average.

The issues in the HWR protocol are checked and solved by either the industrialisation team or by the design team, depending on the type of issue. On average, 96% of the issues are the responsibility of the design team. The HWR protocol is then updated with the action which was completed. In 64% of cases, the design team creates an updated revision as part of the correction. In these cases the product planner must transfer the new documents into the production system and a new production preparation for the product must be completed by the industrialisation team. This is due to the fact that the product has been updated which means that there may be a need for updated manufacturing instructions, labels, markings or production timings. Once all points have been handled each point is checked again by the industrialisation team. This is done in order to confirm that all needed corrections have been made. When this is done any remaining production can be completed, the product can be deemed assembled and the product flow is completed for the individual product.

When all products in the product set have been assembled, a HWR closing meeting is held. During this meeting the points collected through the HWR protocol are discussed together with the responsible stakeholders from both design and industrialisation functions as well as the production manager. In addition, a set of standardised questions are answered in order to check that all necessary activities have been completed. Once parties are in agreement, the HWR process is completed and all documents are ensured to be up to date, so the next time the part is manufactured there will be no issues.

4.2.2 Previously Produced Product Flow Description

Once a product has passed through the above described new product flow and been successfully manufactured, no engineering issues should arise in subsequent production runs. Therefore, the product should be able to be planned, produced and tested without involvement of the industrialisation or design teams. This is however seldom the case, as even though the product has undergone the HWR process, issues still arise during the following production process. For 60% of all products an issue is identified.

The previously produced product flow, which is visualised in *Figure 10* as well as in *Appendix C*, starts when the assembly operator picks an order from the order queue. As for new products, the operator assembles the product according to the available assembly instructions and work guidelines. Assuming no issues are encountered during assembly, the assembled product is sent for quality checking. Here, a visual and functional quality inspection is completed. If no issues are found, the product is completed. However, if an error is discovered during the quality check, the same process is followed as if a manufacturing issues is identified in the new product flow. This includes the creation of an NCR 1, the operator themselves correct the error and subsequently closing of the NCR 1. However, issues arise during the assembly process. As in the new product flow, the issues are classified as either manufacturing issues or engineering issues. If the issue is classified as a manufacturing issue, the same process for handling errors as when the quality check finds an error is followed, including the creation of an NCR 1, the operator themselves fixing the issue and closing the NCR 1. The assembly process can then continue. Of all products, 35% generate an NCR 1 caused by a manufacturing issue, either during the assembly stage or in the quality check.

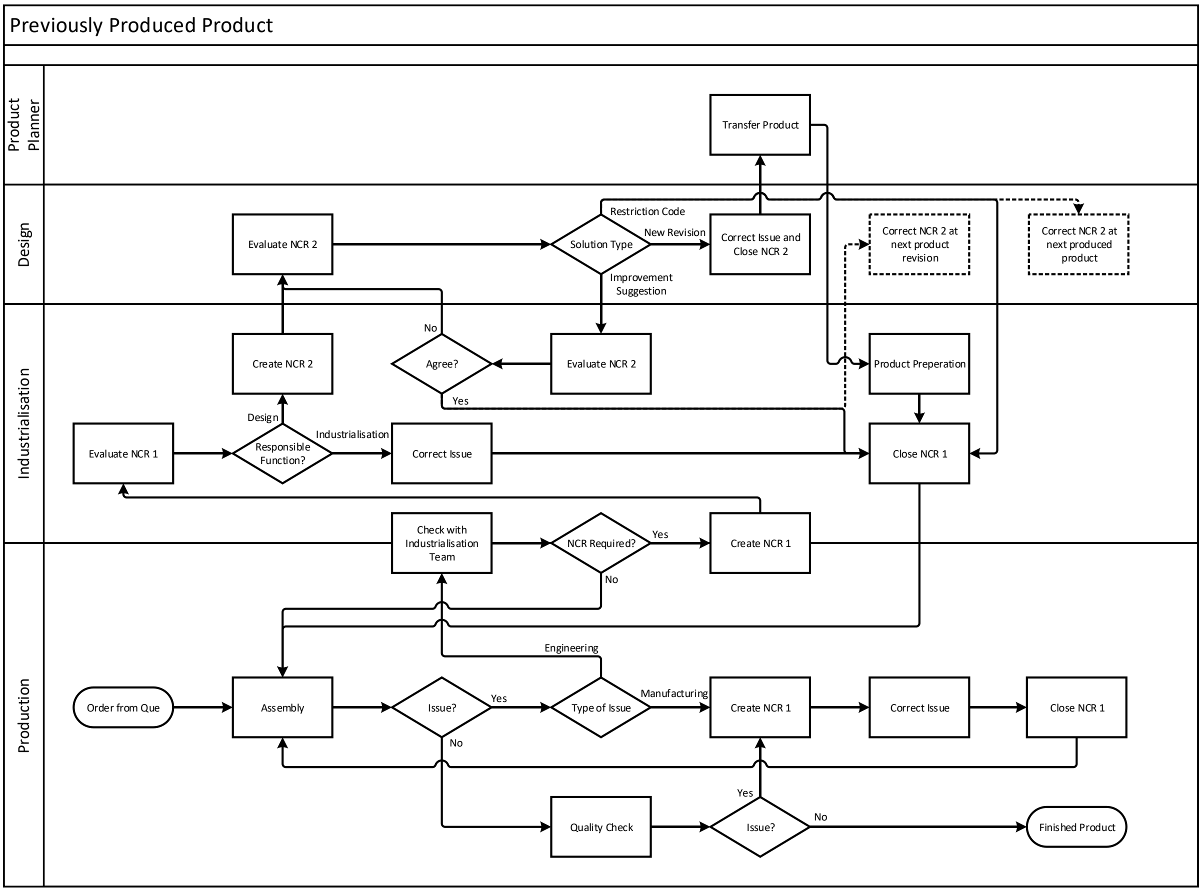

Figure 10. The product flow for previously produced products.

If the issue is classified as an engineering issue, the operator contacts the industrialisation team. This occurs in 25% of all shop orders. If the issue is easy to mitigate, no NCR is required. Instead the industrialisation team solve the issue directly in conjunction with the operator and assembly can continue. However, if the issue is more complex an NCR is required and therefore an NCR 1 is created. Due to this, combined with the waiting times associated with the error handling process, often the affected shop order is placed on hold while the operator starts and continues with other shop orders. The industrialisation team analyse the NCR 1 in order to understand the error and decide which function is responsible. If the issue is related to the industrialisation team's responsibilities, such as for production preparation errors, the team takes appropriate action in order to solve the issue, and then close the NCR 1. If solving the issue is the responsibility of the design function, such as for parts missing in the BOM, a second NCR known as NCR 2 is created. In combination with this the industrialisation team also contact the design manager through email to notify that an NCR 2 has been created. This occurs for 29% of all engineering issues, which corresponds to 7% of all products that enter the product flow. Solving and closing the NCR 2 is the responsibility of the design team. However, the NCR 1 is not closed by the industrialisation team and assembly does not continue until a response on the NCR 2 has been received from the design team, which means that the product cannot be completed until this is done.

The solution to the NCR 2 can be divided into three categories; placing a restriction code on the product, creating a new product revision or issuing an improvement suggestion. If a restriction code is placed, a specific solution for the shop order is created with no implementation of a long term solution. However, the next time the product is to be produced, a long term solution must be in place in order for production to be initiated. If a restriction code is placed by the design function, the industrialisation team in collaboration with the design team implement a product specific solution for the issue. This solution enables the operator to finish assembly of a product that has an implemented solution, while the restriction code ensures that next time the product is to be produced a permanent solution will be in place. Therefore the NCR 1 can be closed and assembly completed.

If the solution from the design team instead results in a new product revision, the design team need to create new design documents, the product planner needs to transfer the design documents into the production system and the industrialisation team need to complete a new production preparation. This is due to the fact that a new product revision entails a significant change to the product and often also a new BOM. This is seen as a long term solution. Therefore the industrialisation team can implement this solution for the NCR 1 as well and subsequently close it. Once both the NCR 1 and 2 are solved and closed, the assembly process can be completed.

The third option that the design team has is to classify the issue as an improvement suggestion, which as for the restriction code, means that no long term solution is created directly. Rather, the long term solution is implemented at the next product revision. This means that the product may be produced again without the improvement implemented, as a new product revision is not always done prior to producing a product. Therefore the industrialisation team evaluates if they agree with classification of the issue as an improvement suggestion. If they do not, they have to contact the design department again who again have to evaluate the NCR 2. They may decide to change the type of solution, which then follows the previously mentioned processes. However, if they still perceive the issue as an improvement suggestion, then the industrialisation team evaluate this decision again. This processes may be repeated several times, until either design select another solution or the industrialisation team agree on the decision of an improvement suggestion. If this is the case, the industrialisation team, as with for the restriction coding, implement a solution in tandem with the design team for the product being produced and the NCR 1 can be closed.

When issues arise during production and NCRs are created, it has a negative effect on the products throughput time through the product flow. Depending on the type of issue, the impact can vary. If the issue is classified as an engineering issue and an NCR 1 is created, the result is a doubling of the throughput time. If the issue is further classified as the responsibility of the design function, the total throughput time is 2.6 times greater than if no engineering issue were to arise. This is visualised in *Figure 11* below.

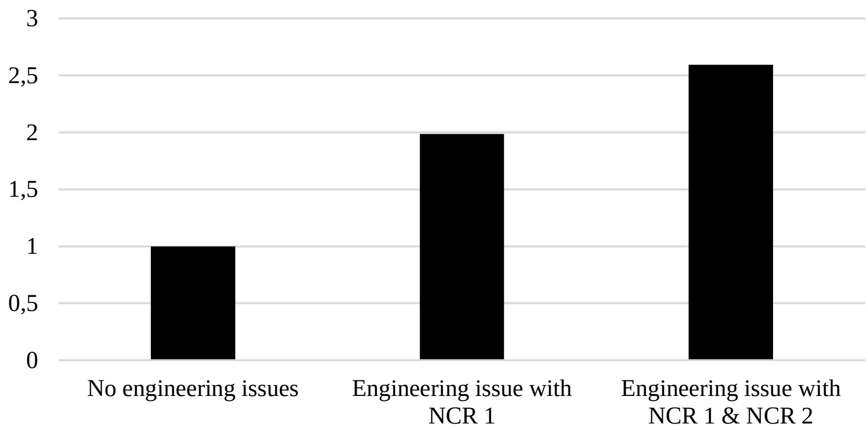

Figure 11. The effect of engineering issues on throughput time.

4.3 Planning and Control

To connect and control the functions involved in the product flow, several planning and control activities takes place, which are presented in this section. First the planning of the product flow will be explained, followed by an explanation of the control activities. Afterwards information is presented about how communication occurs between the functions, both in terms of formal and informal communication.

4.3.1 Planning

The planning of the industrialisation and production function is done in conjunction with each other, in a planning schedule consisting of three weeks sprints. This means that production and industrialisation commitments are divided into batches which run three weeks at a time. Since industrialisation processes occur prior to production processes, three weeks before production start of the specific upcoming production sprint the industrialisation team have to confirm that required industrialisation commitments can be completed, which is done at the I0 meeting. The week after, two weeks before production start, needed material is checked and reserved in an M0 activity. The week before production starts, production stakeholders have a meeting to assure needed capacity and allocate resources in a proper way, known as P0. This is illustrated in *Figure 12*.

Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Sprint 1	I0	M0	P0	Production sprint					
Sprint 2				I0	M0	P0	Production sprint		

Figure 12. Illustration of planning schedule for industrialisation and production functions.

The planning is not synchronized to the current state and actual production rate in the past. Lately, the production has not managed to produce in accordance with the set plan due to problems in production. The amount of back orders are therefore approximately one sprint. This has resulted in that the actual production only consisting of back orders, following a first in first out approach, while the planned production is pushed forward to the next sprint as back orders. The industrialisation assignments however have been able to follow the planned sprints and therefore have no back orders. Industrialisation commitments are subsequently one sprint ahead compared to actual production.

The planning activity for the design function is separated from the industrialisation and production function. The design function’s work is similar divided in sprints, where the assigned activities are managed within the specific teams. These sprints do not correlate to the industrialisation and production sprints. Prioritization for the design function’s sprint is decided on a project level. The design teams work towards set deadlines, when specific design assignments needs to be completed.

4.3.2 Control

Control of the different functions is managed separately by the respective function and is therefore not centralized nor synchronized. The production function is controlled through a physical production board, where the status of current orders is visualised. The status of orders at the production board are divided up into different categories: incoming orders waiting for production start, ongoing shop orders currently being assembled, shop orders waiting for inspection, ongoing orders being inspected and shop orders that have been stopped in production. The operators should, when starting a new order, take the first order in the list. However, in practice the operators choose an order that they are comfortable with and is in relation to their experience. This is since no formal education is conducted and the operators instead develop their experience and knowledge over time through assembling orders. No formal daily control meetings are held, instead a production manager takes an informal tour in the production and talks to every operator individually to check the status. Additionally, continuous improvement meetings are held in the production area once a week.

The industrialisation team have internal meetings, handled by the team leader, where the status of the team is analysed and managed. The industrialisation team also have a common email inbox, where the design team and product planner send requests on design reviews and production preparations. It is the responsibility of each team member in the industrialisation to be updated on the mailbox and complete errands in the inbox buffer, with support from the team leader. The production support role of the industrialisation does not have a specific control activity, instead operators contact the industrialisation team through email or telephone to ask for help when needed, which often results in a meeting in the production area.

4.3.3 Formal Communication

Formal communication occurs between the different functions through some daily and weekly meetings, both to synchronize the planning and solve problems that arise in the product flow. The meetings Guldgruvan, Andon and HWR will be presented in this section.

Daily control meetings are held every morning, specified as Guldgruvan, where managers from production, industrialisation, production planning and material supply are present. The ongoing production sprint is followed up, to see if the production rate meets the plan. During this meeting problems within the production are also communicated to all participants, so all functions get insight in the production status. Solutions on upcoming problems can be solved commonly or the responsibility can be delegated to the affected department. Further, resources can be reallocated if needed within the organization to solve short term capacity problems.

A meeting called Andon is held every afternoon with industrialisation team members, purchasers and engineers from the design function. This meeting serves the purpose of lifting critical issues that are in need of a quick solution, since the issues can stop the production or delay the delivery. Issues handled through the Andon forum only consider previously produced products. Furthermore, not all product groups are handled through these meetings, and Product Group A is a notable example.

Within the HWR process meetings are held to initiate and terminate the process, as previously mentioned. Affected members from design, industrialisation and production functions have an initial meeting to start the HWR process and also to examine the process in an end meeting, to decide if the HWR process can be considered complete. In some cases a status meeting can be held with affected persons during the process, but this is something the included persons decides on and initiates.

4.3.4 Informal Communication

Informal communication occurs through several channels, as email, instant messaging and informal meetings. Since the different departments are not co-located at the site, email and phone is a big part of the communication between the functions. Time for response on emails is often long and the amount of emails is large. Occasionally long email conversations ends up with a planned meeting, to gain faster and clearer communication between employees from the different functions. Furthermore, informal meetings are held sporadically with people from different functions. When team members from the industrialisation team are present in production, operators frequently ask questions or lift problems that have arisen. Also informal meetings are held with persons from design and industrialisation functions, where product designs and other relevant problems are discussed. These informal meetings increase the communication between the functions and often occurs due to a hurry for products to be completed.

5. Empirical Study

In this chapter the empirical study will be presented. Visits have been performed at two companies, company X and Y, with similar operation characteristics to the company studied in this thesis. The visits were conducted in order to investigate the industrialisation process in other companies. A description of how the two companies handle the interface between design and manufacturing as well as how production preparation is completed is presented below.

5.1 Company X

Company X is a business to business manufacturing company which offers customized products. In order to handle demand variation, a modularization strategy has been applied. The products company X develops are based on customer requirements and are created by combining different modules into a customized product. Further, company X can meet more specific customer requirements through modification of the existing modules. At company X the product development process consists of four main phases: a planning phase, study phase, development phase and production phase. Between all phases there are stage-gates present. These include a set of requirements, stated as checklists, which need to be met in order for the product develop process to progress forward. One extra important stage-gate is the transfer from development phase to production phase, according to the industrialisation manager of company X. This is due to the fact that in this stage the product design should be finalized and ready to enter the production phase. It is therefore of highest importance to ensure that the product design is completed, to provide the prerequisite for a smooth production start-up. These stage-gates occur throughout the process in order for progress to be reviewed early and halted if any uncertainty exists to ensure quality. The industrialisation function enters the process in the study phase, hence get involved early, with the goal of ensuring manufacturability. In the study phase, prototypes are generally built, giving a practical anchor for the process.

To synchronize the different departments during the product development process, work is conducted in projects with multifunctional teams. Each team consists of a project leader and employees from all involved functions with responsibility for one specific project. The team work close together and project meetings are held periodically, with both weekly scheduled team meetings as well as additional meetings which occur when the need arises. This results in effective communication between the stakeholders from the different functions and subsequently improves the product development process, since the perspectives of the different functions are taken into consideration throughout the process. All activities which need to be completed during the product development process are visualised in a project plan divided up in the different phases, where the responsibilities of each function are clearly stated. This simplifies the synchronization of the project. To ensure all project activities are conducted, checklists over all the steps of the process are used, to ensure the completion of all necessary activities.

Checklists are also applied during training and education, both to reach higher quality but also to attain standardised education for all employees.

The industrialisation function at company X is divided into two groups, one which focuses on new product development and one which focuses on production support. The group who work with product development are a part of the above mentioned multifunctional teams and are involved early in the process to ensure manufacturability. The group members who focus on production support continuously improve the production area, ensure documents are in place and are responsible for education related to the industrialisation processes. Every morning, meetings are held with both groups from the industrialisation function, which give an opportunity to share experiences and support each other.

On the production floor a team leader is present, who supports the operators and is an extra resource if any issues arise. Every workstation also has a light indicator which shows how the production process is proceeding. The light indicates if problems occurs at a specific workstation and if support is required from the team leader. This enables quick response and solving of the problem which minimizes non-value adding time. In addition, digital visual boards of the production progress and goals are present throughout the production area, which informs employees about the current status in the production. By visualizing the production situation all employees get an understanding of the situation and sources of failure, which need to be corrected. Furthermore, all production employees have the opportunity to suggest improvements in the production. These improvements can either be handled by themselves or by the industrialisation team in their role as production support.

Company X earlier struggled with production problems as result of inefficient development work and collaboration, which led to rework. Over several years company X has improved the way of working, redesigned the product development process and reallocated time to earlier stages in the process. This has decreased the number of problems that arise during the production phase. By reallocating time to the initial stages and increasing the collaboration between the functions, the process have become better with less issues and reduced amount of rework in production. One success factor for an improved product development process for company X, according the industrialisation manager, is that the requirements between the design and industrialisation functions are clearly defined. The industrialisation have set certain specific requirements which the design department earlier have defined as standards to ease their own work. Through clearly defined requirements each function is aware of their responsibilities and what has to be done in order to fulfil the project demands. Furthermore, usage of digital models has simplified communication between the functions and improved quality of designs. Another success factor, raised by the industrialisation manager is a change in culture. A culture of working proactive and spending more time early in the process needs to be in place to empower improvement.

5.2 Company Y

Company Y is an industrial company with in-house manufacturing in a business to business market. The products have a high degree of customization for each order, while volume is relatively low, which makes company Y suitable to study in this thesis. Company Y is a very customer oriented company and therefore flexibility is of highest importance. This is in order to handle the variations of products and volumes in a competitive way.

The product development work follows a company specific development model, with different phases and defined stage-gates. The functions of design, industrialisation, purchasing and the customer service are included in all phases, to ensure important aspects from different perspectives are taken into consideration from start. For continuation to the following phase a stage-gate needs to be passed, which verifies that the required outcomes have been reached in the associated phase. This means that all involved functions needs to have completed a set of specified assignments. Each functions' responsibilities and commitments for the different phases are clearly stated both through the stage-gates and in a common visual project plan. In order for all functions to be involved early and receive the right prerequisites, digital models and rich communication is important so all team members have a common understanding of the situation. By using digital models the production engineers can evaluate the manufacturability in an early design stage and required changes can be completed before the design is finalized. For larger projects prototypes are built, where the design and manufacturability can be evaluated and verified. The development process terminates with a stage-gate where the production function confirm that they can take responsibility for producing the product.

Company Y organizes their product development process on a project basis, with an associated project team, led by a project leader. The teams consists of employees from all involved functions and are therefore cross-functional. All team members are involved throughout the entire development phase, from concept to production ramp-up. The project teams aims to be co-located, since this enhances the communication within the team. Rich and continuously communication within the teams is of key importance during the development phase according to company Y. The project team has a clear project plan which specifies the activities that need to be conducted during the process. These activities are stated in form of checklists and justification is needed if any point is omitted. Through a visual and clear project plan, the project team has a clear action plan for upcoming work. Thereby the postponing of activities is avoided, which otherwise would have a negative impact on the production introduction in a later phase. This clear project management and monitoring increases the understanding of both the project progress and other functions' perspectives. Also, problems which arise can be lifted and solved in collaboration with different functions. In special cases, a stage-gate can be passed even though not all requirements are fulfilled. However, since failure to meet requirements are communicated within the project team there is a common understanding for the situation. By arranging the work on a project basis, the team gets collective and clearly defined responsibility for the end product and thereby also share a common goal, which is in line with the company's overall objectives. Even if all functions do not actively participate in all phases, company Y argues that it is still important for all functions to be involved during the whole process. The involvement builds knowledge, strengthens relations and increases the cross-functional understanding so that the transition from design to manufacturing feels natural and goes smoothly.

The industrialisation function at company Y ensures manufacturability of products, with the objective to get a disturbance free production introduction and develop the manufacturing process. The function cooperates and coordinates with several other functions. Furthermore, the industrialisation team is also responsible for ensuring that production operators get the right education for any special equipment or production methods. However, ensuring basic production skills is the responsibility of the production function. The industrialisation team has a clear process to follow, where their responsibility and activities are stated as checklists. This is especially helpful when design reviews are conducted, as it ensures that all important aspects regarding manufacturability for developed products are taken into consideration. The industrialisation function also define a set of manufacturing requirements for the design function and thereby formalize their expectations on the design function. An example of this is that the industrialisation team provide *assembly golden rules*, which is a set of standardised rules that the design engineers have to take in mind when designing products. The assembly golden rules includes for example accessibility for assembly, ergonomics and impact of specific material choices. The rules are easy to understand and pictures are shown to give practical insight, so that design engineers reflect over the design with manufacturability in mind. These are the basic requirements regarding the manufacturability of the design and more product specific requirements can be added if needed. Thereby manufacturability can be ensured early and product designs can be adapted to current production processes, in order to ease the transition from design to manufacturing.

According to company Y it is of highest importance for all involved functions to be part of all phases in the development and to be involved from start. The later changes are done, the higher the cost. This is something company Y explains needs to be stated and be a part of the company culture. All functions need to take responsibility for the final products and for their contribution during the process. By having a common goal and clearly defined responsibilities, functions do not blame others for failure. Also, having clear performance indicators and measuring the performance of the different functions and teams, helps employees develop and increase their performance. Working in cross-functional project teams is also valuable in terms of communication and collaboration. Company Y argues that the presence of design engineers at the production start-up gives the right signals to employees in the production function as well as gives design engineers practical experience and thereby increases cross-functional understanding. Involving production operators is also important, so they understand the purpose and value of their feedback during the production start-up. Finally, according to company Y, it is important to understand the value of early involvement and that change takes time. If this is in place, improvements can be implemented continuously in order to reach a better product development process and a disturbance free transition from design to manufacturing.

6. Identified Areas of Friction

In this chapter an analysis of the current status description is presented and the second research question of this master thesis is answered. The analysis consists of identified areas of frictions both within and between the processes and functions of the product flow for Product Group A, which includes the end phase of design, industrialisation and production. In the first section common areas of friction for the involved functions are presented, which are both general areas of friction for the product flow of Product Group A, but also areas of friction between the functions. In the subsequent sections areas of friction within the three main functions are presented, more specifically within the design function, industrialisation function and production function.

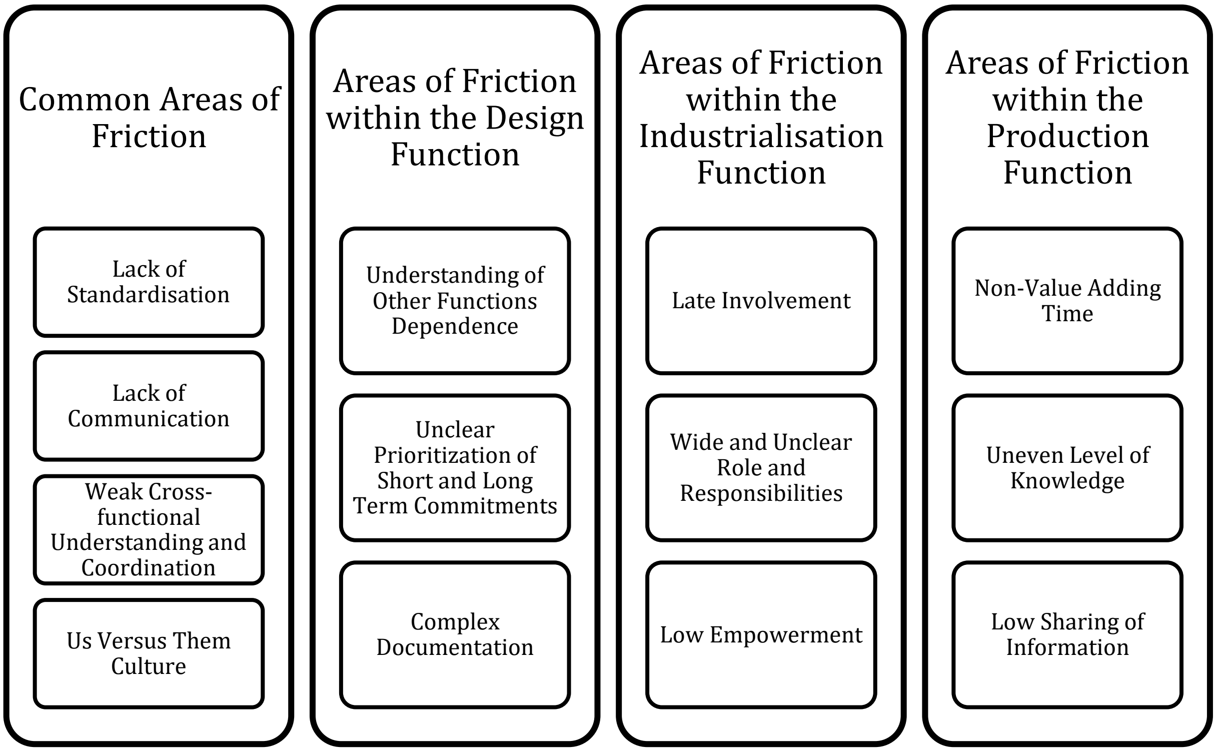

Figure 13. Overview of identified areas of friction

6.1 Common Areas of Friction

In this section common areas of frictions for the functions connected to the product flow for Product Group A are presented. Four main areas of frictions have been identified, which are lack of standardisation, lack of communication, weak cross-functional understanding and an *us versus them* culture. These areas will be presented below.

6.1.1 Lack of Standardisation

Lack of standardisation is one area of friction which has been identified as common and has resulted in a variation of the employees' way of working. The problem is further exacerbated by the large product variation for Product Group A, which in turn has led to a large variety in the actions required and performed. Due to a non-standardised way of working, employees within all functions have developed their own way of working, which results in a high variation of working procedures. In addition, as a result of these individual working procedures, the interfaces between the functions are indistinct. This results in a variation of output from the different functions, further leading to varying starting points for employees in the following process. This variation generates increased start up times since employees need to spend time on understanding the specific situation, which can be defined as a non-value adding activity (Liker, 2004) and thus decreasing the performance of the product flow. Furthermore, variation has a negative impact on flow efficiency and throughput time for a system, according to Modig and Åhlström (2015). Hence lack of standardised working procedures has a negative impact on the performance of the product flow for Product Group A in terms of a less efficient flow and higher throughput time due to variation. Since interfaces between the functions are not clearly defined, responsibilities are unclear and therefore employees act in different ways. Due to insufficiently defined responsibilities, the same type of problems are handled repeatedly, since corrective actions are not taken immediately. Repetitively handling similar problems can be seen as rework and over processing, which is non-value adding resulting in increased throughput time and negatively affect the performance of the product flow (Liker, 2004; Modig & Åhlström, 2015).

Variation in employees working procedures is both an effect of insufficiently defined function requirements, process descriptions as well as non-standardised introductory training. This unstandardised training results not only in variation of level of knowledge, but is also a reason for variation in ways of working. New employees are educated by different experienced employees who in turn have their own individual working procedures, resulting in unstandardised education. Employees therefore develop different ways of working, which negatively affect the performance of the product flow due to variation (Modig & Åhlström, 2015).

6.1.2 Lack of Communication

Since the different functions of the product flow are dependent on each other, there is a need of communication between the functions. Currently, most of the communication occurs over email or telephone, since the different functions are located in separate places. This physical separation of the different functions hinders integration, since it decrease the probability of informal communication to occur between employees from different functions (Vandevelde & Van Dierdonck, 2003). The communication in form of email conversations also becomes time consuming due to waiting times and long conversations before value adding actions are taken. This can to some extent also depend on the location of functions, since the need of communication between physically separated functions increase the amount of time that is non-value adding (Koufteros et al., 2001). The lack of communication hence has a negative impact on the product flows performance, since waiting can be seen as waste and should therefore be eliminated to increase the flow efficiency (Modig & Åhlström, 2015).

How communication occurs between functions depends on the preferences of the people involved, hence the forms of communication vary. The frequency of formal communication in form of meetings for involved stakeholders for Product Group A is low since. For example, Product Group A is not involved in the daily Andon meetings, as mentioned in *4. Current Status Description*. This means that there are no regular formal meetings for employees from the different functions, of the product flow of Product Group A, where issue can be lifted. Instead meetings are booked if there is a need, which often is initiated by long email conversations. Daily formal meetings occur on a management level, through Guldgruvan as mentioned in *4. Current Status Description*, but information captured at this meeting is poorly communicated to employees at the respective functions.

Continuous communication and transparency is important in order to enable a smooth transition from design to manufacturing (Vandevelde & Van Dierdonck, 2003). Therefore lack of formal and regular communication has a negative effect on the performance of the product flow. This is further supported in *5. Empirical Study*, where both company X and Y argue for the importance of continuous communication and collaboration between all included functions of the product development process. Further, poor communication can results in late identification of issues (Wänström & Jonsson, 2006), which in the case of the analysed product flow can be a reason for the high amount of engineering issues identified in the production function, where 25% of orders have an engineering issue. Therefore the lack of regular and direct communication between employees from different functions is identified as an area of friction, since it affects the performance of the product flow in a negative way.

6.1.3 Weak Cross-functional Understanding and Coordination

Another area of friction that has been identified is weak cross-functional understanding and coordination between the different functions. It has been noted in both observations and interviews, that the understanding of other functions situation is low, even if the functions are highly dependent on each other. Thereby, the system overview within the company is low, which has a negative effect since it can lead to sub-optimization due to an isolated focus (Saurin et al., 2013). Further, due to the functional organizational structure, combined with the fact that the design function is in another organizational department, the different functions have different prioritizations and separate objectives, which according to Vandevelde and Van Dierdonck (2003) becomes a barrier for the integration between design and manufacturing. Hence the performance of the product flow is affected negatively. The weak cross-functional understanding is also a result of lack of communication, which was mentioned previously. This is since richness and frequency of communication improves cross-functional understanding (Zirger & Hartley, 2002; Rahim & Baksh, 2003).

The coordination between the different departments is also insufficient. As stated in *4. Current Status Description*, the planning between the different functions is poorly coordinated and synchronized. Even though the production function is behind schedule and has back orders, the other functions planning remains unchanged. The design and industrialisation functions continue on new projects even though the production function does not have the capacity to handle new orders. The lack of coordination has led to push production through the entire product flow, leading to increased amount of work in progress, which generates longer throughput times (Modig & Åhlström, 2015; Rauch et al., 2018) and thereby negatively affects the performance of the product flow. Direct communication is also important to ensure the coordination between different functions in an ETO company (Mello et al., 2017), hence, as mentioned earlier, lack of communication further undermines the coordination between the involved functions for Product Group A. Weak coordination between the functions is identified as an area of friction, since an organization's ability to coordinate has an impact on the performance (Konijnendijk, 1994). Lead times and costs increases, since low coordination results in delays between functions (Caron & Fiore, 1995). Lack of coordination also leads to increased amount of engineering issues during the development process and rework (Caron & Fiore, 1995). If subsequent engineering issues are poorly managed, inefficient manufacturing, low quality and missed deliveries can be the result (Wänström & Jonsson, 2006). Therefore the lack of coordination between the involved functions for Product Group A has a negative impact on the product flow's performance.

6.1.4 Us Versus Them Culture

The last identified area of friction between involved functions is an *us versus them* culture. This attitude becomes a barrier in the integration of design and manufacturing, according to Vandevelde and Van Dierdonck (2003). From observations and interviews this culture has been noted partly due to the functional division of the organization. This culture also depends to some extent on unclear functional responsibilities and lacking collaboration between the functions, since no function takes responsibility over mistakes or problems and instead blame each other. This attitude affects both the relationship between employees and the collaboration between the functions negatively. The identified culture therefore impacts the performance of the product flow as well as the social sustainability at the DSC in a negative way, since a good connection with colleagues is important for a good psychosocial work environment which results in higher productivity (Rubenowitz, 2004). If enjoyment of work is lacking it impacts the intrinsic motivation of employees negatively, which in turn also affects the productivity negatively and results in less qualitative work (Amabile, 1993).

6.2 Areas of Friction within the Design Function

In this section identified areas of friction within the design function are presented. The areas are understanding of other functions dependence, unclear prioritization and complex documentation.

6.2.1 Understanding of Other Functions Dependence

A low understanding of other functions dependence on the design function has been identified as an area of friction. The function does not understand how their work affects subsequent functions in the process. Understanding this is important, since the design process impacts manufacturing efficiency and productivity (Parsaei & Sullivan, 1993; Suh, 1990). Also the total life cycle cost is impacted negatively, due to the fact that around 80-90% of the total cost is set during the design phase (Gatenby & Foo, 1990).

As observed in both observations and interviews, the design function has a low understanding of product designs impact on other functions operations. Incomplete product designs generate issues in the subsequent functions, as when errors or insufficient information is passed on, time and resources has to be spent on corrections. These corrections are also more expensive than if they had been corrected earlier in the process (Turino, 1992). For example, the process defined in this thesis as the design review, which is conducted by the industrialisation team, is seen by the design function as a way to double check the design documents to ensure that all relevant materials are specified. However, the actual purpose of the process should be to check for modularization possibilities and ensure manufacturability. This results in the industrialisation team having to identify errors in the design documents instead of finding improvements of the design from a production standpoint. The manufacturability issues, which should have been found in the design review, then instead arise when the design documents are seen as complete by the design function and set as active. The process for correcting the issues once this has been done both takes more time and is more costly, partly because the design is already set which complicates the updating of documents, but also because more functions are involved.

The low understanding of the impact of product designs is identified as an area of friction, since it affects the performance of the product flow in a negative way. Low integration with the other functions is identified as a cause, which according to Vandevelde and Van Dierdonck (2003) can generate a lack of both understanding and respect of other functions work. The low integration also shows in form of lack of feedback to design engineers. Design improvements identified during manufacturing are not always communicated to the responsible design engineers, which results in both a lack of understanding and no opportunity for improvements in upcoming designs. Low feedback results in low knowledge of results and responsibility of outcome (Hackman & Oldham, 1980).

Furthermore, a long term perspective is missing in the design phase of Product Group A. There is a trend that the design function implement short term and product specific solutions when engineering issues arise during production. At the same time, old designs are often used as a starting point for new design projects within Product Group A. This combination results in reoccurring issues since long term solutions have not been implemented and thus results in longer lead times and higher cost, since the same issues needs to be corrected again. Non-value adding activities such as this rework affects the flow efficiency in a negative way and should therefore be eliminated (Modig & Åhlström, 2015). Design corrections in later steps of the process are also more expensive (Barkan, 1992; Creese & More, 1990), therefore the short term perspective of the design function generates higher costs in total for the product flow. Additional engineering issues also have a negative impact on the products time to market (Syan, 1994).

6.2.2 Unclear Prioritization of Short and Long Term Commitments

A second area of friction identified in relation to the design function is an unclear prioritization of short and long term commitments. In situations when there is demand for both design work for new products and supporting the industrialisation team with engineering issues, what should be prioritized is unclear. As described, planning is separated for the different functions. This makes prioritization for the design function difficult, since they need to make a decision regarding if to follow their own planning or support the industrialisation team. Since own goals are often prioritized, sub-optimization and a push production system results, where products are designed even if there is no capacity to manufacture them. This in turn leads to longer lead times as a results of increased levels of WIP and non-value adding activities (Rauch et al., 2018). Also the different functions' separate performance goals have a negative impact on the product flow performance, since it can lead to sub-optimization, low understanding between functions and lacking coordination (Meyer, 1994). One example of this area of friction is that the NCR-process, described in *4. Current Status Description*, is not prioritized by the design function, even if the other functions are dependent on the solution from the design function in order to deliver finished products. Unclarities in prioritization both impacts the product flow negatively in terms of increase lead times due to waiting, but also tensions in relationships with the other functions. This can have a negative influence on the social sustainability at the company, since the relationship with colleagues affects the psychosocial work environment (Rubenowitz, 2004).

6.2.3 Complex Documentation

The design function has a complex documentation process. This is identified as an area of friction, since it has a negative impact on the product flow performance. Much time is spent on handling and creating design documents, which can be identified as non-value adding and hence should be eliminated (Liker, 2004). Also the high product variety and quality restrictions contribute to this complex handling of documents. Due to the fact that changes are time consuming, design engineers often postpone solutions that require changes in documents. The design team do not want to spend unnecessary time on small changes, since it is perceived as inefficient for them, even if it had been the best solution from a system perspective. As Turino (1992) describes it, spending more time during the design phase to ensure adequate product design, which includes aspects such as manufacturability, testability and serviceability, leads to less spending of time and resources in later process steps and therefore decreased lead times and costs in total. For Product Group A many engineering changes are done late in the process which in turn increases cost and negatively affects the performance of the product flow. In addition, the avoidance of changing documents by the design function can further be an effect of the indistinct line between waste and value within complex socio-technical systems, where specific activities can be identified as waste even if they create value for the system in total (Soliman et al., 2018). Furthermore, the design function does not have any technical or digital tools that assists the design phase and ensure product manufacturability. Instead all material is decided by the design engineer, increasing the risk for errors which need to be handled by the industrialisation team.

6.3 Areas of Friction within the Industrialisation Function

In this section areas of friction within the industrialisation function are presented. The first area is late involvement of the industrialisation function in the product development process, the second is wide span of responsibility of the function and the third is low empowerment of the employees in the function.

6.3.1 Late Involvement

One area of friction which was identified within the industrialisation function is the late involvement in the product development process. The industrialisation team is not continuously involved, but rather get involved generally only when the need arises. For example, when a request for a design review is sent, when the product planner requests production preparation or when an issue arises during production. According to Koufteros et al. (2001), involving key stakeholders, such as the industrialisation function, early in the product development process is essential in order to ensure flow efficiency and shorter lead times. This is also supported by both company X and Y in *5. Empirical Study*, were both companies see several benefits when they involve the industrialisation team early.

The late involvement of the industrialisation function leads to a focus on reactive work for the function, rather than being able to work proactively. If the industrialisation function had been involved earlier, it would allow for the capture and elimination of issues earlier, which in turn reduces time to market (Loch & Terwiesch, 1998) and therefore improves the performance of the product flow. Instead, since the involvement is late, issues regarding manufacturability and product design often arise and are handled once the product has entered production, and then either through the HWR process or NCR process. As presented in *4. Current Status Description*, if a product has to go through these processes there is a substantial increase in the lead time for the product and hence the performance of the product flow is negatively affected. Furthermore, when issues are discovered earlier in the product development process, changes are both easier and less costly to implement (Creese & More, 1990). This is true also at the DSC, since a product revision after a product has been released into production requires the involvement of several stakeholders, as described in *4. Current Status Description*, which increases cost as well as lead time and complexity.

6.3.2 Wide and Unclear Responsibilities

Another area of friction which has been identified within the industrialisation function is the wide and unclear responsibilities the industrialisation team has. The industrialisation team has to be available for production support, so production does not stop. This production support takes a lot of time, based on collected data. In addition, the industrialisation team also need to be available for the design function, as well as the product planner, in order to ensure that the new product development process progresses, which also requires a substantial amount of time to be spent. The spilt role, when combined with the unstandardised way of working mentioned above in section *6.1 Common Areas of Friction*, means that who is responsible for what is unclear. Therefore the industrialisation function have to adapt their working procedure to each specific situation, on a case-by-case basis. This lack of clear responsibilities and roles creates organizational boundaries which decrease flow efficiency and hinders both information and knowledge sharing (Vandevelde & Van Dierdonck, 2003). Furthermore, it decreases the efficiency of the product flow, as described by Modig and Åhlström (2015), due to a human's ability to handle many different things simultaneously which in turn can also generate stress. According to Rubenowitz (2004), stress impacts the psychosocial work environment negatively, which is important to consider since it also negatively impacts the social sustainability at the DSC.

6.3.3 Low Empowerment

The third area of friction identified for the industrialisation function is the low empowerment of the team. As mentioned in *6.3.2 Wide and Unclear Responsibilities,* the industrialisation team has a wide role and is responsible for many aspects of the product flow. The team however has little power to implement changes which are required. For example, when engineering issues arise in production, the industrialisation team is responsible for providing a solution, as described in *4. Current Status Description.* However, even though they can provide a solution, communication with the design function is often required in order to get confirmation that a solution is acceptable and permissible to implement. This means that while they are responsible, they are also dependent on other functions. The dependency increases lead time for the product flow, since even though the industrialisation team may have identified a solution, they often have to wait for confirmation or action from another function before they can complete their responsibilities. If a team is more empowered to make their own decisions, less time would be wasted waiting for approval (Zirger & Hartley, 2002). Also, with every new person who is involved, cost increases. Considering that almost 25% of all orders on previously produced products have to be handled by the industrialisation team, and at least 30% of these need confirmation from the design function, the total lead time and cost increase is significant. Low empowerment also has a negative effect on the psychosocial work environment (Rubenowitz, 2004). Due to a lesser ability to decide on and complete own responsibilities, motivation decreases. This in turn leads to a negative effect on productivity and quality of work (Amabile, 1993) and therefore also worse performance for the product flow.

6.4 Areas of Friction within the Production Function

In this section identified areas of friction within the production function are presented. The three areas are large amount of non-value adding time, uneven level of knowledge and low sharing of information.

6.4.1 Non-Value Adding Time

One area of friction within the production function is the high amount of non-value adding time. Non-value adding time is waste and should be eliminated (Liker, 2004; Modig & Åhlström, 2015; Rauch et al., 2018). Non-value adding time includes activities such as waiting, defects, over processing and other unnecessary activities (Liker, 2004). Many of these non-value adding activities occur in the production at the DSC. Looking at defects for example, in 60% of orders an issue arises which immediately results in additional non-value adding time in order to correct the issue. Of these orders, 41% need to be handled by the industrialisation function, which additional increases the non-value adding time due to waiting times before the issues are handled, as previously mentioned. Based on all orders on previously produced products, the average throughput time doubles if an error arises which requires help from the industrialisation function. If the design function also needs to be involved, the average throughput increases by a factor of 2.6, which is shown below in *Figure 14*. This means that at least half the time spent on an order where an issue arises is non-value adding. Thereby, if no issues arise on any orders, the production output could double, thus increasing the performance of the product flow substantially. In addition to this, since production stops when an issue arises, every issue creates several restarts. One restart occurs once a solution to the issue has been found, and a second restart is required if an order has been started when waiting for a solution and has been paused when the first order is restarted. This causes non-value adding time and inefficiency in the product flow, due to the required set up times, handovers and time spent by the employees to gain insight into the situation (Modig & Åhlström, 2015; Zirger & Hartley, 2002).

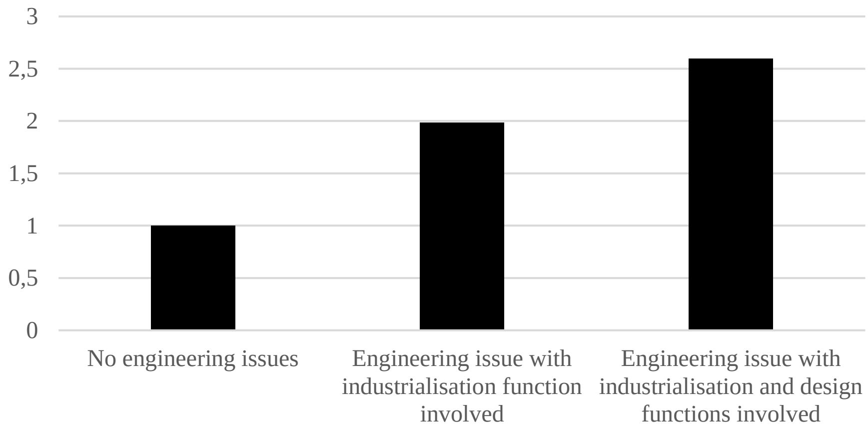

Figure 14. Effect of engineering issues on throughput time.

Another activity which increases the total non-value adding time is time spend on searching for correct documents. Due to the previously mentioned non-standard way of working, different shop orders have different documents connected to them as well as different work guidelines. This creates a variability in the production activity which in turn creates non-value adding time. If the documentation for different shop orders were standardised, variability could be decreased (Saurin et al., 2013), thus decreasing non-value adding time and increasing the performance of the product flow.

6.4.2 Uneven Level of Knowledge

Another area of friction identified within the production function is the uneven level of knowledge of the production operators. This is aggravated by the fact that new operators do not receive a standardised introduction or instructor. While each new operator receives a designated person who they can ask if issues arise, this person is often a more experienced operator who in turn have their own orders to handle as well. The uneven level and lack of knowledge leads to an increase in non-value adding time through interruptions and waiting time. It also increases the workload and creates interruptions for the industrialisation team and leads to a subsequent increase in non-value adding time for them as well. As previously mentioned, non-value adding time should be eliminated (Modig & Åhlström, 2015) as it decrease flow efficiency. This is due to the fact that when an issue arises and the operator has insufficient knowledge, the industrialisation team is contacted, as presented in *4. Current Status Description*, who then need to assist with problem solving and also take on a teaching role. It is therefore important that sufficient and correct knowledge, skills and capabilities are possessed by the production operators in order to ensure efficiency in the interface between functions (Dekkers et al., 2013). Additionally, ensuring adequate operator knowledge, experience and skill allows for a better and more efficient elimination of errors in the process, as the operators are able to handle a wider variety of issues on their own (Mello et al., 2017). Thereby non-value adding time spent on resolving issues can be decreased.

6.4.3 Low Sharing of Information

A third area of friction which has been identified within the production function is the low amount of information shared with the production operators. While there are meetings where the production status is discussed, as mentioned previously in *4. Current Status Description*, these meetings are primarily for management and the production operators do not participate in them. This information is also not communicated to the production operators in other ways. This means that the operators have little knowledge on what the status is in the production, for example how many orders are completed, the size of the current order stock or how many orders need to be completed in order to produce according to plan. A low amount of information sharing increases the boundaries between different functions, which negatively affects performance (Tezel, Koskela & Tzortzopoulos, 2016). This also means that the operators have little knowledge of the production results, which has a negative effect on their intrinsic motivation (Hackman & Oldham, 1980) and thereby also on the productivity (Amabile, 1993). Furthermore, the operators seldom know what projects or end products which their shop order that they work on is connected to. This has a negative effect on their intrinsic motivation as well, as the experience of responsibility for the outcome and what role they play is missing (Hackman & Oldham, 1980). Thus the performance of the product flow for Product Group A is negatively affected by a low sharing of information.

7. Suggested Improvements

In this chapter suggested improvements for better performance of the product flow of Product Group A are presented. The suggested improvements are divided into three key principles, which are collaboration, standardisation and transparency. These are considered important in order to ensure increased performance for the product flow of Product Group A. Each principle contains a set of recommended actions, which support the connected principle and in turn increase performance for the product flow without compromising on quality. The recommended actions within each principle are connected, to a certain extent, as they complement and support each other to strengthen respective principle. The three principles and the improvement suggestions are shown in *Figure 15* below, followed by a more in depth presentation. The chapter is concluded with a section regarding recommendations and sequence of implementation.

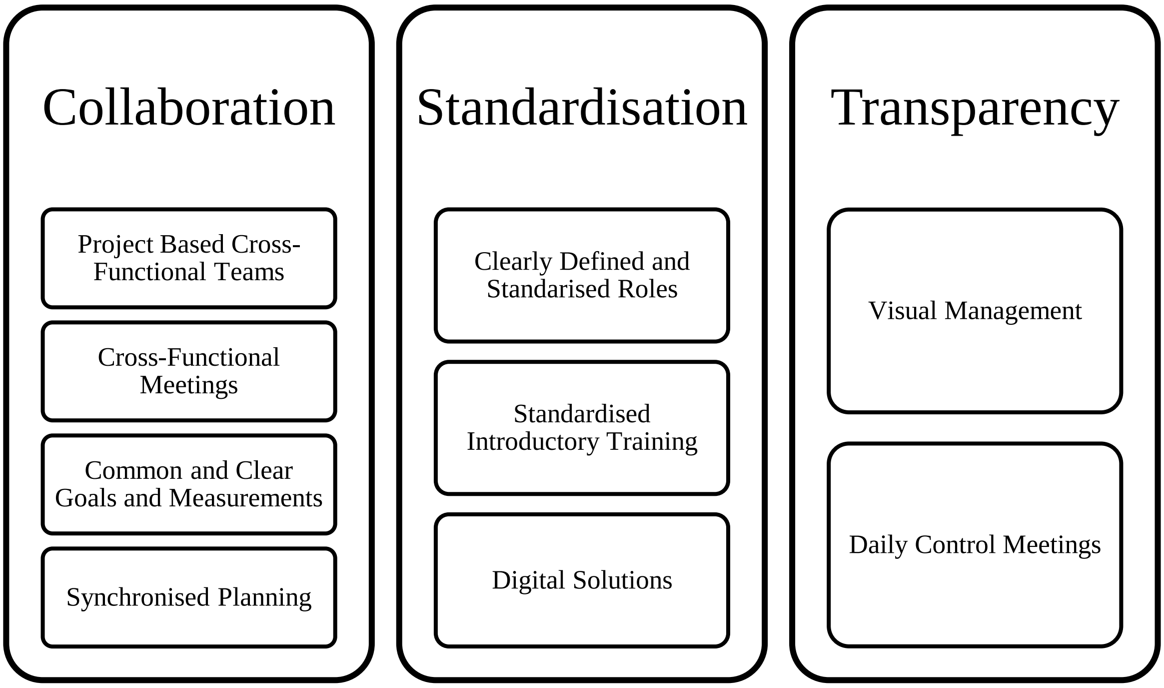

Figure 15. An overview of identified principles and suggested improvements.

7.1 Collaboration

Collaboration is a key success factor for an efficient product development process (Dekkers et al., 2013). In order to increase the collaboration between all the functions of the product flow of Product Group A, four suggested actions are identified. These four actions are project based cross-functional teams, cross-functional meetings, common and clear goals and measurements, and synchronized planning.

7.1.1 Project Based Cross-functional Teams

Creating project based cross-functional teams entails creating teams consisting of engineers from the design and industrialisation functions, which work with Product Group A. The teams should consists of a handful of people, with the exact number depending on the scope of the project, with an assigned team leader in form of a product planner from the projects and planning function. These teams should work in projects centred on product sets of Product Group A, work in close proximity to each other and be empowered to implement changes within their project. The cross-functional teams should have daily meetings, where responsibilities and actions are determined within the team and the team leader's role is leading the work and assure deadlines are met. As mentioned, the team should be empowered to make changes within the projects to avoid dependency on others. Since design and industrialisation engineers are included in the teams, the right skills and capabilities are present and therefore correct decisions can be made directly. By having a product planner as team leader, the cross-functional teams have a closer connection to overall project planning. The purpose of creating project based cross-functional teams is to involve key stakeholders early in the process in order to enable early identification of issues, as well as improved coordination and collaboration between the different functions of the product flow of Product Group A. Also, the cross-functional teams receive ownership over specific product sets, leading to clear responsibilities over corrective actions for issues that arise and therefore decrease lead times since corrections can be implemented directly.

Cross-functional teams are a key mechanism in order to integrate and create an opportunity for early involvement of the different functions of a product development process (Twigg, 2002). This early involvement enables and simplifies communication of requirements and constraints from the different functions, especially if teams are co-located (Rahim & Baksh, 2003; Zirger & Hartley, 2002). Working in cross-functional teams for Product Group A thereby mitigates the late involvement of the industrialisation function, since they would be in the team from the start. Early involvement brings the added benefit of early identification and solving of issues in the product design, as each function of the product flow can immediately bring attention to problems related to their specific function and provide a solution, thereby reducing the need for engineering changes and subsequent delays later in the process (Koufteros et al., 2001; Mello et al., 2017). Identifying issues early and decreasing the need for changes later in the process is important, as the later changes to product design is introduced, the more difficult they are to implement and the greater the negative effect on both cost and time to market (Barkan, 1992; Creese & Moore, 1990; Suh, 1990; Syan, 1994). Thereby, if the functions of the product flow are involved early in the process, issues can be identified and eliminated early and the performance of the product flow of Product Group A can be increased, since both lead time and production cost can be decreased. This would additionally increase the performance of the product flow by decreasing the amount of non-value adding time in production, since errors can be caught in the design phase and do not arise during production.

It is also important for project based cross-functional teams that solutions are developed in collaboration within the team, ensuring that a change in one function does not negatively affect another (Twigg, 2002). Since ETO projects often are complex and contain several different stakeholders with high interdependence, it is vital that all stakeholders are included in the team in order to reduce the risk for conflict (Mello et al., 2017). This means that involved functions of the product flow for Product Group A need to be included in the cross-functional teams, which therefore will increase the cross-functional understanding in the organization and counteract the *us versus them* culture. This is due to the fact that the needs and requirements of each function can be understood by the team members and taken into account during the development process. The cross-functional teams also clarify the product flow's functions dependence on each other, since the effects of one action can be seen and discussed directly, thereby mitigating the area of friction identified. To ensure that changes can be implemented without causing unnecessary delays, the cross-functional team needs to be empowered to act on information, as they often are in the best position to perceive the effects of these changes (Gerwin & Moffat, 1997; Zirger & Hartley, 2002). An implementation of project based cross-functional teams would thereby mitigate the low empowerment of the industrialisation team, since the cross-functional team would be empowered to implement required changes, thereby improving the performance of the product flow due to decreased waiting times.

7.1.2 Cross-functional Meetings

An implementation of cross-functional meetings entails regular meetings between different stakeholders of the key functions of the product flow for Product Group A. These cross-functional meetings should serve as a form of communication between the functions where current projects, orders, status of the different functions and eventual issues can be discussed, with the aim of increasing understanding, improving integration and enabling quick solving of issues. Two different types of cross-functional meetings are suggested. The first type includes meetings between different team leaders from different functions on a weekly basis and the second type entails daily problem solving meetings for Product Group A, known as Andon meetings, which are explained below in more detail. The cross-functional meetings are seen as a first step towards better cross-functional understanding. The team leader meetings should still be held if cross-functional teams are implemented, in order to maintain the collaboration and relationship between functions. The implementation of Andon meetings for Product Group A, however, can be seen as a starting point for implementation of the cross-functional teams suggested previously.

Through regular team leader meetings, continuous and direct communication can be ensured between the functions, which simplifies the transition between design, production preparation and manufacturing (Vandevelde & Van Dierdonck, 2003). These meetings should be held weekly, in order to ensure regularity, and be held between the team leaders from all the functions of the product flow, including design, industrialisation and production. For production in particular, the team leader can be represented by the supporting instructor introduced in *7.2.2 Standardised Introductory Training*. The team leaders have a good overview of what their team's status is, so activities and support between the functions and teams can be adjusted accordingly. Additionally, cross-functional issues can be directly solved with the other affected function and follow-up of these issues is enabled. This increases performance for the product flow, since non-value adding time resulting from waiting for response can be minimised. Furthermore, the direct communication between the different functions of the product flow, which regular cross-functional meetings enable, improves coordination between all the involved functions of the product flow.

Furthermore, direct communication increases responsiveness and enables an efficient handling of engineering changes (Mello et al., 2017), which increases the cross-functional understanding and counteracts the existing *us versus them* culture. This is due to the fact that increased richness, which face-to-face meetings enable, as well as increased frequency, improves both mutual understanding as well as problem solving capabilities (Rahim & Baksh, 2003; Zirger & Hartley, 2002). This has already been seen at the DSC, where Andon meetings are held for other product groups, where problems are solved more efficiently than for Product Group A. Positive effects of regular cross-functional meetings were also seen at company X of the empirical study in this thesis, where every morning cross-functional meetings were held which gave an opportunity to share current status and experiences, leading to collaboration and support within the organization. Therefore it is also suggested that an Andon meeting is held for Product Group A specifically. These would be modelled according to existing Andon meetings, explained in *4. Current State Description*, were affected industrialisation team members meet with their design function counterparts on a daily basis. Critical issues can be monitored, discussed and solved during these meetings, and since only affected members are present the problem solving can be efficient. Due to a high interdependence between the different stakeholders within ETO projects, the need for good communication and collaboration increases (Mello et al., 2017). The fact that the different functions related to the product flow are physically separated further increases this need (Koufteros et al., 2001). As described in *4. Current State Description,* the need of communication is currently fulfilled mainly by email conversation, which are time consuming and often lead to waiting times, which is non-value adding and a waste (Modig & Åhlström, 2015). Replacing these emails with the regular cross-functional meetings described can therefore decrease the non-value adding time and improve the performance of the product flow.

7.1.3 Common and Clear Goals and Measurements

Developing common and clear goals and measurements which are shared between all involved functions in the product flow is another suggested improvement. The goals should involve both short and long term objectives and be continuously updated, in order to ensure the suitability of the goals and measurements. In addition, the common goals have to be communicated to all employees in all the different functions connected to the product flow of Product Group A. The goals and measurements should be valuable and useful for employees, by being connected to daily operations, and provide an understanding of the current status of the product flow. This is ensured by breaking down strategic goals to a more functional and individual level, such as the number of issues which arise, throughput per day or week or delivery precision. The goals and measurements should include both target states, aimed at retaining ways of working, as well as operational effects, which focuses on measuring performance. Strategic goals should be determined on a management level, but in the breaking down of strategic goals employees should be involved in order to understand the strategic connection and purpose of the goals and measurements. By developing common goals and measurements, the integration of functions for Product Group A will increase, which improves coordination (Mello et al., 2017; Meyer, 1994) and thereby also company performance (Konijnendijk, 1994). Improved coordination as a result of common goals can also prevent delays between functions and decrease both cost and lead time (Caron & Fiore, 1995). Furthermore, common goals lower the organizational and cultural barriers between design and manufacturing (Vandevelde & Van Dierdonck, 2003). Hence the integration and collaboration between the functions of the product flow would increase, which has a positive effect on the performance of the system (Rubenowitz, 2004).

The suggested improvement in form of developing common and clear goals and measurements mitigate some of the identified areas of friction presented in *6. Identified Areas of Friction*. First, the weak cross-functional understanding and coordination would improve through utilizing common goals, since employees receive a better system overview. In addition, a better system overview reduces the risk of sub-optimization (Saurin et al., 2013). Also improving coordination through common goals would lead to improved performance of the product flow, in terms of higher flow efficiency and thereby lower lead times (Rauch et al., 2018). As mentioned above, cultural barriers between design and manufacturing can be a result of lack of common goals and measurements. The area of friction *us versus them* culture could therefore be mitigated by usage of common and clear goals, since it is an effect of the presence of cultural barriers (Vandevelde & Van Dierdonck, 2003). Furthermore, the unclear prioritization between short and long term commitments for the design function could be managed. By clearly defining both goals and performance measurements, what to prioritize becomes clearer. This could, for example, lead to quicker corrections of design engineering issues handled in the NCR-process, since the issues would be clearly prioritized. The performance of the product flow for Product Group A would therefore be improved, since non-value adding activities such as waiting times can be eliminated, increasing flow efficiency and decreasing throughput times (Liker, 2004). Also, by integrating the functions of the product flow through common goals and measurements, collaboration and relationships can improve. This would have a positive effect on the social sustainability, in terms of a better psychosocial work environment and higher motivation (Amabile, 1993; Rubenowitz, 2004).

7.1.4 Synchronised Planning

In order to improve the performance of the product flow, a suggested improvement is to implement synchronized planning for the functions of the product flow of Product Group A. The planning of the involved functions should be dependent on each other and synchronized. Design and industrialisation commitments should thereby match the level of output from the production function. More specifically, this entails that the amount of design reviews and production preparations should be adjusted to the production capacity, so thereby excess resources of the industrialisation team can be allocated to assisting the production function and solving eventual engineering issues rather. Therefore a push production system through the product flow can be avoided. Synchronized planning would lead to a lower amount of work in progress, decreasing production backlog and therefore making it easier for all involved functions to focus on the required commitments for meeting customer deadlines. Also the performance of the product flow in terms of lead times would improve, since a lower amount of work in progress decreases the throughput time if the cycle time remains constant, according to Little's law (Modig & Åhlström, 2015). Focusing on the flow efficiency, the integration of functions would be enhanced and further results in better resource efficiency (Modig & Åhlström, 2015).

If plans within ETO organizations are not regularly updated, longer lead times can result, due to a resulting push production system (Rauch et al., 2018). A more synchronized plan would positively affect the identified weak coordination between the functions of the product flow, making it possible to focus on prioritized commitments and reduce the amount of simultaneously activities for each individual. This decreases levels of stress and increases control for employees and thereby also the efficiency (Modig & Åhlström, 2015). A more demand driven product flow would further increase the amount of value-adding activities and make the system more adapted to handle both internal and external variation (Saurin et al., 2013). Utilization of synchronized planning would therefore have a positive effect on the performance of the product flow for Product Group A, since throughput times will shorten due to lower amount of work in progress and less time spent on non-value adding activities. Furthermore, improved coordination leads to fewer engineering changes and less rework throughout the product development process, which also prevents delays (Caron & Fiore, 1995). Better coordination of functions due to synchronized planning can therefore reduce the amount of engineering issues identified late in the product flow for Product Group A, leading to shorter lead times through reduced non-value adding time and thereby increase the performance.

7.2 Standardisation

In this section three suggested improvements which enable standardisation are presented. Lack of standardisation is identified as a common area of friction which needs to be handled in order to increase the performance of the product flow. By handling and reducing variation through standardisation, flow efficiency can increase and throughput time can decrease (Modig & Åhlström, 2015). The three suggested improvements are clearly defined and standardized roles, standardised introductory training and digital solutions.

7.2.1 Clearly Defined and Standardised Roles

One suggested improvement is to create clearly defined roles and responsibilities for involved stakeholders in relation to the product flow of Product Group A. By standardising requirements, uncertainty between functions can be reduced and standardisation is enabled, which in turn decreases delays and minimize the amount of rework needed (Mello et al., 2017). Clearly defined roles should therefore be developed, with supporting checklists where responsibilities are explicitly defined, as seen at both company X and Y of the empirical study. Clearly defined roles further implies developing standardised processes, documents and interfaces between different functions, so expectations become clear.

By having clear roles and responsibilities, with associated standardised processes and interfaces, the variation of working procedures within the product flow can be reduced, which has a positive impact on the performance of the product flow. By reducing variation through standardisation, throughput time can be reduced without changing the capacity utilization (Modig & Åhlström, 2015). Attaining standardised processes is further a prerequisite for continuously developing the product flow, since if there is no standard common base there is nothing to develop from (Modig & Åhlström, 2015). Standardisation not only enables identification of unwanted variability, but also allows for development of standardised methods of handling issues due to unwanted variation (Saurin et al., 2013). The handling of engineering issues within the product flow can thereby be more efficient, leading to reduced lead times and elimination of non-value adding activities, thus improving the performance of the product flow.

Lack of standardisation was identified as a common area of friction due to the negative impact of variation on the product flow. This area of friction is mitigated by clearly defined roles and responsibilities, since there will be clearly defined and standardised responsibilities and processes, which decrease the variation in employees' way of working. Further, clearly defined interfaces between functions, resulting from clear roles and responsibilities, as well as standardised documentation generate standardised outputs and thereby decreases non-value adding start up times for subsequent functions. Also rework in terms of repeatedly handling the same type of problems can decrease if responsibility becomes clearer. This is due to the fact that the functions more clearly receive ownership over problems and required correcting actions can be completed. This requires that the right to make changes is included in the role, thus empowering those who are responsible for the change. Elimination of these non-value adding activities has a positive impact on the performance of the product flow, since non-value adding activities impacts lead time negatively (Liker, 2004).

Due to clearly stated responsibilities, the respective functions need to take responsibility for their actions, leading to mitigation of the identified area of friction in terms of an *us versus them* culture. Thereby the collaboration between employees can become better, positively affecting both the psychosocial work environment and the productivity (Rubenowitz, 2004). In addition, according to company Y, clear responsibilities improve the collaboration and relation between different functions, which has a positive effect on performance. Another area of friction mitigated by clearly defined roles and resulting standardised working procedures, is the amount of non-value adding time spent in the production function. One example is, if the purpose and responsibilities of the HWR-processes are more clearly defined for all involved stakeholders, especially production operators, more issues during the first production run can be identified. This would further lead to fewer engineering issues in subsequent production runs and thereby the amount of time spending on correcting issues in the production function would decrease. This elimination of non-value adding activities in form of both waiting and rework would increase the flow efficiency (Liker, 2004) and hence increase the performance of the product flow for Product Group A.

7.2.2 Standardised Introductory Training

A second suggested improvement, related to standardisation, is to implement standardised introductory training, primarily for production operators. This introductory training should cover essential fundamental knowledge and be standardised for each function, in order for all new employees to receive the same type of introduction. Key process steps and required basic skills should be taught before responsibilities are given, with opportunities for questions and support. The introductory training should also include information about all essential processes and standards, in order to gain a standardised way of working within the product flow for Product Group A. It is vital to introduce the developed standardised processes, previously mentioned in *7.2.1 Clearly Defined and Standardised Roles*, and ways of working to new employees in order to maintain standardisation in the long term. For example, suggested improvements regarding cross-functional teams and meetings should be introduced, as well as usage of checklist, so this becomes natural elements in the new employees' way of working. Furthermore, in the production function, an assigned experienced employee should be appointed as instructor who would be responsible for the introduction to ensure standardisation. The instructor should in addition have a supporting role in the production area, supporting production operators when uncertainties arise during assembly and provide assistance. This is in order to continuously develop the employees, increase the independence of the production function and ensure standardisation.

By introducing a standardised introductory training, friction due to variation in employees' working processes in the product flow for Product Group A could be minimized, which positively affect flow efficiency and reduces lead times (Modig & Åhlström, 2015). Creating and ensuring production capability in terms of staff skill and knowledge is further important to improve coordination between functions, since it enhances identification and elimination of issues and thereby prevent delays (Mello et al., 2017). In addition, a standardised introductory training has a positive effect on the relationship and collaboration between the functions of the product flow of Product Group A, since correct skills and capabilities are needed in order to achieve an effective relationship (Dekkers et al., 2013). This further positively affects the psychosocial work environment, which in turn can lead to a higher productivity (Rubenowitz, 2004). Furthermore, having a supporting instructor in the production area can increase the flow efficiency. According to company X in the empirical study, a supporting instructor has a positive impact on the production efficiency since there is an extra resource which can support and handle issues that arise. A supporting instructor is also a way to make the production more robust and not as sensitive against unwanted and unpredictable variation. By having an extra resource, maximization of resource utilization can also be avoided, which otherwise can generate longer lead times (Modig & Åhlström, 2015) and have a negative effect on the performance of the product flow.

By implementing standardised introductory training, the uneven level of knowledge for production operators can be avoided, which is identified as an area of friction for the product flow. An assured basic level of knowledge for production operators can ensure a reduction of manufacturing issues, which has a positive effect on the performance of the product flow since less non-value adding time needs to be spent on rework and waiting time. This is due to the fact that elimination of non-value adding activities positively affects the flow efficiency (Liker, 2004). In addition, the presence of a supporting instructor in the production area would decrease the interruption of the industrialisation team's work. By having an instructor, questions to the industrialisation team regarding to lack of knowledge or problem solving support can decrease, as these questions can instead be handled by the instructor. This leads to less time spent on restarts for the industrialisation team, hence making their work more efficient. Thereby, a supporting instructor would have a positive impact on the wide role of the industrialisation team, since some of the current supportive and teaching activities would be reallocated. Stress can also be reduced due to the lower amount of simultaneously activities (Modig & Åhlström, 2015), hence improve the psychosocial work environment and productivity (Rubenowitz, 2004). Therefore the performance of the product flow will be increased.

7.2.3 Digital Solutions

The implementation of digital solutions for all involved functions is another suggested improvement. The main goals of an implementation of digital solutions would be twofold. One part is to enable and simplify cross-functional work and the second part would be to simplify handling and increasing availability of relevant information to concerned stakeholders. These goals aim to assist in simplifying and standardising the way of working for all involved functions, by providing a simple and repeatable visual way to collect, store and access information.

In ETO companies, coordination between design, production preparation and manufacturing is important, as the better the coordination the better the performance of the process (Konijnendijk, 1994). Also, increased coordination leads to decreased rework (Caron & Fiore, 1995), which has a positive impact on the performance of the product flow. One way to improve and ensure coordination is the implementation and effective use of IT systems (Mello et al., 2017). Since ETO manufacturing and product development is dynamic and often complex, the requirements are high on the technology used (Powell et al., 2014). In order to coordinate and synchronize the different functions within the product flow of Product Group A, as well as improve communication, the information and data available to each of the functions needs to be integrated and shared in the same system (Mello et al., 2017). Therefore it is suggested that a new common digital solution should be implemented, which is used by the main functions connected to the product flow. This digital solution can be seen as a common software platform, which supports all functions' activities. For the design function, the software should enable easy creation of design documents, including three dimensional models of the products where key information can be easily identified. The required manufacturing materials for products should be specified automatically based on the design and model created by the design engineers, leading to easier documentation and more correct designs. Creating faultless product design in the design phase, will reduce the amount of arisen issues identified late in the production function, increasing performance of the product flow. Less time will thereby have to be spent on creating and handling different design documents, which was identified as an area of friction, since the new digital solution enables standardisation of the processes. The information also becomes both formalized and standardised, which eases the transition of information between functions (Vandevelde & Van Dierdonck, 2003). This further mitigates the area of friction related to standardisation and hence increases the performance of the product flow.

The standardised information available in the system will additionally include fewer errors, as the system will ensure optimal materials based on design specifications, and would thereby allow the industrialisation team to focus on manufacturability rather than correcting the defined materials. This would thereby decrease the amount of errors which arise in production, decreasing the non-value adding time on handling the issues, which increases the performance of the product flow. Furthermore, the design improvements for manufacturability, identified by the industrialisation team, can be annotated directly in the design documents in the system and can therefore be seen directly by the design team. Thereby it would allow for a better management of engineering changes, which also aids in early identification of problems (Wänström & Jonsson, 2006), thus additionally increasing the performance of the product flow. Positive effects of a similar digital solution were demonstrated by company Y, from the empirical study of this thesis, where using a common digital solution enabled production preparation engineers to work closely with design engineers, both to ensure manufacturability before product designs were finalised and issues could be identified early, showing the positive effects of coordination.

An implementation of a new and simplified digital solution would also be able to reduce the non-value adding time in production, with respect to the time spent looking for the right specifications and documents, which was identified as an area of friction. This is since the industrialisation team will in the system be able to create specific assembly guidelines directly connected to the materials and design documents created by the design team. The process of creating assembly instructions will also be connected to the digital model created in the system, allowing for a visual understanding. This is imperative, according to both company X and Y, to increase understanding and decrease non-value adding time. Through a new digital solution, the performance of the product flow can be improved, due to the collaboration which is enabled through the common system with simplified and standardized data available to all and results in a reduction of non-value adding time for all functions.

7.3 Transparency

In this section two suggested improvements are presented, with the aim to increase transparency within the organization. Transparency is a key requirement in order to ensure a smooth transition and integration between functions in the product development process (Powell et al., 2014; Vandevelde & Van Dierdonck, 2003). The two improvements introduced in this section are visual management and daily control meetings. Both suggested improvements aim to increase transparency and give better insight in the daily operations and possibility to take corrective action in order to meet plans and goals.

7.3.1 Visual Management

Implementation of visual management is a suggested improvement in order to increase transparency within the organization, both within each function but also between the different functions of the product flow of Product Group A. Visual management includes information sharing as well as usage of both visual tools and visual control measures, such as signboards and Andon boards. These visual tools should be utilized in the suggested cross-functional meetings and in the cross-functional teams, mentioned previously. The implementation of visual management is also closely connected to the improvement suggestion of creating common and clear goals and measurements, as mentioned previously. An aim of visual management is both to create an understanding of the current state of both the own function as well as other functions, and also to give an idea of the future state, and thereby increase transparency. By following up on goals and measurements and easing understanding through visual management methods and tools, prioritization becomes clearer and eventual needs for reallocation of resources can be identified.

Visual management and related information sharing enables the overcoming of both vertical and horizontal boundaries, thus enabling better coordination across the organization (Meyer, 1994; Tezel, Koskela & Tzortzopoulos, 2016). This is possible because it creates an awareness of others situations as well as and understanding of actual work conditions of the different functions, hence increasing transparency (Powell et al., 2014). Therefore by utilizing visual management, the area of friction regarding weak coordination can be mitigated. Also, if visual management and information sharing is implemented it allows for insight into own performance as well as the performance of others throughout the product flow, and thus enables identification of areas for improvement in order to increase performance (Saurin et al., 2013). This was also observed in the empirical study of this thesis, where digital visual boards were used at company X and Y, which enabled a better understanding of current status and increased performance. It also increases intrinsic motivation through feedback and individual significance (Hackman & Oldham, 1980), which leads to improved performance of the product flow (Amabile, 1993). In addition, by implementing a visual management system, the risk of sub-optimization is reduced for the product flow, due to the fact that an understanding for both the own and other functions status is visualised and focus can be on improving the system’s performance rather than the separate functions’ (Meyer, 1994). Therefore, it is imperative that a visual management system is implemented not only for certain functions, but throughout the organization (Tezel, Koskela & Tzortzopoulos, 2016).

Implementing a visual management system, connected to the earlier mentioned common goals and measurements, will enable increased performance of the product flow for Product Group A, due to mitigation of several identified areas of friction. Since the visual management system shares the current status of functions with other functions, it strengthens the cross-functional understanding within the organization, as well as gives insight in other functions situations and therefore counteracts the *us versus them* culture. Being able to follow other functions performance measurements can also give insight into the interdependence of functions for the design function. Further, the visual management system would allow for a better sharing of information between and within each function connected to the product flow of Product Group A. Therefore, the implementation of a visual managements system enables a better system overview. In turn, this improves performance of the product flow, through improved cross functional understanding and related coordination and collaboration.

7.3.2 Daily Control Meetings

The last improvement suggestion is to implement daily control meetings in order to keep employees updated on the current status of the product flow, as well as increase the control of the product flow in terms of prioritizations, replanning and reallocation of resources. The purpose of daily control meetings should be to distribute information about current status and fulfilment of goals through performance indicators and visual management, so all employees receive insight on the performance of the product flow and are involved. These meetings should cover the performance of both the affected function and the entire product flow, in order to get insight on other functions current situation and performance. In that way cross-functional understanding and transparency can increase. In addition, daily control meetings increase the coordination for the product flow, which positively affects the performance.

Information sharing through daily control meetings helps to overcome barriers between different functions, due to a higher awareness and understanding of the situation in both the own and other functions (Tezel, Koskela & Tzortzopoulos, 2016) and thereby increase transparency (Powell et al., 2014). Therefore daily control meetings would mitigate the area of frictions regarding lack of communication and weak cross-functional understanding, since the information sharing increases which increases the performance of the product flow. Also the area of friction regarding the low sharing of information in the production function can be mitigated. Another benefit of introducing daily control meetings is that employees receive a greater knowledge of results and responsibility of outcomes, since information about performance and other relevant aspects is given. This would positively affect the intrinsic motivation of employees (Hackman & Oldham, 1980), which in turn has a positive impact on performance (Amabile, 1993). The performance of the product flow is therefore not only positively impacted by better coordination, richer communication and increased cross-functional understanding, but also through increased employee motivation.

7.4 Recommendations

The above mentioned suggested improvements aim to answer which guidelines and principles can mitigate the identified areas of friction and thereby improve the performance of the product flow for Product Group A. This has been summarized in *Table 2* below. As shown, no single suggested improvement mitigates only a single area of friction, thus benefits in several areas can be obtained even though not all suggested improvements are implemented. Since some suggested improvements are related, the sequence of implementation needs to be considered, which will be presented in this section. In order to simplify implementation, the suggested improvements are therefore divided up into primary and secondary improvements. Primary improvements are the improvements which are deemed easier or smaller, and can be implemented directly. Thereby immediate wins can be created, positively affected employees' motivation and creating a momentum for further change (Kotter, 1995). This momentum can assist in implementation of the secondary improvements, which are deemed more complex or larger and thereby require more time and resources to implement.

Table 2. Matrix showing which areas of friction are mitigated by the suggested improvements.

Areas of Friction \ Suggested Improvements	Project based cross-functional teams	Cross-functional meetings	Common and clear goals and measurements	Synchronised planning	Clearly defined roles	Standardized introductory training	Digital solutions	Visual management	Daily control meetings
Lack of standardisation					X	X	X		
Lack of communication		X					X		X
Weak cross-functional understanding	X	X	X	X	X			X	X
Us versus them culture	X	X	X		X	X		X	
Understanding of other functions dependence	X	X						X	
Unclear prioritization			X	X					
Complex documentation							X		
Late involvement	X						X		
Wide and unclear responsibilities					X	X			
Low empowerment	X				X				
Non-value adding time	X			X	X	X	X		
Uneven level of knowledge						X			
Low sharing of information								X	X

The primary improvements which can be implemented immediately are the cross-functional meetings, standardised education, common and clear goals and measurements, daily control meetings, and clearly defined and standardised roles. The cross-functional meetings can start to be held directly, primarily between the design and industrialisation teams, thereby immediately aiding in creating an understanding for each other's work. Production can be represented by a manager until such a time as a supporting instructor is appointed. Since standardised training is suggested as an improvement, which can be initiated immediately, this can occur within a short time frame. The instructor can be selected among the current production operators, who are deemed as experienced. For the other functions, a standardised checklist can be created by the respective functions, which should be followed by new employees to ensure that correct skills and processes are included in the introductory training. The goals and measurements detailed in *7.1.3 Common and Clear Goals and Measurements*, are also deemed to be easy to implement and should therefore be done immediately. Once this is done, daily control meetings can be held were each functions individual measurements and goals are followed up on, as well as the common goals. However, daily control meetings should prior to this already be implemented in production, as the need for information to production operators is high and information such as amount of orders completed or size of backlog is already available to share. Finally, the process of defining and standardising the roles of the different functions of the product flow can be initiated, by for example gathering stakeholders in a meeting and discussing together which responsibilities each role has. Since stakeholders from different functions are included, consensus can be reached and uncertainties addressed.

The secondary improvements, where implementation will take more effort and time and therefore may require more planning and momentum, are the project based cross-functional teams, synchronized planning, a new digital solution and a visual management system. As explained above in *7.1.2 Cross-functional Meetings*, the Andon meetings are seen as a starting point for implementation of cross-functional teams. Furthermore, it is important that suggested improvements related to goals and measurements as well as standardised roles also have been completed, so there is a clear definition of responsibility within the teams. Furthermore, the implementation of project based cross-functional teams are connected to the introduction of new products, as these are the initial projects which should be handled by the cross-functional teams. Synchronized planning is also deemed as a secondary improvement, as it also is somewhat dependent on more clearly defined goals and performance measurements. This is since in order for planning to be completed successfully, the goals of the product flow need to be defined. Finally, both a new digital solution as well as new visual management systems require an investment into new systems, which is why they are deemed as requiring more time and effort to implement. Furthermore, they also require that both common and clear goals and measurements and clearly defined and standardised roles have been created.

8. Discussion

In this chapter a discussion regarding the results of this master thesis is held, followed by a discussion regarding implementation of suggested improvements. Also the theoretical and practical contribution of the master thesis will be discussed, as well as the generalisability of the study. Lastly, identified areas for future investigation and research will be presented.

8.1 Discussion of Results

In this section the results of this master thesis will be discussed. The discussion is centred on the three main research questions of the thesis, which covers the current status description, the identified areas of friction and the suggested improvements. The results corresponding to each research question will be discussed in terms of validity, correctness and sources of errors.

8.1.1 Current Status Description

The current status description of the product flow for Product Group A was developed through observations as well as both formal and informal interviews. This has resulted in a description of both functions and product flows which accurately describe the actual situation, due to the data collected being primary data. However, as mentioned in previous chapters, there is a high variation of types of products as well as working procedures of the employees of the functions of the product flow. This has the effect that all produced products do not always follow the same product flow, nor do the completed actions of each affected function always include the same process steps. Therefore, the current status description is generalized and represents that average product flow as well as average responsibilities of each function. Thereby not all activities which may be completed are included in the process flow map. Furthermore, due to the complex nature of the product flow, not all possible combinations of connections between different processes and functions can be included. In order to ensure that the presented findings are representative of the actual current state, several group discussions with different stakeholders from the different functions were held. By allowing representatives from each function to give feedback both regarding the functional descriptions as well as the product flow description, the validity of the findings increases and ensures that no important processes or connections where missing. Thereby, the resulting descriptions for both the product flow for new products and the product flow for previously produced products can be regarded as accurately depicting the actuals product flows and provide a good overview of the current status. The results allow for identification of areas of friction within the flow and show that the flow is complex and iterative, with a negative effect on the performance. Furthermore, by developing a visualisation of the product flow, a common view can be gained within the organisation, which can be utilized beyond this master thesis to continuously develop and refine the flow.

The quantitative data, regarding for example throughput time, in the current status description was collected from the company's management system and ERP system. Therefore this data is classified as secondary data, which assumes that it has been reported correctly in order to be accurate. The risk of using secondary data is that the purpose of the data collection is not in line with the current study, increasing the risk of biased and non-accurate results in this master thesis. Further, certain assumptions were made regarding classification of orders into new and previously produced products, which is another source of inaccuracy. This was however done in collaboration with a member of the industrialisation team who had insight in the different products that have been produced, in order to increase validity. Additionally, the collected data is based upon a limited time period of three months. By conducting the study over a longer time period and including a bigger sample, accuracy of the results could be increased. However, since the main purpose of the presented data was to give an overview of the current status of the product flow, the amount of collected data was deemed satisfactory. The collected quantitative data has resulted in a clear picture of the negative effect of issues which occur in the product flow.

8.1.2 Areas of Friction

The identified areas of friction between and within the functions of the product flow were developed mainly based on interviews and observations, similarly to the current status description. Therefore they are based on primary data, with the aim to accurately capture problems. Since the interviews were semi-structured, the interviewees could themselves define issues which they had identified. The issues were collected and combined with observed issues, condensed into a list of frictions and divided up into the defined categories. The risk of collating the issues is that the nuances of the issues are lost, especially those reflecting how the different functions perceive the same issue. Furthermore, since not all employees of the three different functions were interviewed, and due to the limited time which observations took place, there is risk of areas of friction remaining unidentified. However, through group discussions with different stakeholders this risk was minimised. Inclusion of stakeholders from different functions in the same group discussions also allowed for capture of the different views on the same issue and areas of friction between the functions. The views from different functions were also collected in a survey, which was sent out to employees of the three main functions. Therefore the resulting identified areas of friction are relevant and indicates which areas should be improved within the product flow.

Regarding the areas of friction, it is important to consider that even though in this thesis the identified problems are divided up into common and per function areas, the different areas of friction are tightly connected and affect one another due to the complex environment. For example, the lack of cross-functional understanding exacerbates the *us versus them* culture. Therefore, even though an area of friction might be identified as belonging to a certain function, the friction may be present in or affect other functions as well. Furthermore, as this thesis was initiated by the manager of the industrialisation team, there is an increased risk of bias towards the industrialisation function. This is due to the fact that the thesis is centred on the industrialisation function and its processes and for example only investigates the end phase of design, as per the thesis limitations. Furthermore, the industrialisation team has been the main contact at the company and thus have been a starting point for observations. Eventual bias would manifest in the fact that areas of friction are primarily those which negatively affect the industrialisation function. However, measures have been taken to avoid bias, and therefore both interviews and group discussions were held with representatives from all different functions related to the product flow. All functions were thereby able to give input, feedback and share any concerns regarding identified areas of friction and eventual bias. The areas of friction in this thesis are identified objectively, meaning that the areas of friction are identified without any internal incentives. Furthermore, by studying other external companies' ways of working additional perspectives on the areas of friction are gained.

8.1.3 Suggested Improvements

The suggested improvements for improved performance of the product flow were developed based on the current status description and identified areas of friction, which were then connected to the theoretical framework of the master thesis. The results are aimed to mitigate the areas of friction using academic principles and guidelines, which are then adapted to the environment identified in the current status description. The suggested improvements are therefore a starting point for improvement of performance of the product flow and create a foundation for continuous improvement. Also, when improving the product flow, new areas of improvement can be identified which can lead to further mitigation of the identified areas of friction and therefore increased performance for the product flow.

One area of concern regarding the results is that the suggested improvements may not be sufficient in order to mitigate the areas of friction identified. However, the suggested areas of improvements were developed with the goal that no single improvement suggestion should mitigate one single area of friction. Thereby an implementation of a single suggested improvement should provide improvement within at least one area of friction and an implementation of several suggested improvements should assist in mitigating multiple areas of friction. Furthermore, the suggested improvements are aimed at both reducing the amount of issues which arise in the product flow, as well as improving the handling of engineering issues, which are two important perspectives to consider in order ensure increased performance of the product flow.

Since the suggested improvements are based on both areas of friction and current status description, if there are shortcomings in either of these chapters this would carry forward to the suggested improvements. Thus, the risk of the suggested improvements being incomplete is increased, due to the fact that if an area of friction has not been identified, no suggested improvement will have been created to mitigate it. Furthermore, similarly to the areas of friction, the suggested improvements have been consolidated and refined. They have been grouped into three key principles and several ideas were combined into the final suggested improvements presented. There is therefore a risk of losing details, since important aspects may be lost when combining several ideas into a more encompassing improvement. Another area of concern regarding the suggest improvements is sub-optimization. This is due to the fact that the improvement suggestions are focused on the product flow of this master thesis and does not consider how these might impact other parts of the organisation, which are not studied in this thesis due to defined limitations. However, the suggested improvements have also been mentioned in discussions with different stakeholders of different functions, to ensure that risks of insufficient or inappropriate suggested improvements is minimised. This further has enabled input on how the suggested improvements are perceived by the involved functions and what effects they are presumed to have for the different functions of the organisation. To further improve the suggested improvements, an increased amount of input data could have been collected, for example through more in-depth discussion including management.

8.2 Discussion Regarding Implementation

In this section a discussion regarding implementation will be held. Several suggested improvements are presented in *7. Suggested Improvements*, but in order to gain the positive effects on the performance of the product flow, how they are implemented is crucial. According to Davis and Radford (2014), two important aspects in order to reach a successful implementation are communication and involvement. Therefore it is of importance that changes within the product flow are communicated to all affected stakeholders prior the actual change, in order to involve employees in the change. This gives employees the opportunity to prepare for the change and thereby minimize the risk of internal resistance from affected stakeholders. If changes are not communicated properly, employee involvement becomes low and the purpose of the changes are not clear. According to both the ADKAR model and Kotter's eight steps model, creating awareness and understanding of the need of change is an important first step in change management (Hiatt, 2006; Kotter, 1995). As mentioned, involvement of employees is key in order to reach a successful implementation (Davis & Radford, 2014). Affected employees should therefore be involved in the implementations of suggested improvements, to find appropriate solutions and ways of implementation. This has been initiated through the group discussions during this master thesis and should be continued in order to ensure a successful implementation. Involvement eases the implementation of change due to support from employees, which is in line with the second step in the ADKAR model (Hiatt, 2006).

The scope of the suggested improvements in form of time or required resources varies. In order to initiate the implementation work, smaller and easier improvement should be handled first. By creating short term wins, employees' motivation is positively affected and it creates a momentum of change (Kotter, 1995). It can also be good to build on and develop processes which already work well, in order to initiate the change procedure, since barriers for change are smaller and therefore short term wins can be easily captured. One example of this is to base new cross-functional meetings on the already existing meetings, such as Guldgruvan and Andon explained in *4. Current Status Description*. Combined with this, it is of highest importance to develop measurements in order to see the actual effects of the implemented changes. For the studied product flow, an example of a measurement could be lead time. This not only leads to higher intrinsic motivation due to feedback (Hackman & Oldham, 1980), but also leads to a willingness for further improvements through future changes. In addition, improvement measures assure that changes actual result in a positive change for the product flow, which require time to really be realized due to the complex environment and long lead times. Once smaller and easier changes have been successfully implemented, according to both the ADKAR model and Kotter's eight steps model, changes have to be reinforced in order to retain the positive effects of the changes (Hiatt, 2006; Kotter, 1995). Subsequently it is important to continue with the change and improvement work even if short term wins are captured (Kotter, 1995).

Changes also need to be supported by top management, in order to both ensure retention of the implemented changes as well as ensure the spread of knowledge throughout the organization. Top management commitment is further required for establishing the importance of continuous improvements. Based on the last step in Kotter's eight steps model, a culture of change should be developed within the organization, including the creation of structures which support both implemented and future changes (Kotter, 1995). This is in order to ensure continuous development of the product flow of Product Group A beyond the scope of this thesis and improve the performance in a long term perspective. Top management commitment is therefore of highest importance in order to establish these structures for retention of changes and continuously develop the product flow for Product Group A as well as the entire organization. One example of where continuous improvement is important is the area of standardization. Standardizing roles and processes is suggested in order to improve the performance of the product flow, but after successfully implementing this, continuous improvement work should be initiated, further developing the common and standard basis which has been created. Modig and Åhlström (2015) argues that standardisation should be seen as a method to reach a dynamic goal and not be a goal itself. All discussed aspects regarding implementation should be considered by the studied company, when implementing changes presented in this master thesis.

8.3 Contributions and Generalisability

In this section the practical and theoretical contributions of the master thesis will be discussed, as well as the generalisability of the study.

8.3.1 Theoretical Contribution

The main theoretical contribution of this master thesis is how the interface between design and production can be improved in a high technological ETO environment with high variation. This has been achieved by analysing the industrialisation process at a company in such a context. The area of production preparation in complex ETO environments with high variation has not be academically examined to a great extent in established literature, hence this master thesis contributes through an additional study. Further, this thesis contributes with how lean production and concurrent engineering can be applied in tandem in an ETO environment, in order to improve the interface of design and manufacturing through the industrialisation process. The findings in this thesis indicates that lean in ETO environments and concurrent engineering have similarities and that the combination of the two areas may lead to positive synergy effects.

8.3.2 Practical Contribution

The practical contribution for the studied company is first of all an understanding and visualization of the current status of the product flow for Product Group A. No visualization of the product flow existed prior to this master thesis, which also to a high degree was the reason for the initiation of this study. Through the developed visualization of the product flow, which includes both new products and previously produced products, a common understanding of the flow can be created, which further can be used in order to improve the performance of the product flow in the long term perspective. In relation to this, the practical contribution of this master thesis are also the discussions initiated both within and between the functions. By questioning the ways of working and reflecting upon certain activities or processes through interviews and group discussions, valuable discussion both for the thesis and the organization have been initiated. These discussions have already initiated initiatives regarding improvements of the product flow, in line with the presented suggested improvements of this thesis. Thereby the master thesis have contributed with an understanding of both the current status, but also identified problems in terms of areas of friction and suggested improvements, in order to give ideas on how the product flow of Product Group A can be developed. Since the master thesis covers aspects of social sustainability, areas such as motivation, culture and collaboration at the company have been taken into consideration. Thereby the actions suggested for improvement do not only contribute to improved performance of the product flow in terms of shorter lead times, but also positively impacts the social sustainability at the company.

8.3.3 Generalisability

The findings and outcomes of this master thesis can be generalised to a certain extent and used by other companies in the same operational context. Many of the problem areas in terms of areas of friction for the studied product flow are general and most likely exist at other companies within the same kind of complex environment with high variation. This statement is supported by the fact that two additional companies examined in the empirical study showed that similar areas of problems exists or have existed before improvement of the industrialisation process. Therefore the areas of friction hinder the transition from design to production, via the industrialisation, function are seen to be general to some extent, increasing the generalisability of this master thesis. Also many of the improvement suggestions given in terms of three main principles are general for the transition from design to manufacturing, since collaboration, standardisation and transparency has been important for all three involved companies in this master thesis as well as being supported in academic literature. The principles aims at increasing and improving ways of handling variation, which are present in most ETO environments. The suggested actions within the principles are of more detailed character and are adapted to the studied company's current state and areas of friction. Regardless, inspiration from the suggested improvement can be taken and actual improvements would need to be adjusted according to context. Important to remember is that findings in this master thesis are suitable for environments with high variation and complex products.

8.4 Areas for Future Investigation and Research

During this master thesis, a number of areas regarding future investigation and research have been identified. These have been identified both as a continuation of the work of this master thesis as well as areas where information was perceived as lacking during the literature study.

One area for future investigation would be to conduct additional master theses connected to the product flow of Product Group A, in essence for the design function and the production function. It would been valuable to investigate how outcomes from this master thesis can be applied and utilized in other functions of the product flow as well as in other product flows within the company. This is due to the fact that areas of improvement were identified during the study which were outside the scope of this master thesis. Furthermore, completing similar studies on other functions can decrease the risk of sub-optimization, especially if a number of projects are completed simultaneously. Another area of investigation connected to this would be to have a project devoted to looking at the entire product life cycle of Product Group A. This would be a wider project conducted for a longer time period. The benefit of covering the entire life cycle is to more clearly being able to see the cross-functional effects of cooperation and collaboration, as well as being able to see how all the different functions affect each other.

Another area of future investigation would be to examine the effects of an implementation of the suggested improvements in this master thesis. This would allow for a validation of the results in this thesis, as well as identify which factors are the most important when trying to increase performance of a high variation product flow in an ETO environment. Connected to this could be research done on best practice, where the product development processes at other similar companies are investigated, and key success factors identified.

A more theoretical area of future research, where current research was found lacking, would be a more detailed look at production preparation as the interface between design and manufacturing. Further, a deeper look at how different manufacturing environments affect this would be of interest. Also, studies on how concurrent engineering and lean production can be combined in relation to industrialisation processes would be of interest, specifically both positive and negative synergies which could be achieved through a combination of these two principles.

9. Conclusion

The aim of this master thesis was to improve the performance of the product flow for Product Group A by identifying applicable principles and guidelines. By developing a current status description, several areas of friction were identified. Based on this, suggested improvements were developed with foundation primarily in concurrent engineering, lean production and social sustainability. An implementation of these suggested improvements will improve the performance of the product flow and thereby the aim of this master thesis is fulfilled. The three research questions which have ensured fulfilment of the aim are answered below.

1. *What is the structure of the product flow for Product Group A and how do the different processes interact?*

Based on interviews and observations a visualization of the product flow was created, consisting of one flow for new products and one flow for previous produced products, due to the different processes involved. Due to a high number of interactions and dependencies between primarily the design, industrialisation and production functions, the product flow of Product Group A is very complex. The flow of an individual product depends on if issues arise during the process. If issues arise for a product, the average throughput time doubles, due to the iterative interactions required between the functions of the product flow.

2. *What areas of friction arise during and between the processes of the product flow of Product Group A and how does this affect the product flow's performance?*

Several areas of frictions for the product flow of Product Group A were identified, both within and between the functions. High variation of products and working procedures, as well as weak coordination and lack of communication between the functions results in longer lead times, negatively affecting the performance of the product flow. This is due to the occurrence of non-value adding activities, such as waiting and rework. This is further exacerbated by the late involvement of the industrialisation team and uneven level of knowledge in the production function, increasing the number of issues in the product flow. Lack of feedback and an *us versus them* culture within the product flow also negatively affect both the performance as well as the social sustainability.

3. *What principles and guidelines can be applied in order to mitigate the above frictions or their effects to increase the performance of the product flow for Product Group A?*

Collaboration, standardisation and transparency have been identified as the three key principles in order to increase the performance of the product flow. Within each principle, a set of suggested improvements were identified. Cross-functional teams and meetings, common goals and measurements, synchronized planning, clear and standardized roles and processes, as well as daily control meetings, utilization of visual management and digital solutions are some of the suggested improvements. These positively affect the performance of the product flow in terms of improved coordination and collaboration, shorter lead times, decreased non-value adding times and increased motivation of employees.

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Appendix A – Interview Template

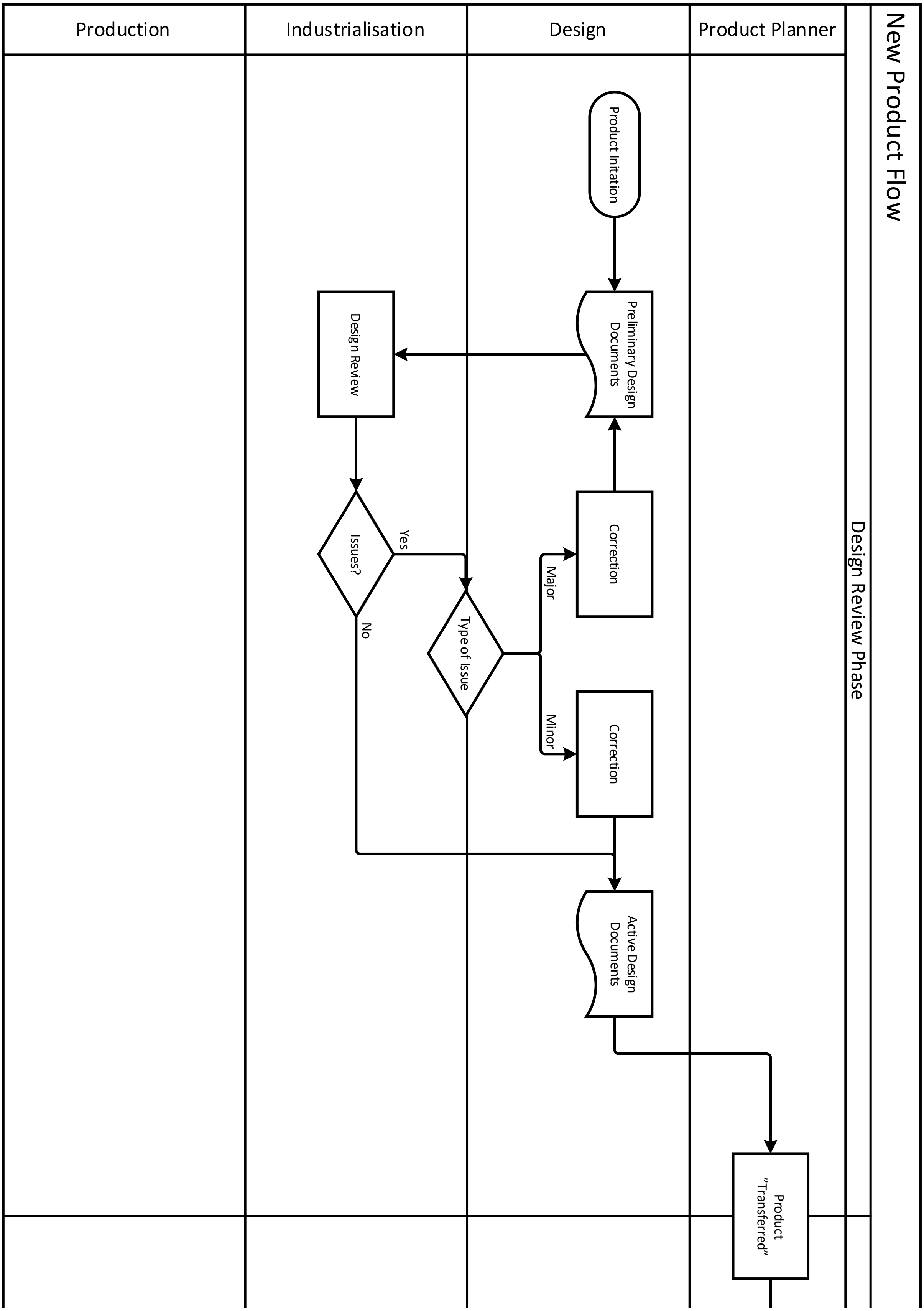
In this appendix the interview template for the semi-structured interviews are presented. The interviews were held in Swedish.

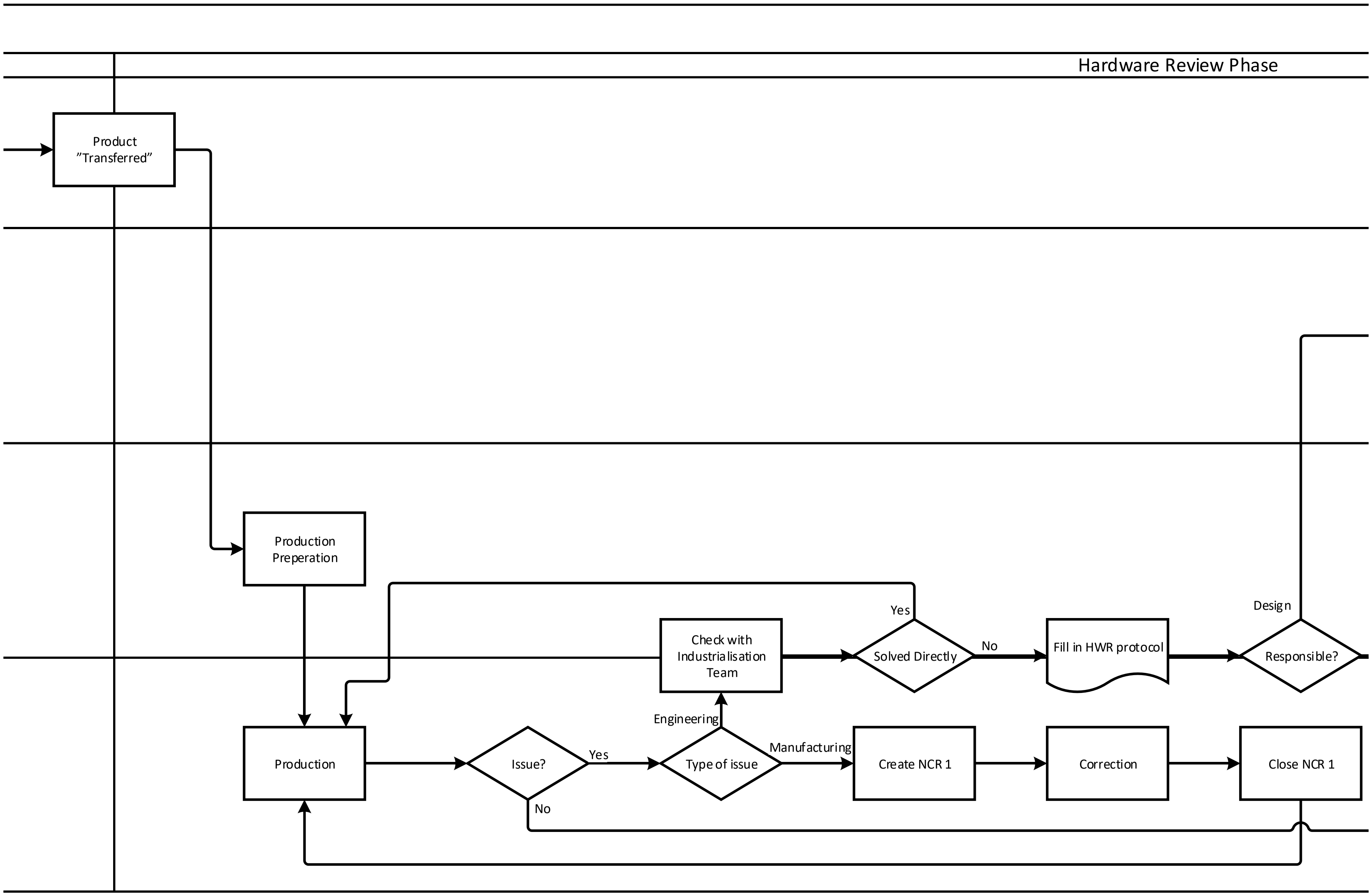
Namn:
Funktion:

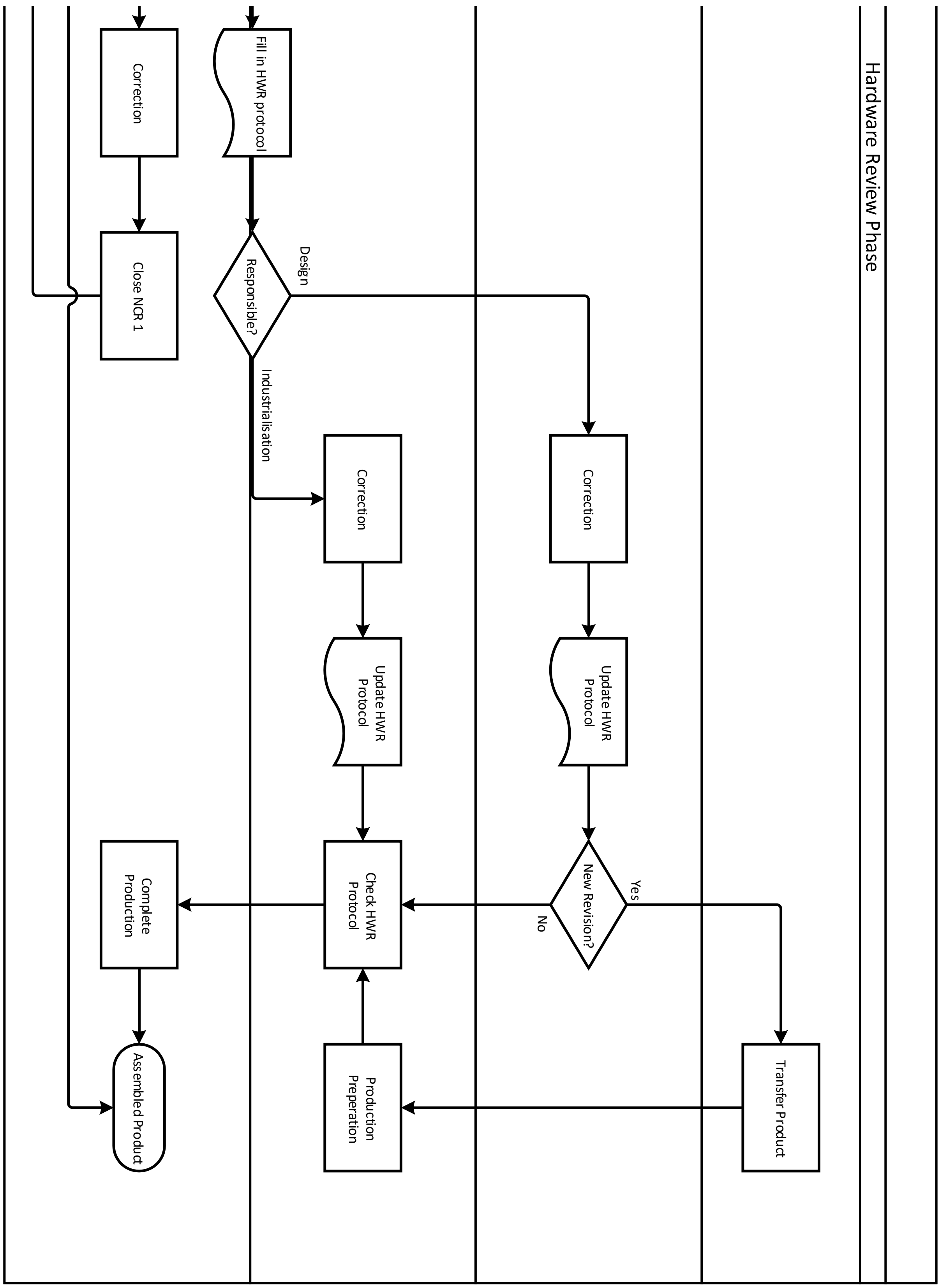
- Vilken roll har du? Vad innefattar den? Beskriv gärna!
- Hur länge har du haft denna roll? Hur länge har du jobbat på företaget?
    - Beskriv hur upplärningen såg ut när du började här. Vad anser du saknas i din upplärning?
- Vad tar mest tid i ditt arbete? Känner du att du måste bortprioritera annat?
- Hur ofta upplever du att det uppkommer störningar i ditt arbete?
- Vilka ansvarsområden anser du att du och din funktion har?
    - Hur ser er daglig styrning ut? Hur vet ni vad ni ska göra under dagen och hur det går med nuvarande arbete i förhållande till plan?
    - Vilka mål jobbar du/ni mot? KPI?
- Vem tar du över efter i processen? Vad är dina förväntningar på dem?
- När du är färdig med dina arbetsuppgifter, vem tar över efter dig? Vad förväntar de sig från dig?
- Hur upplever du tillverkningen av produktgrupp A (från konstruktion till produktion)?
    - Vad fungerar bra? Vad är bristande?
    - Några förslag på vad som skulle kunna ändras?
- Vilka funktioner/ansvar anser du att konstruktion/industrialisering/produktion har?
    - Vad tror du de spenderar mest tid på?
    - Ser du några problem i deras process?
- Hur fungerar kommunikationen och samarbetet inom din funktion?
    - Frekvens? (Dagligen, veckovis osv).
- Hur fungerar kommunikationen och samarbetet mot konstruktion/industrialisering/produktion?
    - Vem har du kontakt med? Frekvens? (Dagligen, veckovis osv).
- Hur upplever du din arbetsbelastning och arbetssituation?
- Hur organiserar du dina arbetsuppgifter? Vem bestämmer prioriteringar?
- Vilka moment eller brister i ditt arbete anser du försvårar din arbetssituation?
    - Tycker du att det finns arbetsuppgifter som är onödiga?
- Är det något övrigt du vill lyfta angående produktion av produktgrupp A?

Tack för ditt medverkande!

Appendix B – Product Flow for New Products




Hardware Review Phase
Product
"Transferred"
Production
Preperation
Production
Issue?
Yes
No
Type of issue
Engineering
Manufacturing
Check with
Industrialisation
Team
Solved Directly
Yes
No
Fill in HWR protocol
Responsible?
Design
Create NCR 1
Correction
Close NCR 1


Hardware Review Phase
Fill in HWR protocol
Correction
Close NCR 1
Responsible?
Design
Industrialisation
Correction
Correction
Update HWR Protocol
Update HWR Protocol
New Revision?
Yes
No
Check HWR Protocol
Complete Production
Transfer Product
Production Preperation
Assembled Product

Appendix C – Product Flow for Previously Produced Products