THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Challenges in Global Multi-Variant Serial Production
- A Study of Manufacturing Engineering Processes

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Cover: A production network showing dispersed manufacturing
in terms of localization and product variants.

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'You are not allowed to have pillows in the water.
They might sink, and then the ducks, sharks and crocodiles will come.'

– Alice, age 3

Abstract

Global manufacturing companies have hard times to manage their global production networks as dispersion in their networks increases. Such dispersion is caused by the increasing level of product variety and more parameters to control as the networks grow. Handling product variety becomes more difficult as products become more complex and integrated. Product variety and its impact on productivity have been studied for several years. Those studies show that product variety has negative impact on productivity. There are no signs that product variety will decrease in the future. Nor are there any signs showing that the size of global product networks will decrease over time. Therefore, it is important to understand how product variety affects global production networks.

The aim of this thesis is to investigate how global manufacturing companies operate their production networks in terms of manufacturing engineering processes and operational performance with respect to product variety. Due to the size of global production networks, engineering processes and systems tend to be dispersed. Therefore, the focus of this thesis is on studying manufacturing engineering processes in terms of standards for creating assembly work instructions for manual assembly and the effects of high product variety on operational performance in the same production network. In this study similarities and dissimilarities in such processes are mapped within one global production network.

Four different cases studies have been designed and conducted collecting important data defining the setup for the investigated production network. Questionnaires, interviews and production data are used to map current manufacturing engineering processes and to study the effects of high product variety on operational performance. Results from the case studies show that the studied production network handles high levels of product variety and that the manufacturing engineering processes are highly dispersed due to lack of global standards. The high level of product variety has negative impact on operational performance as operators are facing unfamiliar product variants on a daily basis. Furthermore, the high level of product variety makes it more difficult for manufacturing engineering to create better and more supportive assembly work instructions.

Future research activities should focus more on early phases of the engineering process. By studying the engineering process in more detail, a mature information model can be created defining (1) what information is used, (2) by whom it is used, (3) where in the process it is used and (4) for what purpose the information is used. Such an information model is essential to be able to develop better methods to handle high product variety in global production networks.

Keywords: *Global production networks, product variety, product and process standardization, product and production complexity*

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Gothenburg, Sweden, March, 2016
Pierre Eric Christian Johansson

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Definitions

Automotive industry	Passenger car industry
Built-to-Customer	The product is customized to fit a specific customer.
Built-to-Stock	The product is customized by a dealer to fit a group of potential customers.
Group leader	A person with responsibility to organize a group of operators under the production leader. The group leader is normally a part time operator.
Vehicle industry	Vehicle industry containing passenger cars, heavy duty trucks, busses etc.

Abbreviations

GATT	The General Agreement on Tariffs and Trade
GPN	Global Production Network
ICT	Information Communication Technology
IMVP	International Motor Vehicle Programme
NAFTA	North American Free Trade Agreement
OEM	Original Equipment Manufacturer
RQ	Research Question
WTO	World Trade Organization

Preface

A major part of this thesis has been conducted in the frame of the research project GAIS[i] (2013-02648), *Global Assembly Information Strategies*. The project was conducted from 2013 to 2015, 24 months. Representing one of the industrial case companies the focus was to identify how of ICT tools are used for transfer assembly information to operators at the shop floor. The reason was to identify how standards are implemented and used for a part of the manufacturing preparation process. The project was founded by Vinnova-FFI and was carried out in collaboration between Volvo Group, SAAB Aeronautics, Chalmers, Gothenburg Technical College and Scania.

Figure I: The logotype used for the GAIS project.

Another research project that has made this research possible, is the EU-founded project Know4Car[ii], grant agreement number 284602, funded by the EC Seventh Framework Programme theme FoF-ICT-2011.7.4. The result of the project is related to this thesis in terms of product variation management and is published in papers listed under *additional papers*.

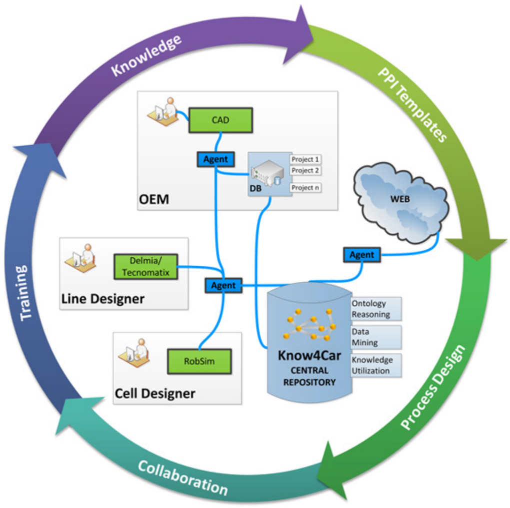

Figure II: The key features of the Know4Car platform.

[i] http://www.vinnova.se/sv/Resultat/Projekt/Effekta/GAIS/
[ii] http://www.know4car.eu/

1 Introduction

This chapter includes an introduction of what the reader can expect from this thesis.

1.1 Background

As an effect of the intense competition in the world market, companies enter new markets to reach potential new customers. A non-homogeneous market is challenging for global companies; therefore, the companies seek to diversify their products and service offerings to better suit market requirements (Hart, 1995; Pine II, 1999). As a result, product life cycles are decreasing and product variety is increasing (ElMaraghy et al., 2013). Today, product variety and operations have become more important. Therefore, it is necessary to find a balance between product simplification and keeping up satisfactory levels of market differentiation (Burkett, 2008). Without such balance there are risks that the operational costs from increased variety become equal or higher than the gain from the increased revenue (M. Fisher, Jain, & MacDuffie, 1995).

Handling product variety becomes more difficult as products become more complex and integrated. This is particularly evident within manual assembly in the vehicle industry. From previous research (Vachon & Klassen, 2002), a link between product complexity and production process complexity (number of parts/components and sub processes) and delivery performance was found. A decrease in such complexity has a positive effect on lead time and throughput time. Other researchers (Falck, Örtengren, & Rosenqvist, 2014) found significant correlation between complexity and assembly time as well as between complexity and assembly errors. These newer findings support earlier conclusions which claim that product variety is negatively correlated with productivity (M. L. Fisher & Ittner, 1999). As the amount of product variety is correlated with productivity, there is a need to understand how production of products with high variety can be better managed in the manufacturing engineering process providing support to manual assembly.

Different industries have different needs. Most research concerning vehicle manufacturing has focused on the automotive industry and its conditions. When it comes to manufacturing of heavy vehicles there are fewer explicit contributions to the field. Although these industries share similar problem areas, significant differences are evident. The amount of customization in a heavy duty truck is tremendously higher than in a common passenger car model and brand. For the automotive industry it is more common to have short cycle times during assembly while the heavy vehicle industry typically uses longer cycle times. Such differences are of particular interest for the research of cognitive processes as the amount of work content affects the cycle time needed. These examples of differences indicate that there are research gaps that need to be addressed as new technology besides increasing customization, is continuously making production of heavy vehicles more complex.

1.1.1 Handling high product variety in extensive global production networks

More and more independent vehicle manufacturers merge with larger multinational companies. Such multinational companies dominate the global market. Companies like Daimler AG, Volkswagen AG, FCA group and Volvo Group have extensive product portfolios and brands. As manufacturing companies continue to grow, so do their global production networks. Depending on whether the growth is organic or accomplished by mergers or acquisitions, a certain amount of legacy is added to the new company structure. Companies that have grown according to a defined acquisition strategy have a difficult time dealing with integration; their businesses become too diversified (Hitt, Ireland, & Harrison, 2001, p. 116; Ireland, Hoskisson, & Hitt, 2008, p. 141). When a company grows it becomes more important to find a correct balance between corporate strategy and manufacturing decisions. This becomes troublesome when no stated strategy for integration has been clearly defined. Skinner (1969) lifted this dilemma already in 1969: 'when companies fail to recognize the relationship between manufacturing decisions and corporate strategy, they may become saddled with seriously non-competitive production systems which are expensive and time-consuming to change'(pp.136-137).

One of the key points when developing global supply chains is to come closer to the potential market and to better serve the market demands (Lüthje, 2015). But being global is challenging for companies who struggle with being able to offer their products on a global market while trying to manage their global production networks. The amount of factors that affect the production networks are increasing as the companies continue to grow (Olhager, Pashaei, & Sternberg, 2015). Traditionally, these networks have been categorized by their use of fixed systems constraints and their limited reflection on network dynamics. This has made production networks hard to reconfigure within limited time frames (Ferdows, 2014). Instead, by incorporating structural flexibility and being more responsive, the companies will be able to reconfigure their networks when needed (Brennan et al., 2015). When a global manufacturing company is facing quick changes in the market, it is their product strategy in terms of product variety and flexibility in their production systems that will determine the robustness of their business (Wiendahl, 2007).

The extensive product portfolios of the vehicle manufacturers, can offer customers customized solutions for their specific needs. This vast variety of products and components is complex to handle in terms of product development and production development. Over the past few decades, trucks have become more complex in terms of new materials, new features and more software and electronics. In combination with highly customized vehicles the available product variants are rapidly increasing which puts a dilemma on the agenda; cost effective production with highest available quality (Aoki, Staeblein, & Tomino, 2014). In a study from 1999 (M. L. Fisher & Ittner, 1999), a correlation between product variability and rework was found. Today, this has become even more interesting since product variability has continued to increase.

As the amount of product variety continues to grow new methods and principles need to be incorporated so that manufacturing processes remain robust. To understand how high product variety and better responsiveness can be handled in a proper way in the future, it is important to understand current levels of product variety and their implication on production performance. Traditionally, standardization has long been the baseline for maintaining high production performance. In this thesis, standardization has been of particular interest as it is believed to strengthen global processes making production networks more responsive and easier to reconfigure. This thesis has focused on manual assembly and the process of creating assembly work instructions for heavy duty trucks to see how product variety is treated and affects production performance. Furthermore, it has focused on how standardization is incorporated in such a process.

1.2 Research context

The research activities and result presented in this thesis have been conducted during the GAIS project, introduced in the preface of this thesis. The general aim for that particular project was to investigate how smart ICT tools can be used in the globalization of smart manufacturing. This thesis focuses on one of the case companies in the project. Extensive research activities have been performed within the GPN of the case company. The GPN consists of 45 factories around the globe manufacturing trucks, engines and transmissions.

The research in this thesis has, in particular, investigated manufacturing engineering processes where assembly work instructions are created for manual assembly of heavy duty trucks, engines and transmissions. As the product variety is high within this product segment, during the project it has been hypothesized that such product variety has negative impact on production performance. Therefore, the investigation has focused on what challenges exists and what impact such challenges have on production performance in the context of manufacturing engineering processes within a global production network.

1.3 Aim and research questions

The aim of this thesis has been to investigate how a typical global manufacturing company operates their GPN in the context of standardized manufacturing engineering processes. In such processes the focus has been put on the creation and handling of assembly work instructions. The thesis focuses on increasing the knowledge of the impact of high product variety and its impact on production performance. Increasing this awareness and knowledge lays the foundation for designing robust, flexible and responsive production systems. Therefore, two research questions (RQ1 and RQ2) were defined to guide the research activities.

RQ1: What is the current state of using standards when transferring assembly work instructions to the operators in manual assembly?

In the automotive industry, the implementation and use of standardized processes is a well-used practice. Standardization is a major enabler of operational consistency (Liker & Meier, 2006). As mentioned in the background, a general growth strategy in industry is through acquisitions. Such acquisitions cause production networks to grow larger making them more difficult to manage. For industries, like the vehicle industry, it is common with high product variety which is treated in standardized processes. With global production networks that contain multiple brands and product models with rich variety, there are risks that such production networks tend to become less standardized. Mapping the current state of using standards when transferring assembly work instruction to the operators, will serve as a knowledgebase of how standards are perceived and used by manufacturing engineers.

RQ2: What are the challenges in manufacturing engineering processes in production networks handling multiple brands with high product variety?

Companies that become global are facing challenges as their engineering processes and operations tend to become more fragmentated by the disperged location of their entities (Egaña, Kamp, & Errasti, 2013). Such fragmentation may cause diversification of operations.

It is well-known that high product variety and complex products makes manual assembly more error prone if non sufficient support systems are implented in the manufacturing process (Fast-Berglund, Fässberg, Hellman, Davidsson, & Stahre, 2013). Operations are dependent on that sufficient assembly information (e.g. instructions and specifications) are provided to the operators to gain consitency and high quality. But, high product variety is challenging to handle in manufacturing engineering processes. This would imply that these challenges would have impact on operational performance. Studying the effect of high product variety, as the research question implies, would enable construction and design of methods and tools that can limit performance loss due to high product variety. Such methods and tools will be the aim for future research activities.

1.4 Delimitations

In this thesis the effects of large amounts of product variants has only been studied in the context of manual assembly since it was considered that product variants have a strong correlation with operational performance in manual assembly. In literature it is stated that auto manufacturers build cars in two setups; built-to-stock and built-to-customer (Pil & Holweg, 2004). Since manufacturing of heavy vehicles, in general, only considers high levels of customization, the thesis is only considering built-to-customer configurations. This thesis does not consider different methods for product development nor the development process itself. Instead, it uses product development as a source for product variety which puts constraints on manual assembly. In this thesis the focus has been put on the process for creating assembly work instructions and how these are distributed and presented to the operators. Such a process is in this thesis defined as a manufacturing engineering process. The case studies presented in this thesis have been conducted within one global production network belonging to a truck manufacturing company.

1.5 Disposition of thesis

This thesis is divided into six chapters. The disposition of the thesis and an overview of each chapter are presented in Table 1.

Table 1: Disposition of the thesis.

Chapter	Content
1. Introduction	The first chapter introduces the background for global manufacturing and its development. The focus is put on the growth of global companies and how their production networks are affected by internal and external factors as well as by company strategies. It also presents the aim of the research together with the two defined research questions. Additionally, it explains the delimitations for this research.
2. Theoretical framework	The second chapter presents the literature studies which demonstrate current research results and gaps. Here, globalization, global production networks, perception of complexity, challenges and product and process standardization are presented to be able to discuss the implication of increased product variety in the manufacturing context.
3. Research approach and methods	The third chapter presents the overall research approach used giving the result presented in this thesis. It also presents the research methods used to collect and analyse data in each case study.
4. Summary of appended papers	The fourth chapter presents the main findings as a summary of research papers written and published. Their contributions to the research question are also explained.
5. Discussion	The fifth chapter discusses the research results and their relations to previous research and their implications of future development of global manufacturing strategies.
6. Conclusion	The sixth and final chapter summarizes the thesis and provides answers to defined research questions and the contribution to the research area.

2 Theoretical framework

2.1 Companies that grows

Acquisitions and mergers are common corporate strategies enabling economic growth. In general, acquisitions and mergers are different in legal terms (Hubbard, 1999, pp. 6–7). In this thesis, both are addressed as acquisitions for the case company. Five reasons why companies acquires other businesses through acquisitions are gain in market power, increased growth, reduce costs, management of risks and economical actions and learning of capability building (Ireland et al., 2008, p. 133). Furthermore, by acquiring companies, the acquirer can diversify its business by enlarging the product portfolio with already existing products on the market (Graebner, Eisenhardt, & Roundy, 2010). However, acquisitions are also connected to certain risks and pitfalls that might negatively affect the outcome of an acquisition (Graebner et al., 2010; Hubbard, 1999; Ireland et al., 2008). One of the major risks when performing acquisitions, is to over-diversify the business where it no longer can be efficiently managed (Hitt et al., 2001, p. 116; Ireland et al., 2008, p. 141). Especially when it comes to establishing synergies between two former separate entities, many companies fail. The new business capability is intended to be greater than the value the entities have created independently (Hitt et al., 2001, pp. 85–86). Therefore, when performing acquisitions preconditions, as well as post-conditions, are important to consider. During the process it is important to understand the business value behind the decisions, and the ability to succeed with post-acquisition integration between involved entities (Sudarsanam, 2003, p. 5). The integration between the two entities in the acquisition can be expensive and time consuming but important to reaching business growth, especially in 'knowledge intensive industries'. Performing acquisitions without performing knowledge exploitation or exploration would not provide any economic value (Verbeke, 2010, p. 44). Furthermore, when companies grow, it is important that necessary support processes are in place to handle the new business situation that arises (Tatum, 2007).

2.2 Becoming global

The world has undertaken a transition towards globalization for several centuries. In the beginning of the 19th century, globalization in terms of economy was not very present among politicians and business men. At the beginning of the 20th century the picture was totally different. Local markets were influenced by other markets, development, investment in and by foreign countries (O'Rourke & Williamson, 2001, pp. 1–2). A major breakthrough of globalization started when different trade barriers began to be demolished. The General agreement on tariffs and trade, GATT, was introduced at the late 1940s (Barton, Goldstein, Josling, & Steinberg, 2010, p. 2). In 2015, no less than 161 countries were members of the World Trade Organization, WTO, where the GATT is incorporated as a master agreement (World Trade Organization, 2015). Analysis of the effect of the GATT has been conducted by several researchers and the further improved analytical method concludes that the trading system has an increasing effect of bilateral trade in both the short and the long term perspective (Herz & Wagner, 2011).

Globalization has changed the prerequisites for handling the manufacturing capability of a company. Short-lived products, as a cause of rapid changes in product demands around the globe, provide opportunities and at the same time challenges the capabilities of the manufacturing companies (Koren, 2010, p. 1). Potentially, there are four different groups (see Figure 1) of drivers which drive the globalization in industry; government, competition, cost and market (Yip & Hult, 2012, pp. 10–11). Through globalization, moving competition from the national arena to the global arena, increases the possibilities for the company to invest in a larger potential customer base and to achieve new levels of competiveness. Competition stands also in relation to the performance of other actors and what investments they make (Hill, 2008, p. 368). New trade legislation and the establishment of free trade agreements like the North American Free Trade Agreement, NAFTA, and EU have made it easier for companies to become global and access a wider market. Additionally, the introduction of widespread technical standards has made it possible for companies to offer their products to new potential customers (Hill, 2008, p. 369). Cost drivers correspond to the economic development strategy of the company and its running costs. By globalizing production, the company could potentially reduce cost by investing in production in low-cost countries. Furthermore, as transportation costs have generally decreased (Chase-dunn, 1999), the cost impact of transport between production plants in low-wage countries and high-wage countries is lower in some industries. The enlarged market potentially increases the possibility for companies to find customers with the needs and preferences that fit their offerings. The globalization has made it possible for customers to find suppliers on a global basis which may better address their needs (Hill, 2008, pp. 366–367).

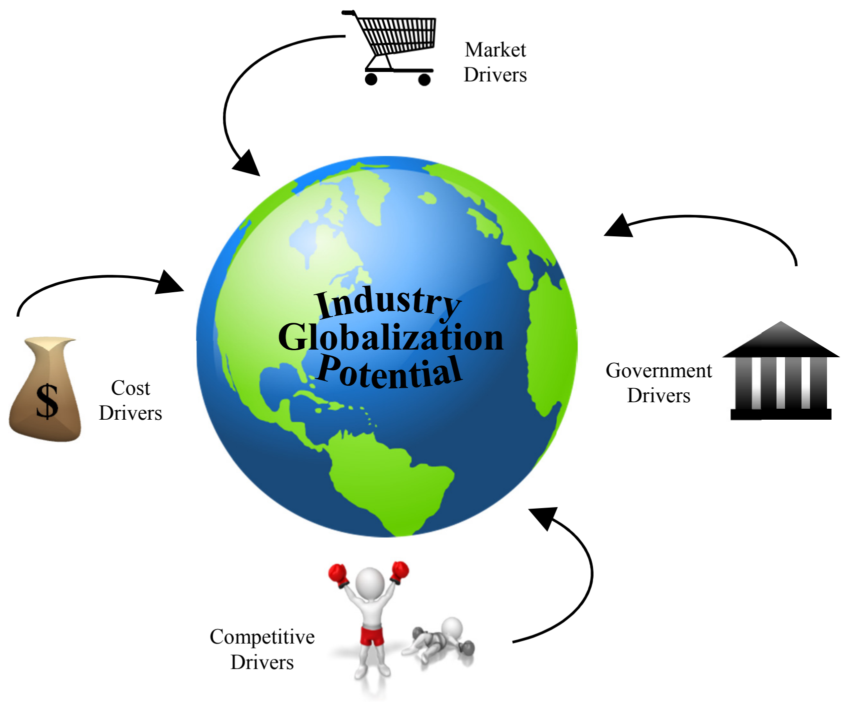

Figure 1: Factors that drive the globalization of industry (Yip & Hult, 2012, p. 10), edited.

Trade in goods and services, is expanding faster than the growth rate of the global economy. The configuration of global manufacturing is strongly driven by the outsourcing and off-shoring trends (Brennan et al., 2015). It has been argued that the growth of globalization is affected by new communication technology and transportation technologies, see (Abele, Meyer, Näher, Strube, & Sykes, 2008; Egaña et al., 2013; Ferdows, 2009). The development of global manufacturing is stimulated by decreasing taxes and tariffs. The ability to source low cost material and man power from low wage countries influences the trend towards global outsourcing (Gong, 2013, p. 53). As globalization is driven by different cost factors, capital intensive production often stays in the home country while the labour intensive part of the production is often localized in low wage countries (Lüthje, 2015). Replacing capital intensive production processes with labour intensive processes makes it possible for manufacturing companies to use their potential to set up cost effective factories in low wage countries (Abele et al., 2008, p. 193).

2.2.1 Global production networks

The globalization paradigm has resulted in demolition of boundaries as the traditional national manufacturing companies became global with operations in multiple locations. These companies are now organized as global production networks, GPN. A GPN may consist of several units where each unit serves a specific function. To distinguish among the different nodes in a GPN, six strategic roles are used to define their different functions. These roles are offshore, source, server, contributor, outpost and lead and are further described in Table 2 (Ferdows, 1997).

Table 2: Different factories within a GPN serve a specific function.

Function	Description
Offshore factory	Manufactures components to low cost. Low investments in technology and managerial resources as well as low on-site engineering capabilities.
Source factory	A source factory is focused on low cost production, but has technical capabilities and access to high skilled labour.
Server factory	The server factory supplies a specific market to overcome tariff barriers and its technical capabilities are limited to minor product adjustments.
Contributor factory	The contributor factory supplies a specific market and has engineering capabilities to control product and process. It competes with the home factory to test new processes and technology.
Outpost factory	The main function of an outpost factory is to collect strategic information from the local market (e.g. competitors, research institutes etc.) A secondary target is to function as an offshore or server factory.
Lead factory	The lead factory develops new products, processes and technology for the whole company.

The GPN also includes different layers of suppliers which may serve the network factories with both supplier developed and manufactured components (Karlsson & Christer, 2003). The key node in such a production network is in literature referred to as the flagship which may both define the company itself and also its function in the network. Such flagships organize the setup of the production network (Rugman, 1997, p. 182) and may be categorized as either ‘brand leader’ or ‘contract manufacturer’. The ‘contract manufacturer’ refers to manufacturing companies which supply OEMs on a global basis and consists of its own GPN (Ernst & Kim, 2002). In Figure 2, a GPN is illustrated showing the flagship and it’s inter and intra company connections. Such a flagship can function as a lead factory in the production network.

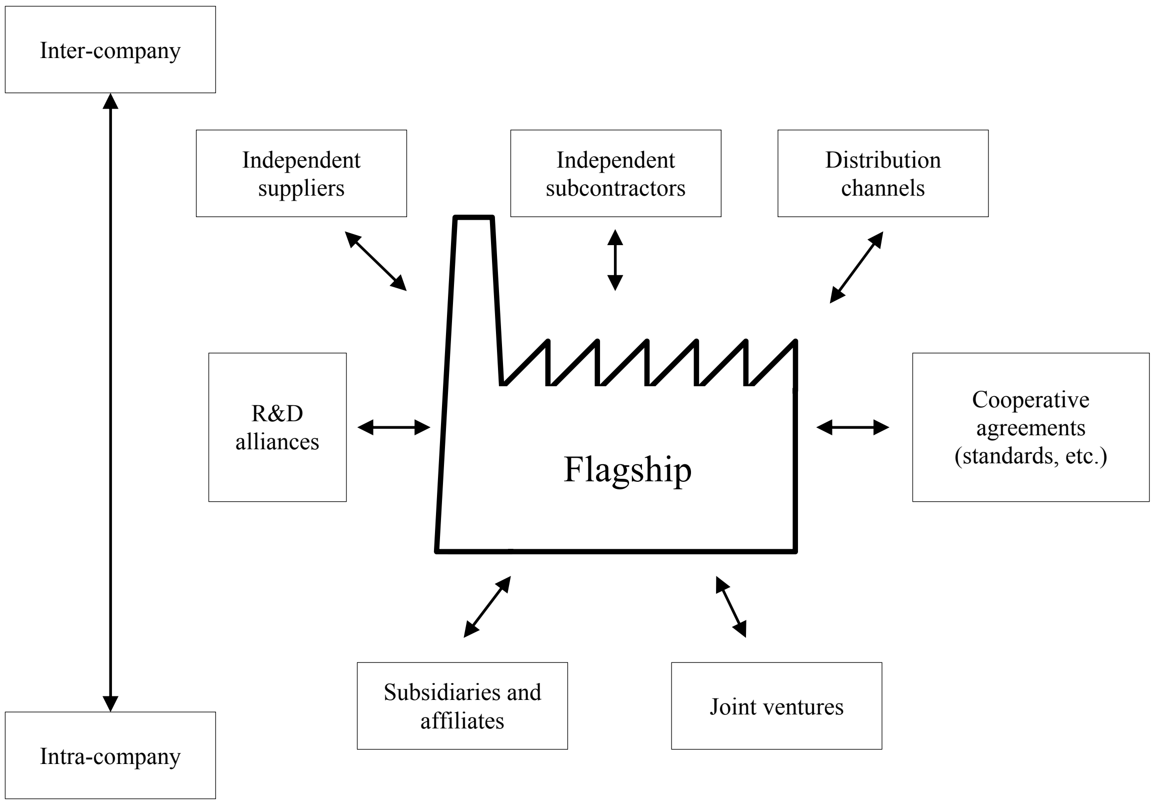

Figure 2: A production network with a flagship in the middle (Ernst & Kim, 2002), edited[1].

There are several benefits for manufacturing companies going global and establishing GPNs. Since the costs and risks when performing international transactions have decreased, the establishment of global production networks gains from the access to external resources and capabilities. Those resources and capabilities are needed by the manufacturing companies when the competition becomes more complex as a direct effect of business dispersion. The production networks need to better integrate such expertise, knowledge and resources in to the manufacturing companies’ organizations (Ernst & Kim, 2002). However, production networks can also be hard to manage due to their complex structures and the amount of variables that control the changeability and evolution of the networks. The complex structure of a production network can make it hard for rapid changes when market opportunities changes (Ferdows, 2014). This is supported by Lampel and Giachetti (2013), who argue that diversifying manufacturing will limit positive development as it increases internal costs and constraints to maintain the GPN. The GPN is also challenged in overcoming cultural and language barriers that might occur as a direct effect of expanding geographically. Additionally, the dispersed entities in the network make it a challenge for management to transfer knowledge and best practice around the network assuring that all entities gain from

[1] With permission from Elsevier.

local process improvements made (Abele et al., 2008, p. 313). Since one of the general purposes of a GPN is to spread so called ‘know-how’ from one part of the world to another in order to be globally competitive, it is of utmost importance for the company to assure that such process is implemented and functioning (North, 1997, p. 1). An implementation of a global production system can be an enabler of this (Abele et al., 2008, p. 313).

2.2.2 Challenges in global manufacturing companies

The international motor vehicle programme, IMVP, is the biggest international study of the automotive industry. The book *The machine that changed the world* (Womack, Jones, & Roos, 1990), was ground breaking as it introduced lean manufacturing and the gain of working with continuous improvements as the core, step-by-step, increasing production performance. The competitive manufacturing company never stops working with continuous improvements of their manufacturing capabilities. Continuous improvements can sometimes be hard, especially when there are several factors that play certain roles in the bigger picture. The sand cone model (illustrated in Figure 3) introduced by Ferdows and De Meyer (1990) is often used as it demonstrates how the investment towards a certain goal depends on other factors as well. In their example they suggest quality as the base of the sand cone. To gain in dependability, speed and finally cost efficiency, one has to pour more sand over the sand cone. To reach cost efficiency (height of the sand cone), the sand cone must grow in width. This means that larger investments in quality are needed.

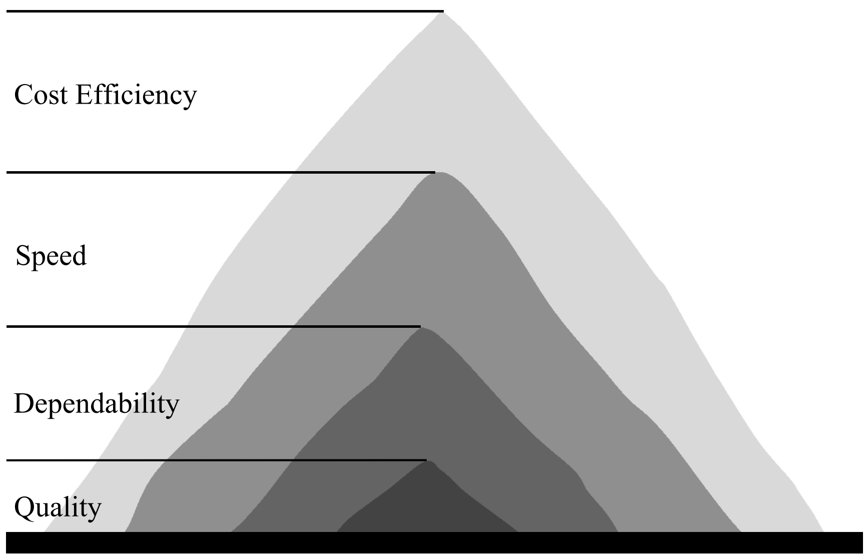

Figure 3: The Sand cone model (Ferdows & De Meyer, 1990), edited[2].

Many manufacturers tend to over-diversify their business in terms of introducing new products, new markets and new technology. With this diversification, the manufacturing company risks facing internal competition and a combination of problems which are difficult to solve and will end in increasing costs (Skinner, 1974). In more present time, researchers highlight that the rapid change in the market and the shortening of product life-cycles affect production quality in factories. During the introduction of new products in production, the discard rate and amount of products with quality defects are high, which causes economical

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loss for the manufacturing company. Production quality in assembly is negatively affected by the frequently altered products (Su, Liu, & Lai, 2009). Product variety causes a direct problem for the operator. An operator needs to be able to identify a specific product variant when it arrives at the work station. High product variety will make it harder for the operator to perform such identification as well as to recall the correct assembly sequence and components (Huang & Inman, 2010), especially, when the operator is rotating at different assembly stations. This is also depending on the length of the cycle time. The cost impact of introducing more variety into a production system is hard to measure as there are several sources behind the impact. Furthermore, decision makers are rarely aware of the consequences that come with an increase of product variety (Ericsson & Erixon, 1999). Such variety makes it hard to create good assembly work instructions for the operators. When the assembly work instructions lack vital information the operators need to trust their knowledge and experience to make decisions (Berger, 1997). In previous studies it has been shown that the amount of assembly errors increases when the room for making own decisions is increased. The lack of cognitive decision support influences production quality negatively (Fast-Berglund et al., 2013). This cognitive support is required to reduce the negative impact of production with high levels of perceived complexity (Fässberg & Fasth, 2011). When introducing more product variety, the manufacturing company is dependent on IT. But to make IT work there must be an alignment between current business processes and IT assets in the organization of the company. From research it is suggested that most alignment work is only focusing on alignment of IT with business and not the opposite; alignment must consider both aspects (Luftman, 2015, pp. 7–8).

2.2.3 Perception of complexity in an industrial context

Several researchers have focused their attention on complexity in a manufacturing context. A definition of plain complexity can be defined as 'the measure of uncertainty in achieving the functional requirements of a system due to poor design or lack of understanding and knowledge about the system' (Suh, 2005, p. 140). This definition can be applied to most areas. For the manufacturing area, the complexity definition has been further developed to be better adapted and is defined as 'the interrelations between *product variants*, *work content*, *layout*, *tools and support tools* and *work instructions*' (Mattsson, 2013, p. 61). This means that all components of a production system and their interrelations constitute a certain level of complexity. To understand how complexity affects the production facility, four different complexity sources have been identified in literature; *product complexity*; *number and similarities of products in a plant*; *marketplace complexity* and *supply chain complexity*, see Figure 4. These sources of complexity are beyond the control of the production facility as they emerge from other areas. Product complexity defines the number of components and the degree of difficulty for the operator or machine to assemble the final product. The market contributes to the level of complexity by controlling the product variant mix offered. Furthermore, the plant is dependent on the footprint of the suppliers, the structure of the supplier network and reliability of inbound and outbound logistics (Huang & Inman, 2010). At least for the vehicle industry, it is common to outsource sub-assemblies to suppliers. By outsourcing certain sub-assemblies, the factory faces less inventory and lower complexity at its assembly stations. However, according to Inman and Blumenfeld (2014), such strategy will only affect the home factory, while the complexity in the production network remains at the same level. Even if such complexity lies outside the responsibility of the home factory, it will most likely affect the factory production performance.

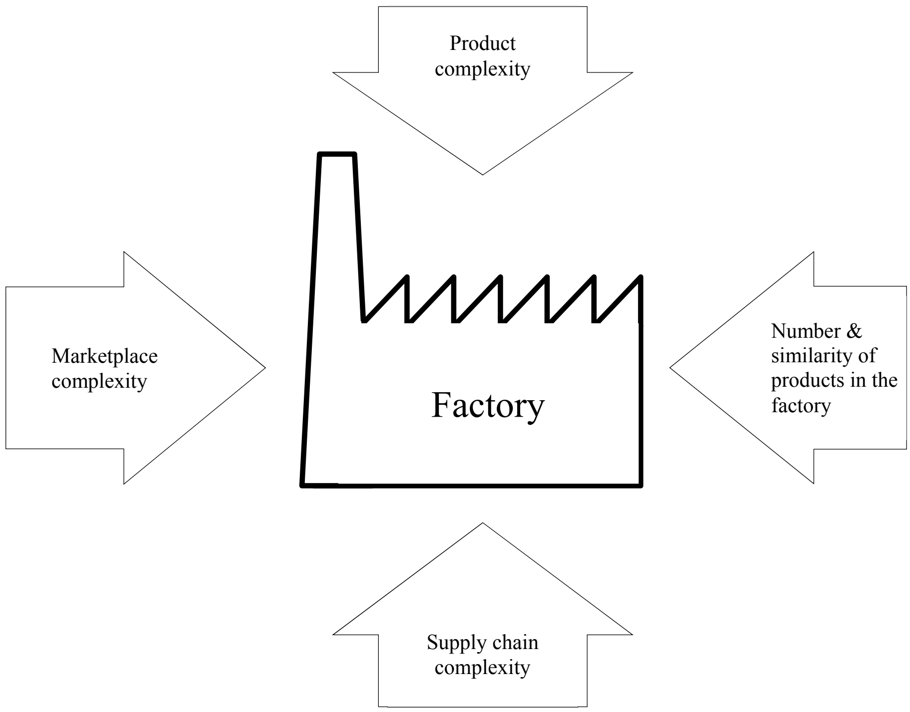

Figure 4: Four sources of complexity that affect the factory (Huang & Inman, 2010), edited.

Even if customization increases product variety and complexity, there are fundamental differences between different product categories. In Figure 5, differences in product complexity among product types are exemplified. Home appliances are typically types of products that have considerably lower product complexity compared to products from the vehicle industry. Not only have the products fewer interfaces between components and sub systems, they are also less affected by regulation than the vehicle industry. When it comes to the vehicle industry, there are major differences between product types. Even if products from the automotive sector are considered as customized, they have less complex interfaces between components and sub systems than most heavy duty trucks. Such trucks have larger amounts of adjustable attributes in their configurations than an ordinary passenger car.

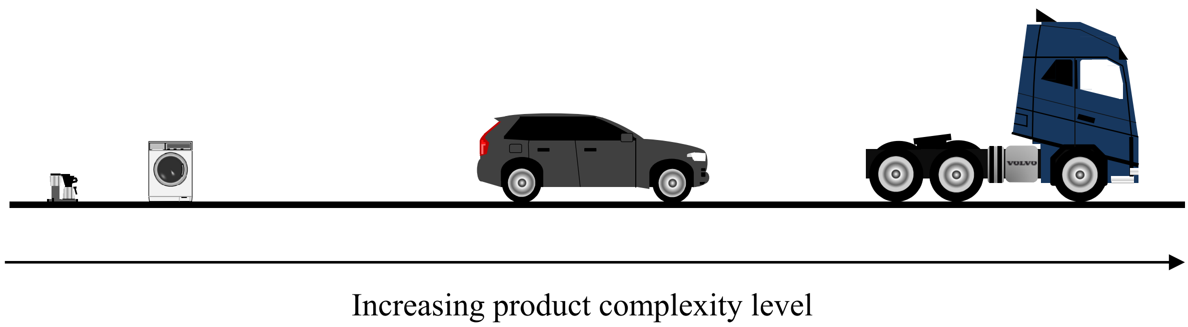

Figure 5: Different product categories have different levels of product complexity.

Customization of products drives increasing product variety which affects the level of unique components in inventory. If such level is high there are greater risks for disturbances in delivery performance compared to if the level is low (Inman & Blumenfeld, 2014).

When it comes to product complexity, there is much research conducted on its relevance for the manufacturing process. The shift from mass production to mass customization has been widely described, see (Pine II, 1999). Mass customization became the strategy to enable providing customized products to customers without added costs. It was considered that the investment of flexible process and organization structures would enable the realization of customized products manufactured in a low-cost, standardized, mass production systems (Hart, 1995). Standardization was the solution. Mass customization is often connected to modularization; the standardized interface in-between different components and subsystems and the reduction of those (Ericsson & Erixon, 1999). It has also been argued that the implementation of modularization into the product design and manufacturing process would decrease the level of inventory (Nambiar, 2009), improve quality (Ericsson & Erixon, 1999) and increase the level of flexibility across the organization (Sanchez & Mahoney, 1996). Despite the sometime ago introduction of modularization and modularity, manufacturing companies are still struggling with the implementation of these strategies. The definition of modularity might be differently interpreted in an organization (e.g. production and product design). Instead it is suggested by MacDuffie (2013) and Ulrich (1995), that manufacturing companies should focus their attention on interdependencies within and outside product and organizational architectures. With this knowledge a company is better prepared to define boundaries of modules and implement a strategy which does not intervene with production and design goals. The failure to implement such strategy leads to what can be interpreted as complexity (MacDuffie, 2013).

2.2.4 From product idea to physical product

Traditional product realization starts with product design and ends at the end of the assembly line. Figure 6 illustrates the product development process its preparation for production. It all starts at defining the product needs. Then product design follows, where the product is developed. The process then enters the prototyping phase where the product is tested and evaluated, both virtually and physically. The manufacturing engineering phase is next, where the manufacturing process is defined and assembly work instructions are created. Manufacturing engineering is followed by pilot production where the manufacturing process is verified. The product realization ends with start of production (Kalpakjian & Schmid, 2010, pp. 8–11; Scallan, 2003, pp. 35–37).

In literature, the term process planning is in general referring to what in this thesis is referred to as the manufacturing engineering process. Scallan (2003) states: ‘Process planning comprises the selection and sequencing of processes and operations to transform a chosen raw material into a finished component. It is the act of preparing detailed work instructions to produce a component.’ (p. 38).

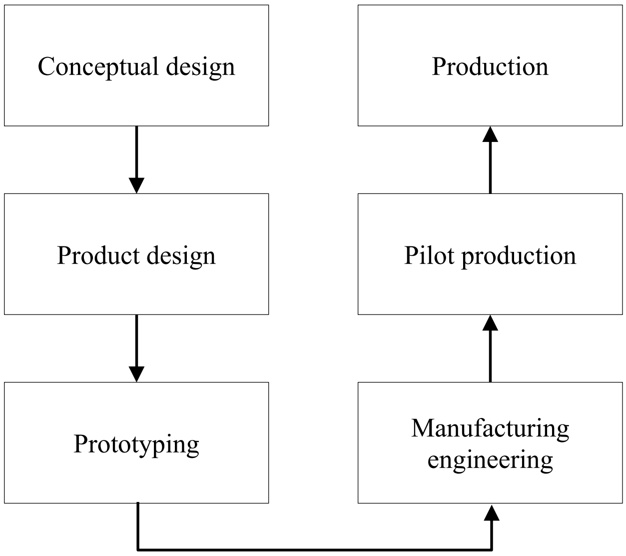

Figure 6: Product realization, adapted from (Scallan, 2003, p. 36)

2.2.5 Product and process standardization

As the product variety in the automotive industry is high, efficient methods for handling these are needed. Especially when the manufacturing company grows and becomes global, there are certain risks that the company may become too diversified (Hitt et al., 2001, p. 116; Ireland et al., 2008, p. 141). Modularization and component standardization is a way to improve part commonality in a product and to substantially reduce the amount of part numbers within a supply chain (Ulrich, 1995). This is supported by Inman and Blumenfeld (2014), who argue that decreasing inventory of unique components through standardization of components across different product variants, would still offer the market variation, but make the production system less vulnerable to disturbances in performance. Ulrich (1995) states: ‘Standardization can arise only when: (a) a component implements commonly useful functions; and (b) the interface to the component is identical across more than one different product. Otherwise, a component would either not be useful in more than one application or would not physically fit in more than one application.’ (p. 431). This implies that, as long the interface of a component or part is common across different product variants and share common functionalities, the customer can be offered a customization option (e.g. car seat fabric, USB-battery charger, etc.).

Standardized processes have been deeply discussed among Lean educators and practitioners. A standardized process can be seen as the best practice as it defines and visualizes a method which continuously adapts to create the best result possible (Liker & Meier, 2006, p. 112). McIntyre (2009) defines standardization of a process as: ‘making sure that important elements of a process are performed the same way every time’ (p. 284). Furthermore, McIntyre argues as inconsistence will cause process defects, standardization provides process owners with the possibility to work with preventive activities. Global process standardization has in previous research been proven to cut costs and redundant work in processes when implemented. Furthermore, such standardized processes make it easier for the company management to manage capacity utilization in production networks (Manrodt & Vitasek, 2004). The implemented standards simplify management functionalities in global manufacturing companies. Additionally, if the standards are considered more temporary than fixed, the manufacturing company will be focusing more on continuous improvements (Clarke, 2005, p. 10). Previous studies identified four critical factors to consider when implementing standards; technology planning, market intelligence, core activities and the supply network. Without these four factors there are risks that standardization would negatively affect business performance (Gudmundsson, Boer, & Corso, 2004). Business process complexity assessment is of utmost importance when standardizing processes as it evaluates whether a process is suitable for standardization or not (Schäfermeyer, Rosenkranz, & Holten, 2012).

On the basis of current research on process standardization a conceptual model (see Figure 7) was created by a research team (Romero, Dijkman, Grefen, & van Weele, 2015). By conducting an extensive literature study on process standardization they identified 11 contextual factors with proven relation to process standardization. On the basis of indicators found in literature measuring standardization levels, the model was added with six aspects of standardization. Furthermore, three groups of elements of business performance were added to the model. These elements were in literature identified as elements that are affected by changes of process standardization. The arrows and signs in the model demonstrate the relation between contextual factors, level of standardization and the impact on business performance. This suggests, as shown in Figure 7, that an increase in number of acquisitions would have negative impact on the level of standardization as standardization is harder to achieve. Furthermore, an increase of process standardization would have positive effects on business performance in terms of efficiency and quality.

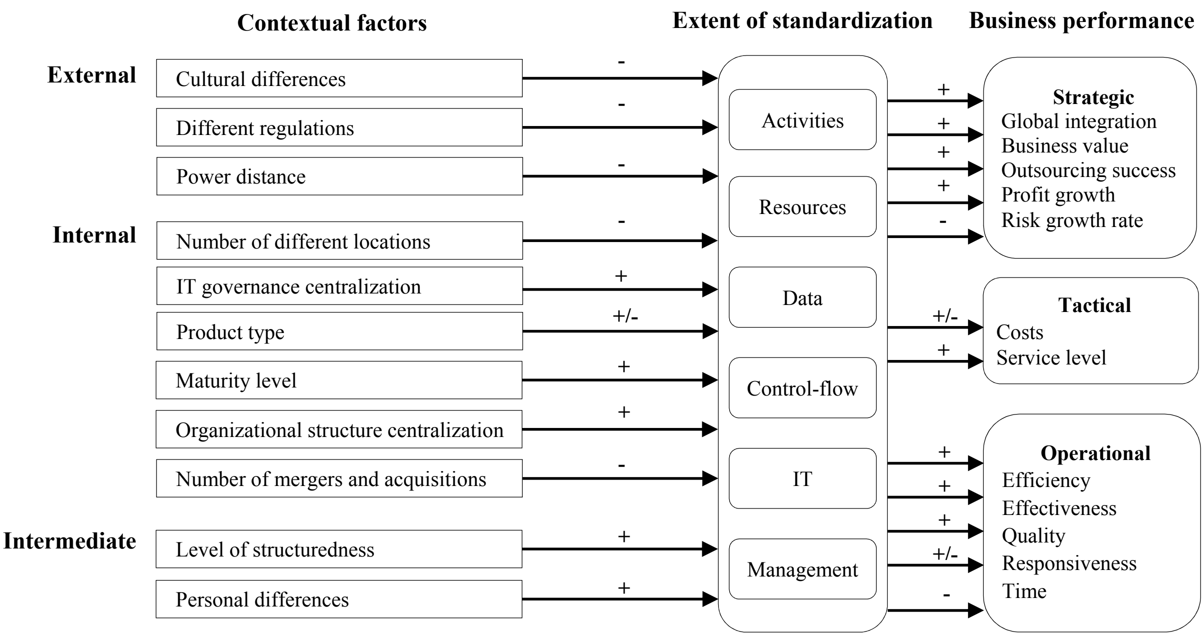

Figure 7: Drivers and implications of process standardization (Romero et al., 2015), edited[3].

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3 Research approach and methods

In this chapter the research approach is defined and presented together with the chosen data collection methods, data analysis methods and research quality.

3.1 Research approach

The research approach used in this thesis is shown in Figure 8 which is influenced by Flynn's systematic approach (Flynn, Sakakibara, Schroeder, Bates, & Flynn, 1990). The systematic approach contains six steps towards the publication of the research. The first step is to create a theoretical foundation on which the research activities are based. In empirical research, such activities are designed to either build (inductive) or verify (deductive) theory. The second step in the research approach is to choose proper research design adapted to the field of research. The research design can be single and multiple case studies, field experiments, surveys etc. The third step is to select data collection methods that suit the research design and the aim of the study. Common data collection methods are interviews and questionnaires. The fourth step, implementation, is focused on selecting the right population and right sample for the study. The fifth step is the data analysis of the collected data. The sixth and final step is the publication step which focuses on presenting the research results.

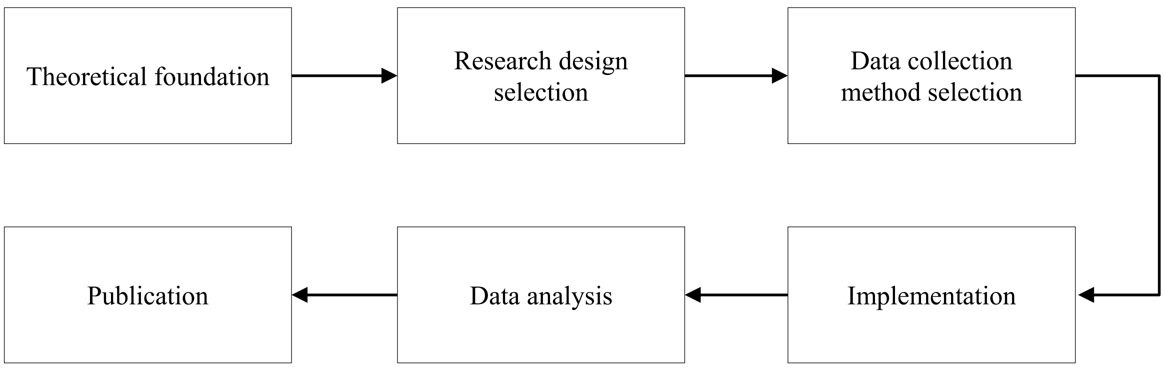

Figure 8: Empirical research – systematic approach.

This thesis presents the results from four different case studies which all contribute to the two defined research questions. Each case study is shortly presented in sections 3.2.1 to 3.2.4. In Figure 9, a timeline is presented where the different research activities are indicated. Case study A and case study B answer research question one, while case study C and case study D answer research question two. The research was divided into two parts: managerial and operational. The managerial part sought to study the use and availability of standards when providing assembly work instructions to the operators, whilst the operational part sought to study the effects of high product variety on manufacturing engineering processes as well as manual assembly. The research activities have partly been of inductive and deductive character and further addressed in the following sections. The case studies have all been conducted within the global production network of the case company.

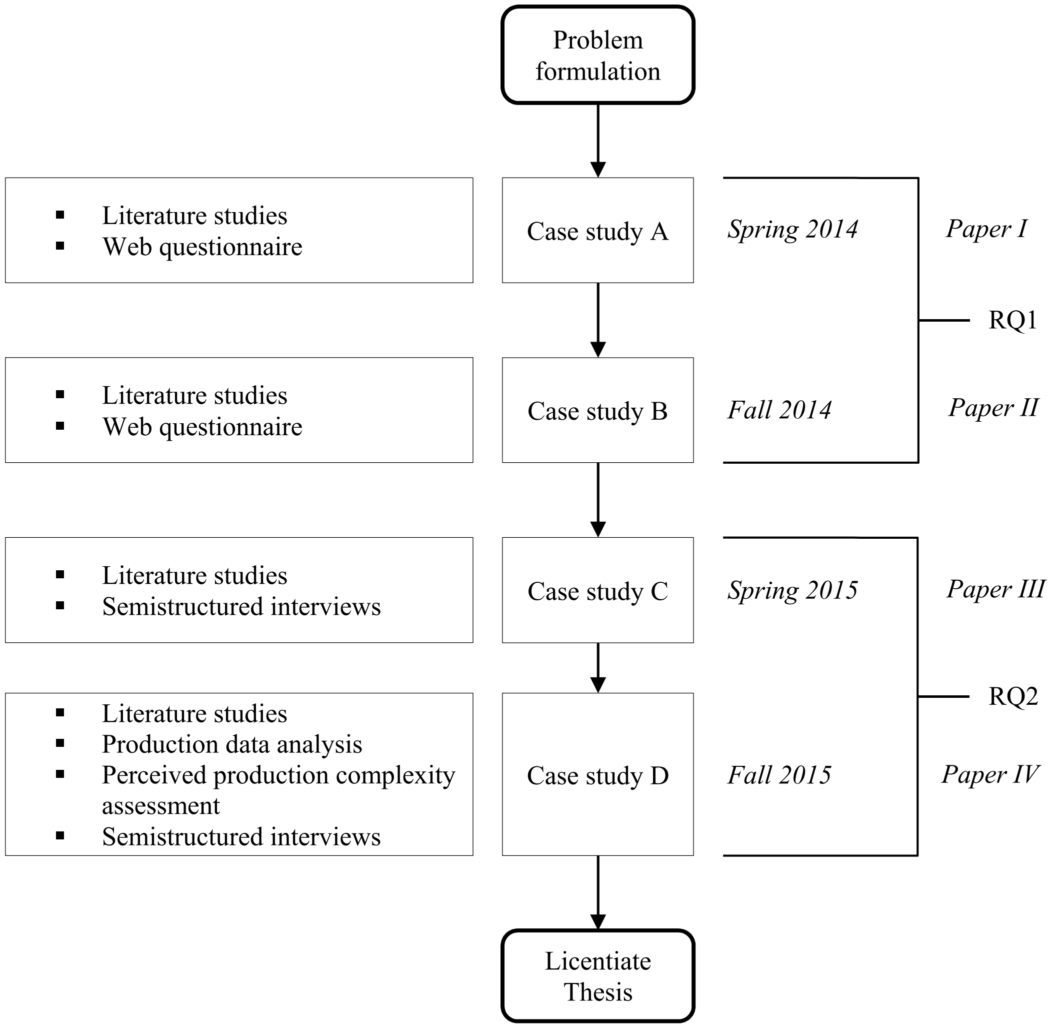

Figure 9: Timeline of the research activities.

3.2 Case studies

A case study can be defined as an inquiry that 'investigates a contemporary phenomenon (the "case") in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident' (Yin, 2013, p. 16). The case study can both be of single and multiple characters. In the single case study, a careful and detailed study is conducted for one particular place, while the multiple case study focuses on a multiple set of places with focus on similarities and dissimilarities (Flynn et al., 1990).

In the following four sub sections, the methodologies of the case studies are presented.

3.2.1 Case study A

Case study A was carried out during the spring of 2014. The study was of quantitative character and followed an inductive approach where a survey was conducted. A web questionnaire was created and addressed to production engineers at local engineering departments at three factories in Sweden belonging to the GPN studied. In total, 35 engineers and one operator participated in the survey. The questionnaire contained single choice questions, multiple choice questions and ranking questions using Likert scales. The questionnaire used is presented (translated from Swedish to English) in Appendix A. The link with an invitation letter was sent out to the target group via a global function which has contacts with the target group on a regular basis.

The aim of the survey was to understand what kind of ICT is used when transferring assembly work instructions to the operators. It also investigated the information content and information design of the instructions. Furthermore, it focused on the usage of standards when creating such assembly work instructions. Likert scales were used to rank how well used ICT, content and information design were working.

The case study is presented in appended paper I and the result refers to case A in that paper.

3.2.2 Case study B

Case study A was followed by case study B using a broader population selection. Case study B was conducted during the fall of 2014. This study was also of quantitative character and followed an inductive approach where are a survey was conducted. The previous web questionnaire was further developed and additional questions where added and as the questionnaire was designed to reach a broader population; the questionnaire was translated into English, Dutch, French, Japanese, Portuguese and Russian. The web questionnaire was addressed to production engineers and operators at the main factories within the GPN. In total, 40 production engineers and 18 group leaders and operators representing 12 factories participated in the study. As the first version of the questionnaire, it contained single choice questions, multiple choice questions and ranking questions using Likert scales. The questionnaire used is presented (the English version) in Appendix B. The link together with an invitation letter was sent out to the target group via the engineering department manager at each of the 12 factories.

The aim of the survey was to extend the knowledge gathered from the first study which only considered factories in the home country of the case company. This survey had a global perspective. As the case company represents multiple brands, similarities and dissimilarities were of particular interest. The survey focused as in case study A, on usage of ICT when transferring assembly work instructions as well as the content and information design of the instructions. Also in this survey, the usage of standards was of particular interest as the survey had a global perspective.

The case study is presented in appended paper II.

3.2.3 Case study C

By designing case study C as a multiple case study, it focused on finding similarities and dissimilarities in the manufacturing engineering process. The study was carried out during the spring of 2015 and was qualitative and the data was collected by an extensive set of interviews held with different roles involved in the studied process. This case study was carried out as a master thesis project (Delin & Jansson, 2015), where I designed the study and defined the research questions. The study followed an inductive approach where the focus was on identifying key process steps for creating assembly work instructions. Furthermore, the study was designed to study differences of how the manufacturing engineering process is carried out within the GPN, only focusing on the factories located in the home country of the case company. The case study methodology is shown in Figure 10. In addition to the interviews held, documentation of processes and assembly work instructions were analysed. In total, 18 persons with different roles involved in the manufacturing engineering processes were interviewed. These roles were both considered global and local. By using multiple data sources, reliability could be kept at a satisfying level.

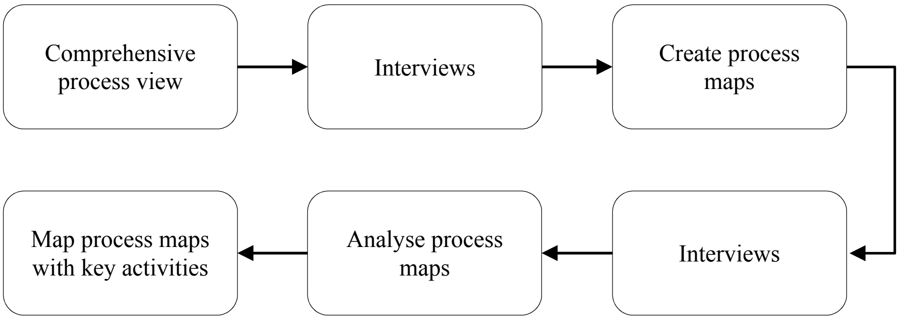

Figure 10: Multiple case study – methodology.

Interview questions are shown in Appendix C. The case study is presented in appended paper III.

3.2.4 Case study D

Case study D was conducted during the fall of 2015 as a single case study combining inductive and deductive methods as it partly tested published theories about product complexity by studying it in another manufacturing context. It also used an inductive approach which, on the basis of collected data, built a theory by combining theories and introducing an important link between them. This study used a mixed method approach combining both quantitative and qualitative data to build theory. The particular method was based on the explanatory sequential design (Creswell & Plano Clark, 2011, p. 71; Creswell, 2013, pp. 224–225) and is presented in Figure 11. As shown in Figure 11, the study was conducted by using multiple data collection methods. Furthermore, it used multiple data sources to keep reliability high.

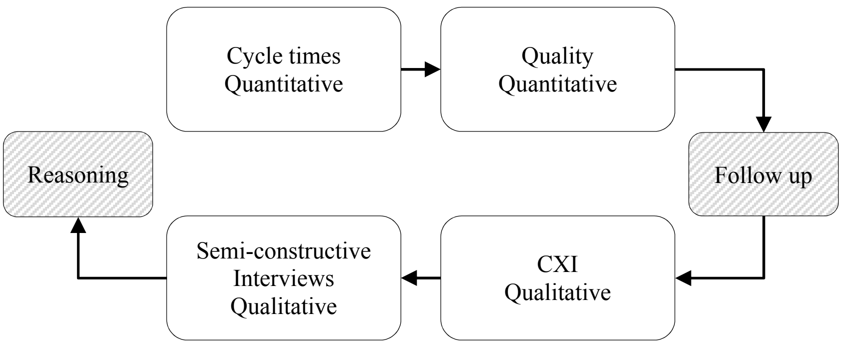

Figure 11: Mixed method research – Explanatory sequential design.

The aim of the study was to investigate how the high level of product variety affects production performance by studying a chosen factory within the GPN. The study was divided into two quantitative parts and two qualitative parts. By accessing the production IT systems of the case company, access to calculated cycle times and quality data was granted. A sample of assembly stations was selected together with a sample of already assembled trucks. Based on the analysis of the collected quantitative data, the study continued as qualitative where complexity index was measured and interviews with operators, production engineers and a production leader were held. Interview questions are shown in Appendix D. The measuring of perceived complexity was conducted by using questionnaires (Mattsson, Tarrar, & Fast-Berglund, 2016; Mattsson, 2013). The case study is presented in appended paper IV.

3.3 Data collection

The results that this thesis presents are based on data collected using different data collection methods; semistructured interviews, production data from case company IT systems, and questionnaires.

3.3.1 Production data

In case study D, data was collected from the production IT systems at the case company. Both quality data and cycle times were collected for a certain sample of manufactured trucks and for a sample of preassembly stations. The use of this quantitative data has been used together with qualitative data to describe different phenomenon. To secure that collected and used data is accurate, the steps used to extract data from the systems have been verified by key roles who are working with the IT systems on a daily basis.

3.3.2 Questionnaires

During case study A, B and D, questionnaires were used to collect data. For case study A and B web based questionnaires were used. By using web based questionnaires it is easier to access the potential group of respondents and as the questionnaire is completed by the respondent it is directly stored in a database. Therefore, it is also possible to check new responses in real time and the overall lead time for the survey can be shortened (Bethlehem & Biffignandi, 2012, p. 45). The quality of the data from a questionnaire is dependent on several factors such as the quality of written questions, the respondents' behaviour, accuracy and ability to understand the questions and to correctly record the responses (Brace, 2013, pp. 11–12). Additionally, coverage errors, sampling errors, non-response errors and measurement errors are problems that might appear when conducting a survey (Dillman, Smyth, & Christian, 2014). Therefore, the data from the web questionnaires was mainly used an indication of current practices. Instead, at a later stage of the research process, interviews were used to collect data with higher reliability and validity.

For case study D, a paper based questionnaire was used which was designed on the CXI method (Mattsson et al., 2016; Mattsson, 2013). The paper based questionnaire is a result of ongoing research (not in scope for this thesis) for analysing perceived complexity in manual assembly and has been validated and published in several papers. Therefore, it was considered as a valid method for collecting important data for the purpose of this thesis.

3.3.3 Semistructured interviews

In case study C, an extensive set of semistructured interviews were performed. Such interviews were also conducted in case study D. When conducting qualitative research, it is important that the interviewees are not constrained by the researcher. Instead the researcher should benefit from letting the interviewee to define and describe the investigated phenomenon. By using semistructured interview forms, the researcher can give certain direction by having guiding questions prepared and still collect additional information that would strengthening the understanding of the phenomenon (Hesse-Biber & Leavy, 2011, pp. 102, 128; Merriam, 2009, p. 90). For semistructured interviews to be successful, the researcher needs to be careful by thoroughly preparing the interview, reserving enough time for data analysis and keeping up creativity and discipline during the interview (Wengraf, 2001).

The interviews conducted in the case studies were based on previously collected data from web questionnaires. Since the interviews were of explorative nature and used to map currently used processes for creating assembly work instructions, semistructured interviews were considered to be more suitable for the matter than structured interviews due to the risks that the latter form would narrow and neglect vital understanding of the process. Interviews were held with people with different roles to increase the reliability of the studies.

3.4 Quality of research

For a study to be repeatable, it has to be generalizable with correct measures, valid, reliable and possible (Creswell & Plano Clark, 2011). Validity in quantitative research can be approached as internal validity and external validity in terms of research design and validity when it comes to measuring. Furthermore, validity in terms of design and measurement is dependent of each other as the design can only be valid if the measurement is valid and reliable (Newman & Benz, 1998). Internal validity is addressed to ensure that the effect of a study is caused by manipulation of an independent variable and not a extraneous variable (Picardi & Masick, 2014). External validity addresses the possibility for the results from a study to be considered for other areas as well (Merriam & Tisdell, 2015).

Triangulation is a research method for improving validity by using multiple data sources to strengthen the evidence from the study (Bush, 2012). When conducting interviews, one can achieve high validity by interviewing people with different views and roles (Merriam, 2009, p. 216). Triangulation can also be conducted by using different data collection methods. This thesis presents research activities conducted by both interviews and questionnaires that have been addressed to multiple roles on the same subject to get as accurate descriptions as possible of the studied area. This thesis presents results from studies with both quantitative content as well as qualitative content. Part of the studies have also used a mixed method approach as it strengthens the understanding of a phenomenon by combining quantitative and qualitative data (Creswell, 2013). Reliability in a study is referred to its repeatability. Reliability can be tricky in qualitative research since the environment studied is not static (behaviour and perception) (Merriam & Tisdell, 2015; Merriam, 2009, p. 220). By using questionnaires in surveys, reliability can be determined (Bush, 2012). The first two papers appended in this thesis (Paper I and Paper II) are based on questionnaires which fulfil the reliability criteria. According to Merriam (2009), as reliability of qualitative research is difficult to address, it is more important to address 'whether the results are consistent with the data collected' (p. 221). To improve reliability of the qualitative part of this thesis, Paper III and Paper IV are both based on data from multiple sources and Paper IV is also based on data from multiple collection methods.

4 Summary of appended papers

This chapter contains a summary of appended papers and presents their main findings and their contribution to the research questions.

The two research questions have been investigated by conducting four case studies which are described in section 3.2. These case studies have resulted in four appended papers, paper I to IV. Appended paper I and II present the results of the case studies that answer RQ1 and appended paper III and IV answer RQ2. An overview of the relations between papers, research questions and case studies is presented in Figure 12. Together, both research questions provide a strategic and practical analysis of the impact of high product variety on operational performance and the incorporation of standards in manufacturing engineering processes, within one GPN.

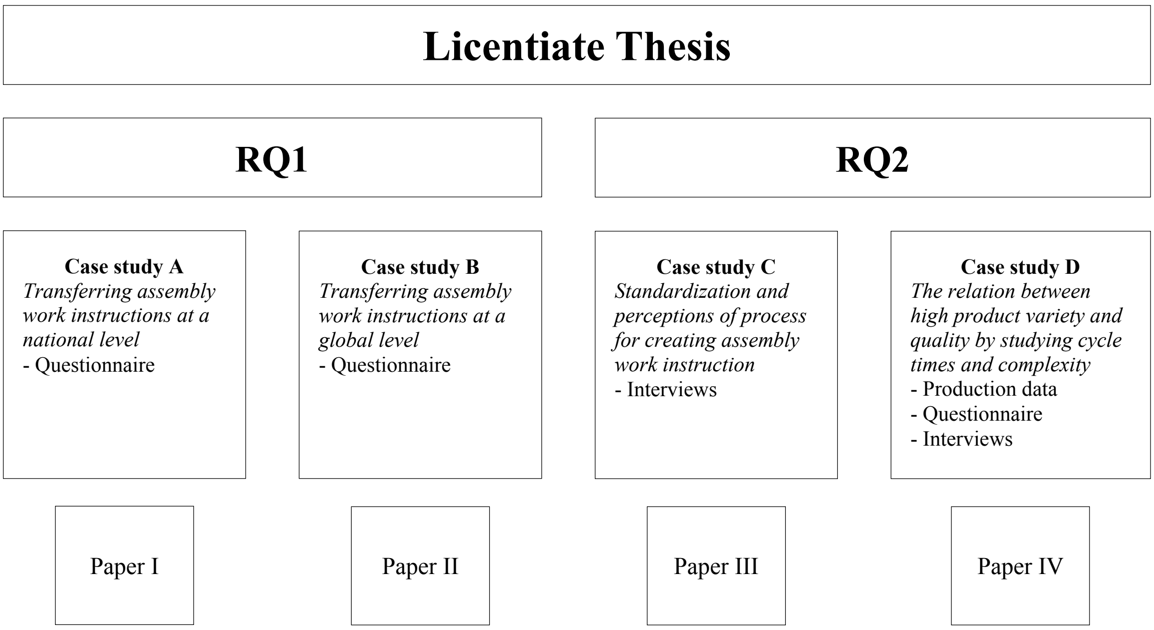

Figure 12: Relation between RQs, case studies and appended papers.

The case company studied in this thesis has during the last decades heavily extended their truck business through acquisitions and new market introductions. The case company is in transition focusing on globalization and standardization. However, to globalize and standardize such an extensive business is a huge challenge. The appended papers in this thesis describe challenges and suggest directions for such transition.

4.1 Paper I

Title: *Creating Strategies for Global Assembly Instructions – Current State Analysis*

The aim of Paper I was to investigate the current state of transferring assembly work instructions to the operator. The paper focused on three questions; (1) what types of information carriers are used for information and communication handling today? (2) How is the content of information presented? (3) Are there standards for constructing/designing instructions within the companies?

4.1.1 Results from case study A

The web questionnaires used in this case study, described in section 3.2.1, resulted in 35 responses from production engineers and operators working at three different factories within the home country of the case company, referred to as the national level. Table 3 and Table 4 present the main findings from the current state analysis at a national level. A majority of the respondents stated that the most common information carriers are paper, personal meetings, and screens together with assembly work instruction as the most common content type, and text and photos as information design. Among the production engineers 71 % claimed that current ICT tools are good. The case study also investigated the perception of usage of standards in the process of transferring production information to the operators. A majority of 86 % claimed that standards are followed while 14 % argued that there were no standards or standards are under development. The claimed use of standards is not consistent with the responses that highlight the use of carrier, content and design for distributed production information. This inconsistence suggests that people in the engineering process, perceive current standards in different ways.

Table 3: Information carrier, information content and information design at national level.

	Information Carrier (WITH WHAT) (Top 3 of 13 alternatives)		**Information Content** (WHAT TYPE) (Top 3 of 9 alternatives, could answer more than one alternative)		**Information Design** (HOW) (Top 3 of 6 alternatives, could answer more than one alternative)	
Case A N = 35	Paper	86 %	Assembly work instructions	100 %	Text	80 %
	Personal meetings	76 %	Blueprints 2D	34 %	Photo	51 %
	Screens (production info)	59 %	Maintenance instructions	34 %	Animations (3D)	9 %

The correctness of information in assembly work instructions was claimed to be the production engineers' responsibility. The most common software for creating assembly work instructions is the traditional office suite and other internal production IT-systems.

Table 4: Standards, correct assembly work instructions and used software at national level.

	Standards		**Responsibility for Correctness** (Top 3 of 6 alternatives, could answer more than one alternative)		**Where (Software)**
Case A N = 35	Yes	86 %	Production engineers	86 %	AviX, MS Excel, MS Word, Internal IT-systems
	No	6 %	Me	49 %	
	Under development	8 %	Operators	20 %	

The results from the survey suggest that there is no common view or perception of standards, if they are implemented and on what level. Since the survey only addressed creation of assembly work instructions on a national level, it was necessary to get a global view of the topic as well. Therefore, it was decided to develop a global questionnaire to broaden the target group.

4.1.2 Contribution to research questions

The result from case study A (appended paper I) partly answers RQ1 (*what is the current state of using standards when transferring assembly work instructions to the operators in manual assembly?)*. The current state analysis of how assembly work instructions are transferred to the operators at a national level contributes to the overall aim of the research question. The survey provides an indication of the usage of standards in such a process. Furthermore, the result contributes to the research question by revealing gaps in how standards are interpreted at a national level.

4.2 Paper II

Title: *Use of Assembly Information in Global Production Networks*

The aim of paper II was to follow up on paper I by studying eventual diversification in the process for transferring assembly work instructions to the operators at a global level. The question for the paper was defined as - Can diversity be perceived in the development and use of assembly information within a global production network and in what forms? The survey addressed main factories within the GPN of the case company studied.

4.2.1 Results from case study B

The web questionnaires used in case study B (described in section 3.2.2) resulted in 58 responses from production engineers, team leaders and operators within one production network. The questionnaire reached 12 factories manufacturing trucks representing four truck brands and engine and transmission factories. The main findings from the global current state analysis are presented in Table 5 and Table 6. As for case study A, the respondents rated personal meetings high, but on a global basis, paper used as the information carrier was perceived lower. On a global level it was still the assembly instruction that was rated highest (93 %) and text and pictures are common in terms of information design. The majority who claimed that standards when transferring assembly work instructions are implemented was slightly lower than on a national level (72 % compared to 86 %). An additional question was asked in terms of the usage of standards in the process. Using a Likert scale from 1-5, the average response regarding to what extent standards are followed was 3.75. The analysis of the responses on that particular question shows that standards are interpreted differently, not only between different factories but also within a factory. For instance, for one of the factories only 60 % of the participating production engineers claimed that standards where actually implemented.

Table 5: Information carrier, information content and information design at global level.

	Information Carrier Multiple choices allowed		Information Content Multiple choices allowed		Information Design Multiple choices allowed	
Case A N = 58	Personal meeting	88%	Assembly work instruction	93 %	Text	97 %
	Computer	76 %	Drawing 2D	59 %	Picture	88 %
	Paper	69 %	Shift/Personnel information	45 %	Film	14 %
	Telephone	59 %	One-point-lesson (Best practice)	38 %	Animation	10 %
	Whiteboard	33 %	CAD 3D	31 %	Voice	2 %
	Barcodes	31 %	Machine instruction	28 %		
	Monitor/Screen	31 %	Tacit knowledge	28 %		
	Pick-to-Light	14 %	Maintenance instruction	24 %		
	State lamps	10 %	Sprint Tickets (internal)	2 %		
	QR code	5 %				
	RFID	3 %				

When it comes to the responsibility for correctness in assembly work instructions, the majority state that the production engineers have the main responsibility. However, the result from the questionnaire shows that not all production engineers agree that they have such responsibility. As aligned with case study A, the software used for creating assembly work instructions are the traditional office suit together with internal production IT systems and CAD tools.

Table 6: Standards, correct assembly work instructions and used software at global level.

	Standards		Responsibility for Correctness (Top 3 of 7 alternatives, could answer more than one alternative)		Where (Software)
Case A N = 58	Yes	72 %	Production engineers	78 %	CAD, MS Office, Internal IT-systems
	No	16 %	Me	53 %	
	Under development	12 %	Quality engineers	19 %	

The conclusions drawn from case study B is that there is diversification within the production network in terms of creating assembly work instructions and distributing those to the operators. Furthermore, as aligned with case study A, results indicate that even if standards are implemented, they are interpreted differently and not always followed.

4.2.2 Contribution to research questions

The results presented in appended paper II partly answer RQ1 (*what is the current state of using standards when transferring assembly work instructions to the operators in manual assembly?)* by providing the current state of transferring assembly work instructions for the operators at a global level. Together with the result from appended paper I, the survey provides a statistical current state analysis for the engineering process. This current state mapping is important to be able to understand the complexity of a multi-brand GPN. The statistical analysis shows that there is widespread dispersion in how assembly work instructions are handled at different factories within the GPN. These results show that the quantitative analysis needs to be enhanced with a qualitative analysis of the engineering process.

4.3 Paper III

Title: *Global Truck Production - The Importance of Having a Robust Manufacturing Preparation Process*

The results from case study A and case study B initiated case study C, which was the scope for paper III. The aim of paper III was to investigate the manufacturing engineering process in terms of creating assembly work instructions. The study focused on one truck brand and on engine and transmission production in Sweden as they can be considered as the main factories for the truck brand and the engine and transmission supply for the brand. The first part of the study was to identify the key activities involved in a manufacturing engineering process to be able to create assembly work instructions. The second part of the study was to perform an analysis of the process mappings to identify similarities and dissimilarities in the manufacturing engineering processes.

4.3.1 Results from case study C

Case study C investigated the current manufacturing engineering processes for truck, engine and transmission production in Sweden. The case study is based on an extensive set of interviews carried out with different key functions in both local and global organizations within the GPN. Interviews were held with people working both within the engineering process and outside the process. In Figure 13 eight key activities are shown representing the manufacturing engineering process which ends up with the created assembly work instructions. The case study showed that these activities are important in order to create assembly work instructions. The part of the manufacturing engineering process studied starts with reception of the product design. Then product design review follows to verify that all requirements are fulfilled for manufacturability. New introduction of new components needs to be set in the production IT systems. Time analysis is performed for operations with new components. The production line is rebalanced on basis of updated components and components are assigned to specific assembly stations. Assembly work instructions are then created and broken down to each operator at an assembly station. Finally, information is shared within the process.

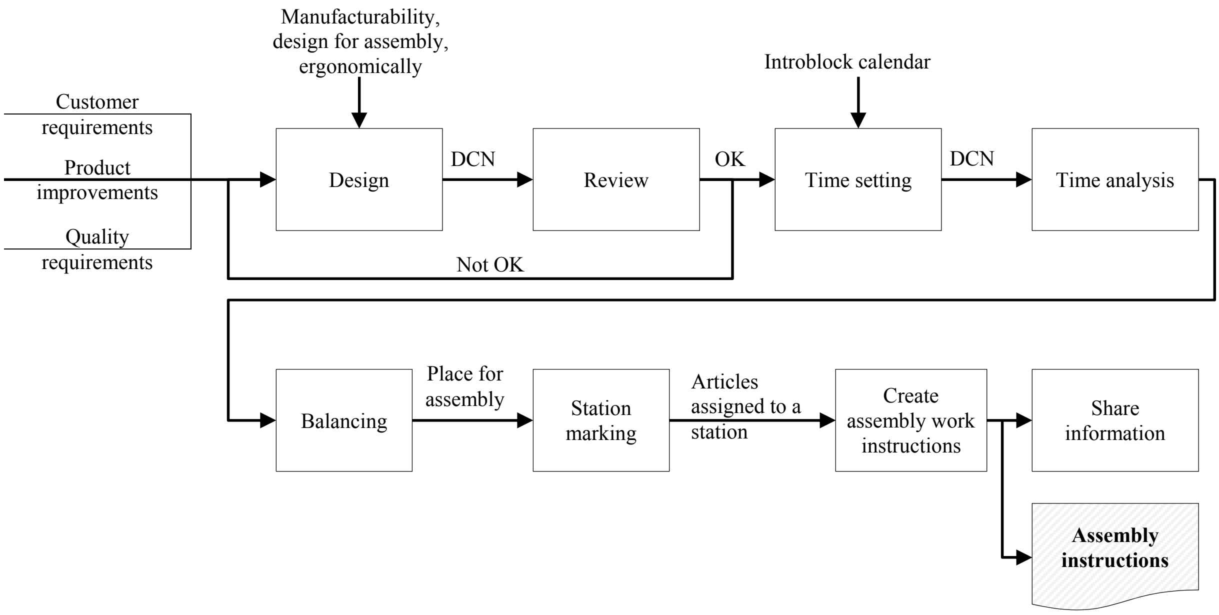

Figure 13: Key activities that constitute the manufacturing engineering process.

The case study revealed differences in the process depending on where the factory is located. To be able to illustrate how the process differentiates among factories within the GPN, a timeline was created highlighting the design phase, time setting and when assembly work instructions are created, see Figure 14. The dashed lines in the illustration indicate that a detailed study of the factory has not been conducted. In general, the manufacturing engineering processes in terms of creating assembly work instructions is carried out locally at each factory. For cab and vehicle production in Europe, the main part of the process is carried out globally. The assembly work instructions are created in global functions and local adaptation and adjustments are performed at each factory. In Europe, production engineers from different factories are collaborating with each other to support and share knowledge. For cab and vehicle production in Brazil and Australia, the manufacturing engineering processes deviated from the European setup and larger parts of the processes were executed locally at each factory.

For the engine and transmission factories, all manufacturing engineering processes are carried out locally. Even if the processes are locally conducted, they were found to be very similar. For manufacturing of engines and transmissions in other countries, it was stated that they shared similar setup as seen in Sweden.

During the interviews it was also indicated that different functions in the manufacturing engineering process interpret the process differently. Furthermore, it shows that different parts of the GPN are working towards different KPIs and use different production IT systems. Additionally, even if the same production IT systems were used, they were structured and used differently which means that knowledge and information cannot easily be shared across the GPN.

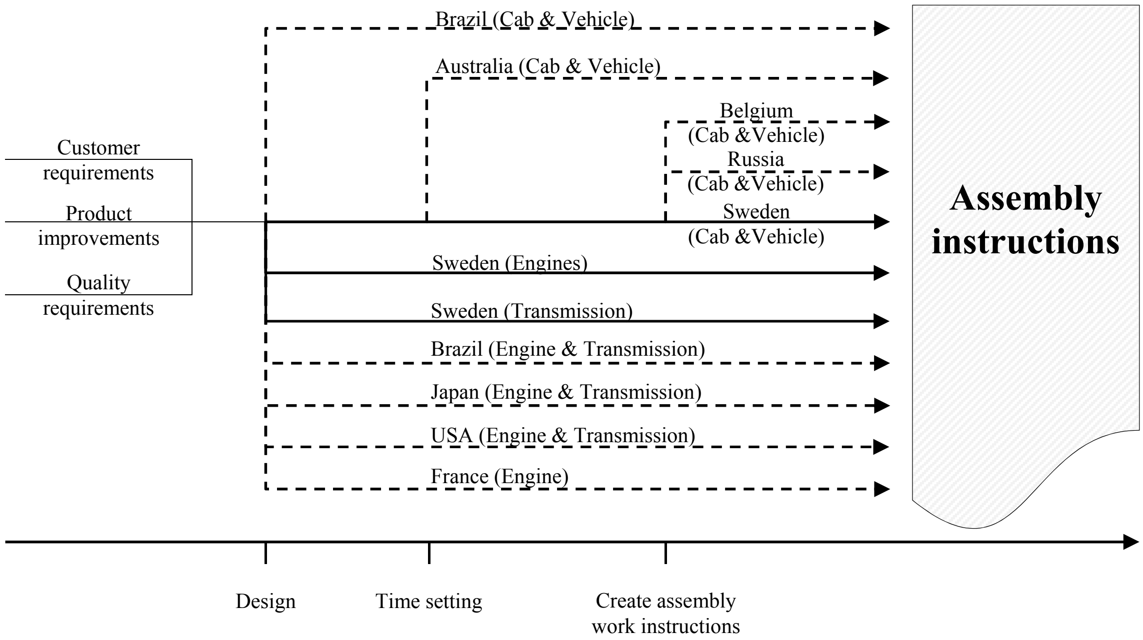

Figure 14: Dispersion of manufacturing engineering processes in parts of the GPN.

The multiple-case study shows that there are both similarities and dissimilarities in how manufacturing engineering processes are carried out for different factories within the GPN. Furthermore, the study indicates that there is no standardized manufacturing engineering process implemented on a global level. However, the study does show that there are some levels of standardization in some parts of the GPN.

On the basis of the result of the study, it can be concluded that there is not enough transparency within the GPN and within the manufacturing engineering process. The lack of commonality and transparency affects the outcome of the manufacturing engineering process which, in turn, affects production negatively. Since product variety is high within the GPN, operators require high quality outcome of the engineering process.

4.3.2 Contribution to research questions

Appended paper III partly answers RQ2 (*what are the challenges in manufacturing engineering processes in production networks handling multiple brands with high product variety?)* by providing a detailed current state analysis of the manufacturing engineering process and evaluation of the performance of that process. It does also contribute to RQ1 by validating findings presented in appended paper I and II. Furthermore, it states similarities and dissimilarities in the manufacturing engineering process and problematizes the impact of high dispersions in a process as such.

4.4 Paper IV

Title: *Multi-serial truck production - Product variants and its impact on production quality in manual assembly*

The aim for paper IV was to investigate the relation between having high product variety and the level of quality in production. One of the reasons was to see how production is affected by the outcome of the manufacturing engineering process. Furthermore, the paper aimed to investigate if high product variety affects perceived production complexity among operators. The case study D, as this paper refers to, focused on eight preassembly stations where some of the stations were considered to have high product variety and some stations to have lower product variety.

4.4.1 Results from case study D

For the study, a sample of 2034 manufactured trucks was chosen. In total, eight preassembly stations were chosen. Two of these stations were considered to have lower product variety than the other nearby assembly stations. Four different data sources were used during the study. Cycle times were extracted from one of the production IT systems. Quality data for the truck sample was extracted from a follow up system. Perceived complexity was measured by using the CXI method (Mattsson, 2013). Finally, interviews were conducted with a group of operators, two production engineers and the responsible production leader.

During the study, it was concluded the cycle time varied differently among the sample stations. The analysis of extracted cycle times for the sample of trucks showed high standard deviation for half of the stations, see Table 7. The high standard deviation for the air tank station depends on that the station is only used for trucks with heavy configurations. It was concluded that cycle time variations affect the optimization of the line balancing. Distribution of work content among the assembly stations, where customized trucks are considered as almost unique, is challenging.

Table 7: Cycle times in seconds extracted from one of the production IT systems.

Station	Min	Mean	Max	Std. Deviation
Kitting	297	375	529	± 48
Cable mat	22	465	520	± 42
Cabling	165	295	662	± 93
Valve/Tank	155	325	617	± 115
Air tanks	0	154	577	± 145
Bogie valves	166	454	658	± 119
Engine	437	346	468	± 8
Front	268	445	470	± 60

On basis of the quality data extraction from the follow up system, it was concluded that the most common quality deviations are assembly errors. However, the quality data was not broken down on a station level, instead the data was broken down on a production area level. It was concluded that quality data that are only addressed on a production area level do not give enough prerequisites for the operators to receive proper feedback.

To get a better perspective of how the operators perceive their work environment, perceived production complexity was assessed using a standardized questionnaire addressing areas as station design, work variance and disturbances. The result from the assessment, shown in Table 8, indicates that seven of the sample stations are considered to have a high level of perceived complexity. The main contribution to the high scoring is the present work variance.

Table 8: Complexity assessment for the chosen sample stations.

Station	Kit	Cable mat	Valve/ Tank	Air tanks	Bogie valves	Engine	Front
Station design	3.3	3	2,8	3	4	3.2	2
Work variance	4.7	4.5	4	5	3	3.8	4
Disturbances	1.7	1.8	4,3	4.5	4	3.3	4
Total CXI:	4.5	4.1	4.3	4.9	5	4.5	5

On basis of the data from the interviews it is concluded that the manufacturing process is constrained by the amount of product variety. The complex products in combination with the amount of product variants make the operators dependent on their assembly work instructions. Sometimes the operators neglect the instructions and use their skills and experience, which may cause quality deviations. It was also highlighted that, relatively often, there are direct errors in the assembly work instructions which causes quality deviations. During all interviews it was stated that product variety affects production quality negatively. In Figure 15 a suggested relation between product variety and quality is illustrated and considered to be connected with several areas which increase the perceived complexity level at the assembly stations.

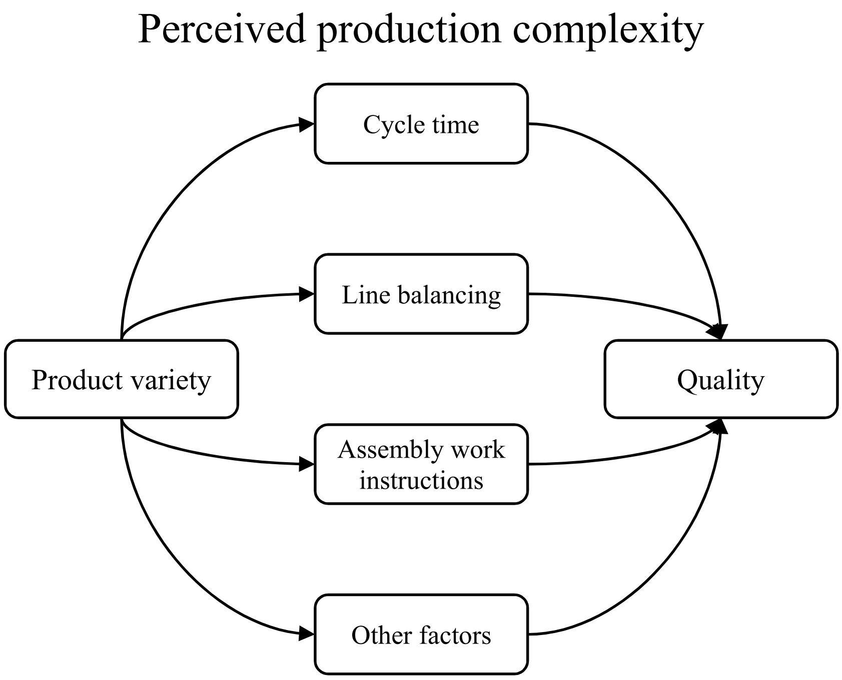

Figure 15: Product variety affects several complexity factors which affect quality.

The study concluded that there is an evident, negative, relation between high product variety and production quality. Furthermore, the high product variety affects the perceived production complexity among the operators. The work variance makes the production sequence sensitive to production disturbances.

4.4.2 Contribution to research questions

Appended paper IV partly answers RQ2 (*what are the challenges in manufacturing engineering processes in production networks handling multiple brands with high product variety?)* by providing an analysis of the impact of having high product variety in production. This analysis is important for the knowledge base and to be able to establish global strategies for the manufacturing engineering process and how the process can be better designed to handle high product variety. It also validates the results from previous case studies presented in this thesis by setting the research scope in an operational context.

5 Discussion

This chapter contains a discussion of how the result from this thesis contributes to creating global strategies for multi-variant serial production, quality and limitation of the thesis and proposal for future research.

Many companies diversify their product portfolios to offer truly customized products and services to their customers. For the case company studied, the diversified product portfolio has had a direct effect on diversifying the production system. Does it necessarily mean that diversified products need a diversified production system? The purpose of this thesis has been to provide an analysis of how manufacturing companies handle global processes by deeply studying a case company which offers a high level of customized trucks and transport solutions to their customers. As the history of the case company has formed the business to mainly focusing on transport solutions, the case company sold their passenger car business and have conducted numerous acquisitions during the latest decades. As theory argues, that diversifying business is one reason why companies perform acquisitions (Graebner et al., 2010) it became interesting to understand how the new constellation of the case company affects overall performance in their production system, especially in manual assembly. At the beginning of this research, it was necessary to define a starting point. By creating the first two case studies and creating questionnaires that were mainly addressed to manufacturing engineering departments around the GPN, primary data could be collected providing a knowledge base about the current state. This data has been collected from 93 engineers and operators in the GPN of the case company. The following first two sections of this chapter will discuss the results from the empirical and literature studies answering RQ1 and RQ2 respectively. The third section discusses the result from a global perspective which contributes to answering both research questions. The fourth section discusses research quality and limitations while the fifth section discusses future research approach.

5.1 Use of standards when transferring assembly work instructions to operators

The first part of the research focused on mapping current practices of using standards when transferring assembly work instructions to the operators. Traditionally, manual assembly requires both assembly specifications, including lists of specific components, and assembly descriptions defining how assembly of a specific component shall be performed. The case company used in this thesis is using a combination of these types of information in the same document which has been consistently referred to as assembly work instructions. This is important to mention as it constrains how information handling can be set up in the context of systems infrastructure.

Both questionnaires indicated that assembly work instructions are transferred to the operators in different ways. The level of diversification suggests that there are different views on what is considered a standard and what is not. The diversification of handling assembly work instructions in the GPN is not a problem in itself, but the level of diversification might make it harder to efficiently manage daily work, especially when GPN handles multi-brand production. This is in line with what was described by Hitt et al. (2001) and Ireland et al. (2008) when they claimed that there are certain risks that come out of an acquisition process, such as over-diversifying the business. Both case studies (A and B) indicated multiple data sources in the organization. It is obvious, on basis of the data, that the acquisitions have played a major role of over-diversifying the IT infrastructure in the GPN. Skinner (1974) warned about the risks of growing in such a way that internal processes become too complex and hard to manage. Today, this is basic knowledge, but apparently there are factors that overweigh the risks of becoming over-diversified.

The data from the first two case studies indicated that there are not just diversifications between factories but also within a factory. This comprehension is an indicator that there are no high level standards implemented and there is a lack of transparency over processes in general. However, 72 out of the 93 respondents advocated the fact that there are standards implemented despite that their overall answers do not support such stance. The respondents in case study B who advocate that standards are implemented, stated that the use of such standards rated 3.75 out of 5 on a Likert scale ranging from 1-5 where 1 is to a low extent and 5 is to a high extent. One of the risks of being over-diversified is that redundancy easily arises. Such risk of redundancy, as argued by Manrodt and Vitasek (2004), can be decreased by introducing global standards. The purpose of such standard is to provide consistency over time. The case studies did also provide support for unclear responsibility for correctness in assembly work instructions. When assembly work instructions are incorrect or not available, the operators have to trust their own knowledge and experience. This is supported by Berger (1997) and further processed by Fast-Berglund et al. (2013) who mean that the lack of cognitive support negatively influences production quality.

5.2 Multiple brands and high product variety in manufacturing engineering processes

Case study C was created to investigate the manufacturing engineering process focusing on the creation of assembly work instructions while case study D was designed to focus on implications from the shop floor. These results are answering RQ2 by providing a motivation of how current business setup affects both the engineering and assembly processes. Case study C was carried out by performing interviews with key functions in the manufacturing engineering process. This case study identified key steps in the process which ends with the creation of assembly instructions. The findings support previous case studies in stating that there is no global standard for creating the assembly work instructions. The study also identified that different internal IT systems are used in the process depending on where the factory is located and for what brand. Such dispersion of IT was suggested by Luftman (2015) to harm business performance. Since the product variety is high at the case company, this has a major impact on the process of creating assembly work instructions as the availability of internal data sources is dependent on location and brand. As the process for creating assembly work instructions is very dependent on (1) where the production is located, (2) by whom it is conducted and (3) for which brand and product type an additional case study (D) was conducted. This cases study focused on the implication of high product variety on production performance. The result of this study is based on interview data and data from internal production IT systems and questionnaires. The case study was carried out in a factory handling the highest level of product customization within the GPN of the case company. The reason for doing so was to demonstrate the impact of high product variety in manual assembly.

The first implication was that the level of product variety is causing line balancing complexity. This product variety also makes it harder to reach satisfying levels of accuracy and correctness in the content of the assembly work instructions. Modularization is one technique to lower negative impact on operational performance and is promoted by an extensive number of researchers. Ulrich (1995) suggested that this technique would slow down the introduction of new components and reduce the total amount of components on a long term basis. Modularizing the product would lower the level of product complexity for the manufacturing engineering process. As an example, independently of the size and shape of a fuel tank, the assembly step would always use the same fasteners if the fuel tank was fully modularized for assembly. But, despite this knowledge, the amount of available components in the production system of the case company is incredibly extensive. The product variety and the amount of available components in the production system both make manufacturing engineering and manual assembly complex. Complexity in manual assembly affects the cognitive process of the operators who face high level of product variety on a daily basis. The nonalignment between product offerings and cognitive support in the manufacturing process influences production quality negatively. The impact of product complexity is supported by Vachon and Klassen (2002) who provided evidence that a decrease in product complexity would positively affect lead time and throughput time which leads to improved production quality. Furthermore, the high level of product variety was claimed by Huang and Inman (2010) to make it harder for the assembly operators to identify a specific variant and the work that needs to be performed on that specific variant. Therefore, it is of utmost importance that the assembly work instructions contain such identifiers.

Case study D identified a link between product variety and production quality which was supported by the amount and type of assembly errors extracted from one of the production follow up systems. That link was also supported by the result from the interviews conducted with operators and production engineers. This link is also supported by older studies made by Fisher and Ittner (1999) who found supporting evidence that product variety drives rework in the manufacturing process. The overall level of mass customization at the factory studied is high and the amount of common truck configurations is low. Such production setup is very dependent on operator training, assembly work instructions and minimal disturbances. In the case study, it was stated that the assembly work is vulnerable to such disturbances and new introductions of components as the assembly work instructions do not provide necessary decision support to the operators.

Overall complexity is affecting production in different directions. It was states by Huang and Inman (2010) that there are different sources of complexity which affect the performance of a factory. This is supported by the findings from case study D which concludes that much of the perceived complexity can be addressed to product development. Adding the factor that no product variants are similar to one another, there are risks that the complexity will give negative consequences during production.

5.3 Globalization aspects

From a global perspective, acquisitions may seem justified as business growth is a way of enabling needed investment to guarantee long term business success. However, for the case company, such acquisitions have had consequences. From literature it is argued that integration is important during such processes (Sudarsanam, 2003, p. 5; Verbeke, 2010, p. 44). The product portfolio of the case company has grown from containing only one truck brand to containing seven truck brands (including joint ventures). All these truck brands have different prerequisites as they are focused on certain geographic areas and market segments. One of the consequences of the non-complete integration of the acquired businesses is an advanced and complex production IT infrastructure containing product data and processes. The dispersed product portfolio has limited the commonality between brands and products. Growing fast has consequences and is in line with what Doug Tatum (2007) stated. He means that companies which are undergoing rapid evolvement risk losing business advantage as they fail to implement needed support functions to support the new level of business.

The case company consists of a large number of factories around the globe. Together the factories form a global production network. This GPN does also include a supplier network and other actors as shown in Figure 2. Different factories have different purposes in the GPN, as suggested by Ferdows (1997). As the GPN grows there are certain risks that the network becomes inefficient as it becomes difficult to manage. Additionally, there are possibilities that certain functions become unessential as the network evolves. For the case company, it appears that the production network is dispersed in the way it is being managed in terms of manufacturing processes and manufacturing preparation processes. Therefore, it might not be robust against external effects. When analysing the collected data from the four different case studies it is clear that the GPN lacks global processes and strategies that are standardized across the entire network. It is also evident that operations are very dependent on the manufacturing engineering process which in turn is constrained from product development. The case company needs to focus more on making the manufacturing engineering process robust by implementing standardization across the GPN. Such standardization secures the engineering process which guarantees the best conditions to support the operators in the assembly process (Manrodt & Vitasek, 2004; Romero et al., 2015).

On a global level, manufacturing is very people and location dependent. Therefore, it is hard to follow up on quality and continuous improvements in the entire GPN. It also makes it harder for long term improvements in both the assembly process as well as the manufacturing engineering process itself. It is also evident that product variety plays a key role as it greatly limits possible changes in short term perspectives. Global process standardization could cut out redundancy across the production network (Manrodt & Vitasek, 2004). Standardization would make it possible to improve processes across different levels in the organization (Romero et al., 2015). The case studies have shown that the dispersed way of working makes the GPN tremendously redundant. Such redundancy harms the case company in limiting possibilities for needed investments and changes. The use of a holistic approach would make it easier for collaboration with product development in terms of clearly defined production constraints earlier in the product development process. Standardizing vital processes on a global basis would considerably limit the possibility for severe abnormalities and performance disturbances in both engineering processes and in manufacturing processes.

5.4 Quality and limitations

This thesis is based on both qualitative and quantitative research activities. As the thesis focuses on global production networks, it was decided to focus on one case company. The first two case studies, A and B, used quantitative method to get an overview of the current state of using standards when transferring assembly work instructions to the operators. As the quantitative data collecting method was anonymous it was not possible to follow up participants with interviews. Therefore, case study C was conducted with a qualitative method to carefully investigate the manufacturing engineering process, focusing on the creation of assembly work instructions. Together with the quantitative data, the study provided an interesting analysis of the manufacturing engineering process which answers both research questions.

One limitation from case study C is that it considers only one truck brand and production of engines and transmission in Sweden. It would have been interesting to also investigate another of the truck brands acquired by the case company to perform a comparative analysis of the manufacturing engineering processes. Furthermore, it would be interesting to perform case study D in a factory for another of the truck brands of the case company as well.

It is always difficult to conduct qualitative studies with people working within the manufacturing process. In case study D a mixed method approach was used to collect statistical data from production IT systems and compare it with interviews with operators, production engineers and the production leader responsible for the production areas studied. Access to operators for interviews was limited and therefore a group interview was conducted. Although the interview resulted in what was required, separate interviews would result in more details. As the operators were difficult to access, it was not possible to follow up the perceived complexity assessment with interviews. Another aspect of case study D was that the quality data available from production IT systems was not broken down on a station level. Furthermore, as the GPN of the case company is large, focus was particularly placed on the factory that handles the highest amount of customization in the GPN.

The case studies in this thesis have been focused on in-depth analysis of one case company. Focusing on one case company provides better possibilities to get a genuine understanding of the phenomenon studied.

5.5 Future research

On the basis of previous studies, it has was claimed that much of the perceived complexity in the production system is out of reach for the factories themselves (Huang & Inman, 2010). Therefore, focus should be addressed to earlier phases during the manufacturing engineering process and product development. Such studies should focus on boundary constraints for production. By further investigating the manufacturing engineering process, an information model could be created defining (1) what information is used (2) by whom it is used (3) where in the process it is used and (4) what the information is used for. Such an information model is a key for standardizing vital processes across GPNs. The vision for future research activities is a new production system with no legacy systems/data constraining such development. Such an approach is needed to evolve the current production system without being limited by historical activities and managerial decisions.

6 Conclusion

This thesis has focused on the process to create assembly work instructions, what they contain and how they are presented and used by the operators in manual assembly of highly customized trucks, engines and transmissions. Since manufacturers of trucks are most often organized in global production networks, the focus has been on similarities and differences in such networks. The research activities have been focused on the creation of assembly work instructions (the manufacturing engineering process) and operational performance in a high product variety context.

What is the current state of using standards when transferring assembly work instructions to the operators in manual assembly?

In case studies A and B, 93 production engineers, team leaders and operators answered questionnaires which were designed to investigate the use of standards when transferring assembly work instructions to the operators. The majority of the respondents stated that there are standards implemented to support this process; however, there is less support for the conclusion that these standards are actually followed. Furthermore, even if there are standards implemented, those standards are differently interpreted among different brands, different locations and sometimes within the very same factory.

What are the challenges in manufacturing engineering processes in production networks handling multiple brands with high product variety?

Case studies C and D, investigated the effects of high product variety in manufacturing engineering processes and manual assembly. Due to the extensive set of brands and product variety in the GPN, the manufacturing engineering process is conducted differently for different brands and locations. The lack of commonality and a holistic perspective when creating assembly work instructions, results in diversified engineering processes. Commonality and holistic perspective are needed to prevent sub-optimization, and to increase knowledge transfer within the GPN. When assembly work instructions are incomplete, or when operators do not read instructions, the amount of assembly errors increase. The link between production engineering and operations is vital, especially when product variety is at its extreme. When product variants are new to the operators, they are dependent on their assembly work instructions. These instructions may be difficult to read and to follow. Additionally, if these instructions also contain errors, there is an obvious risk that production performance will be negatively affected.

The results presented in this thesis indicate the need for finding better methods to handle high product variety in global production networks. If such methods are in place, manufacturing companies will be prepared for groundbreaking changes.

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Appendices

Appendix A
Web questionnaire used in case study A, used in Swedish.

Appendix B
Web questionnaire used in case study B, originated from Swedish, but was also available in English, Dutch, French, Japanese, Portuguese, and Russian.

Appendix C
Interview questions used in case study C.

Appendix D
Interview questions used in case study D.

Appendix A

(Translated from Swedish to English)

At what Company do You work?

What is your profession?

- Production Engineer
- Quality Engineer
- Team leader
- Operator
- Other:

In what part of the company do you work?

- Production
- Quality
- R&D
- Other:

How long have you been working at the company?

- 0-5 years
- 6-10 years
- 11-20 years
- > 20 years

How long have you been working at your current position?

- 0-5 years
- 6-10 years
- 11-20 years
- > 20 years

What type of information carriers do you use today to transform information to the production operators?

- Personal meeting
- Phone
- Paper
- Computer (stationary)
- Computer (laptop)
- Smart phone (Android, iOS, Blackberry, Symbian)
- Whiteboard
- Monitor/screen
- Pick-by-Light

- State lamps
- Barcode
- RFID tag
- QR codes
- Other:

How well do the information carriers work?

- Good
- Bad
- Other

What type of information is used?

- Assembly instruction
- Drawing (blueprint), 2D
- CAD model, 3D
- Machine instruction
- Tacit knowledge
- One-point-lesson (good examples)
- Shift/Personnel information
- Maintenance instruction
- Other:

How well does the information work?

- Good
- Bad
- Other:

How is the information presented?

- Text
- Picture
- Film
- Animation
- Other:

How well do they work?

- Good
- Bad
- Other:

Who is responsible for that the information is correct? Ex. Developments, updates etc.?

- Me

- Production engineer
- Quality engineer
- Lean coordinator
- Operator
- IT-department
- Centralized to Swedish office
- Other:

If you answered ME on previous question, describe the process shortly:

Where do you create the instructions? Please write the name of the system in the box called other.

- Business System
- CAD-program (e.g. CATIA, DELMIA, ProE)
- Microsoft Office (Word, Excel, PPT)
- AVIX
- Other:

Are there standards when creating assembly instructions?

- Yes
- No
- No, but ongoing work

When You are developing the instructions, what is MOST important?

- Simplicity
- Usability
- Trust in information
- Decrease workload
- Easy to do right
- Competence (skill of the operator)
- Other:

Do You have any other comments regarding assembly work instructions and the process?

Appendix B

(Translated from Swedish to English)

In which country do You work?

- Japan
- Brazil
- Sweden
- France
- Russia
- Belgium
- Other:

At what Company do You work?

What kind of operation is handled on the plant?

- Cab – BiW
- Cab – Assembly
- Powertrain – Machining
- Powertrain – Assembly
- Truck – Assembly
- Other:

What is your profession?

- Production Engineer
- Quality Engineer
- Team Leader
- Operator
- Other:

In what part of the company do you work?

- Production
- Quality
- R&D
- Other:

How long have you been working at the company?

- 0-5 years
- 6-10 years
- 11-20 years
- > 20 years

How long have you been working at your current position?

- 0-5 years
- 6-10 years
- 11-20 years
- > 20 years

What type of information carriers do you use today to transfer information to the production operators?

- Personal meeting
- Phone
- Paper
- Computer (stationary)
- Computer (laptop)
- Smart phone (Android, iOS, Blackberry, Symbian)
- Whiteboard
- Monitor/screen
- Pick-by-Light
- State lamps
- Barcode
- RFID tag
- QR codes
- Other:

How well do the information carriers work?

1	2	3	4	5
Bad				Excellent

How is the information presented?

- Text
- Picture
- Film
- Animation
- Other:

How well is the information formulation/layout presented to the operator?

1	2	3	4	5
Bad				Excellent

What type of information is used?

- Assembly instruction
- Drawing (blueprint), 2D
- CAD model, 3D
- Machine instruction
- Tacit knowledge
- One-point-lesson (good examples)
- Shift/Personnel information
- Maintenance instruction
- Other:

Rate the capability of an inexperienced operator to understand and execute accordingly in relation to the information presented.

1	2	3	4	5
Low				High

Who is responsible for that the information is correct? Ex. Developments, updates etc.?

- Me
- Production engineer
- Quality engineer
- Lean coordinator
- Operator
- IT-department
- Centralized to Swedish office
- Other:

Where do you create the instructions? Please write the name of the system in the box called other.

- Business System
- CAD-program (e.g. CATIA, DELMIA, ProE)
- Microsoft Office (Word, Excel, PPT)
- AVIX
- Other:

How fast is incorrect information adjusted (Max limit in hours)?

How fast is incorrect information adjusted (Average response time in hours)?

Is the operator involved in the creational process? (feedback and updates)

- Yes
- No

Are there standards when creating assembly instructions?

- Yes
- No
- No, but ongoing work

If YES on PREVIOUS question, in to what extent are the standards followed?

1	2	3	4	5
Low Extent				High Extent

When You are developing the instructions, what is MOST important?

- Simplicity
- Usability
- Trust in information
- Decrease workload
- Easy to do right
- Competence (skill of the operator)
- Other:

How much of the development work is carried out locally? (from high level instructions to instructions for specific order)

To what extent is collaborative work performed with global and local functions relating to assembly instructions?

Appendix C

The interview questions are translated from Swedish to English.

Interviews with people inside the process

1. What do you do in your daily work?
2. What do you need in order to perform your work tasks?
3. What improvement opportunities can you identify?
4. How would you describe the preparation process?
5. Which departments are involved in the process?
6. Is the preparation process documented?
7. What is the result from your work?
8. Which goals are you working towards?
9. Can you see any difficulties in your daily work?
10. Which countries do you cooperate with?

Interviews with people outside the process

1. What is important to consider when creating master processes?
2. Does a master process exist for the preparation process?
3. How does one proceed when creating master processes?
4. Have any differences between brands been identified?
5. Is there a great need for master processes?

Appendix D

Interview questions to operators (only to guide the interview)

1. Do you experience that the work content varies much?
2. Do you experience that the product looks different each time?
3. Do you experience stress when you are working?
4. Do you find the assembly work instructions unclear?
5. Do you find education is proper to manage the work well?
6. Do you find that the assembly line is properly balanced?
7. Do you find the work on this assembly station difficult with a high level of complexity?
    a. What do you find difficult?
    b. Are available assembly work instructions helpful or do you rely on your own experience?
8. How many assembly errors have occurred that you have got feedback on?
9. Eventual quality deviations on this station, are they solved within reasonable time?
    a. Do you know if these deviations are considered to be local or global?
10. Do you find this station to have more quality deviations than nearby assembly stations?
11. If we focus on the variance in the assembly process:
    a. In respect to product variety
        i. Does it make the work more difficult?
    b. In respect to assembly steps
        i. Does it make the work more difficult?
    c. In respect to assembly work instructions
        i. Does it make the work more difficult?
12. Do you find the cycle time in respect to takt time varies much, and how does that affect your work?
    a. Do you find that variance in cycle time makes the work more difficult?
    b. Do you find that variance in cycle time makes the work more distracting?
    c. Do you find cycle times to be well suited with current takt time?
13. Do you find that product variants affect the cycle times?
14. The assembly work instructions that are distributed, do you consider these to be good or bad, and do they affect the result of your work effort?
15. Is there anything you would like to add?

Interview questions to production engineers (only to guide the interview)

1. Can you describe your role as a production engineer?
2. How is the amount of product variants affecting your assembly stations?
3. How is quality secured at an assembly station?
4. What is the current quality level at each station:
    a. What is the amount of assembly errors?
    b. Are quality deviations properly reported?