THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Future Assembly Information Systems

Redefining the Manufacturing Systems of Tomorrow

PIERRE E. C. JOHANSSON

CHALMERS

Department of Industrial and Materials Science

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PIERRE E. C. JOHANSSON
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Department of Some Subject or Technology
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Cover:
A board showing the six focus areas accompanied by an operator.

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"These facts are not up for discussion. I am right, and you are wrong."

- Professor Hans Rosling, 2015

ABSTRACT

Product variety continues to increase as the manufacturing industry introduces customized products and services to address the varying demands of their customers. In the manufacturing industry, it is common for large and global manufacturing companies to grow through mergers and acquisitions. As a consequence, these companies have hard times to find proper information systems integration strategies and to find commonality in their product portfolios. The introduction of Industry 4.0 kick started the digitalization journey that permeates society. Despite the digitalization initiatives, the manufacturing industry has fallen behind in terms of technology introduction in manufacturing systems. In the spirit of Industry 4.0, the manufacturing industry needs practical support on how to prioritize the development of future manufacturing systems.

The objective of this thesis is to expand the knowledgebase about the impact of the digitalization in the manufacturing industry. This thesis presents a current state analysis of the challenges of handling assembly information in manual assembly intense manufacturing companies. The thesis also presents critical aspects to overcome the identified challenges and aims to support manufacturing companies in prioritizing initiatives and in making proper preparations for starting the digital transformation. This thesis is based on three case studies conducted between 2016 and 2017. The case studies show that there are many challenges that the manufacturing industry is currently facing that make it difficult to create smart manufacturing systems. The result of the thesis is intended to be used as input when deploying new assembly information systems to assure high flexibility and operability. Future assembly information systems will allow more customization towards the intended end-user (e.g. operator and engineer), increased automation and data-based decision-making.

On basis of the current challenges and the identified critical aspects, an industrial demonstrator has been developed to be used for validation of several design principles that have been formulated. The demonstrator will be tested by real operators during the spring of 2018 and the result will be used to spread knowledge of the impact of enhanced assembly information systems.

Keywords: Industry 4.0, Assembly information systems, Manufacturing systems, Manual assembly

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Pierre Eric Christian Johansson
Gothenburg 2018

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LIST OF APPENDED PAPERS

PAPER

A

Johansson, Pierre E. C., Enofe, Martin O., Schwarzkopf, Moritz, Malmsköld, Lennart, Fast-Berglund, Åsa, Moestam, Lena (2017). Data and Information Handling in Assembly Information Systems – A Current State Analysis, *Procedia Manufacturing, 11, 2099-2106.*

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B

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PAPER

E

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LIST OF ADDITIONAL PAPERS

1 Johansson, Pierre E. C., Delin, Frida, Jansson, Sofie, Moestam, Lena, Fast-Berglund, Åsa (2016). Global Truck Production – The Importance of Having a Robust Manufacturing Preparation Process. *Procedia CIRP*, 57, 631-636.

2 Johansson, Pierre E. C., Mattsson, Sandra, Moestam, Lena, Fast-Berglund, Åsa (2016). Multi-variant Truck Production - Product Variety and its Impact on Production Quality in Manual Assembly. *Procedia CIRP*, 54, 245-250.

3 Ebrahimi, Amir H., Åkesson, Knut, Johansson, Pierre E. C., Lezama, Thomas (2016). Automated Analysis of Interdependencies Between Product Platforms and Assembly Operations. *Procedia CIRP*, 44, 67-72.

4 Ebrahimi, Amir H., Åkesson, Knut, Johansson, Pierre E. C., Lezama, Thomas (2015). Formal analysis of product variability and the effects on assembly operations. *2015 IEEE 20th Conference on Emerging Technologies & Factory Automation (ETFA)*, 1-4.

5 Johansson, Pierre E. C., Moestam, Lena, Fast-Berglund, Åsa (2015). Use of Assembly Information in Global Production Networks. *Proceedings of the 25th International Conference on Flexible Automation and Intelligent Manufacturing*, 258-265.

6 Fast-Berglund, Åsa, Åkerman, Magnus, Mattsson, Sandra, Johansson, Pierre E. C., Malm, Anna, Pernestål Brenden, Anna (2014). Creating Strategies for Global Assembly Instructions – Current State Analysis. *Proceedings of the 6th Swedish Production Symposium*.

7 Ebrahimi, Amir H., Bengtsson, Kristofer, Johansson, Pierre E. C. Åkesson, Knut (2014). Managing Product and Production Variety – A Language Workbench Approach. *Procedia CIRP*, 17, 338-344.

8 Johansson, Pierre E. C., Lezama, Thomas, Malmsköld, Lennart, Sjögren, Birgitta, Moestam, Lena (2013). Current State of Standardized Work in Automotive Industry in Sweden. *Procedia CIRP*, 7, 151-156.

DEFINITIONS

ASSEMBLY INFORMATION SYSTEM	An information system that contains and handles all assembly relevant information to the work station (e.g. information to system-controlled equipment and assembly work instructions etc.).
INTEROPERABILITY	Characteristics of a product or system where the interfaces are fully understood by other products or systems.
MANUFACTURING ENGINEER	A person with technology responsibility on a broader level than the manufacturing technicians.
MANUFACTURING EXECUTION SYSTEM	A computerized system in a manufacturing company that tracks and controls the manufacturing process and its information flow.
MANUFACTURING TECHNICIAN	A person at a plant with technology responsibility for a set of assembly stations. This person is responsible for assuring that the assembly work instructions are correct.

ABBREVIATIONS

AIS	Assembly Information System
GPN	Global Production Network
GTO	Volvo Group Trucks Operations
IS	Information System
IT	Information Technology
KPI	Key Performance Indicator
MES	Manufacturing Execution System
OEM	Original Equipment Manufacturer
SME	Small and medium-sized enterprise

PREFACE

This thesis is mainly based on the research conducted within the GAIS projects since 2013. GAIS is the acronym for Global Assembly Instruction Strategies. The first GAIS project[1] (2013-02648) was conducted from 2013 to 2015, 24 months. The GAIS 2 project[2] (2016-03360) is running between 2016 and 2018, 24 months. The two projects are sponsored by FFI – Fordonsstrategisk Forskning och Innovation (Strategic Vehicle Research and Innovation), which is a collaboration program between the Swedish vehicle industry and Vinnova (The Swedish Innovation Agency). The logotypes for the projects are shown in Figure I.

The aim of the first GAIS project has been to investigate globalization strategies for assembly work instructions and how these instructions are handled between manufacturing engineering and the operator in final assembly. The project consortium consisted of Volvo Group, SAAB Aeronautics, Chalmers, Gothenburg Technical College and Scania. The project budget was 5 500 000 SEK.

The aim of the GAIS 2 project is to develop models and strategies focusing on centralized and decentralized approaches for assembly information systems (AIS). The contribution as presented in this thesis is to identify critical aspects on how future AIS should be designed to satisfy information requirements from the shop floor. The project consortium consists of Volvo Group, SAAB Aeronautics, Combitech, XMReality, Chalmers and University West. The project budget is 5 600 000 SEK.

The author of this thesis is employed by the main case company with the responsibility to conduct research within the manufacturing domain. The research has been conducted in close collaboration with academic partners and other external industrial partners through publicly funded research projects. The author focuses on the challenges that arise with the global economy development and the opportunities through the rapid technology transformation. The work is supervised by two academic institutions; Chalmers University of Technology and University West in Sweden.

Figure I: The two logotypes used for disseminating the GAIS projects

[1] https://www.vinnova.se/p/gais/

[2] https://www.vinnova.se/p/strategier-for-globala-monteringsinstruktioner-2-gais-2/

1 INTRODUCTION

This chapter introduces the ambition of this thesis by providing a background, staring point and vision of the research domain. It presents the research objective of the thesis and the three research questions defined. It also provides a research context as well as delimitations of the research ambition and a disposition of the thesis.

1.1 Background

The idea of an Industry 4.0 has gotten a foothold in the manufacturing society. The forth industrial revolution is focused on the Internet of Things (IoT) and the Internet of Services achieving cyber-physical systems by connecting resources in the manufacturing systems in large global networks. As resources in the manufacturing systems become connected, they may share information with each other making the factories smart (Gilchrist, 2016). It is the information that is shared within the manufacturing system that makes it smart. The manufacturing industry is dependent on their information systems (IS) to remain productive. To keep up with external forces (i.e. customer demands and competition), technology advances, legislation and optimization, the manufacturing industry needs to continuously adapt its external and internal IS (Romero and Vernadat, 2016). As the manufacturing industry is under transformation to become digitalized, new skills and job profiles are needed to successfully implement such changes (Pinzone *et al.*, 2017).

1.1.1 The starting point

The manufacturing industry is characterized by rigid supply chains where the OEM (original equipment manufacturer) acts as the central node. In the modern economy, manufacturing companies become global as they seek to enlarge their market shares by attracting a wider customer base on new markets (Hill, 2008; Yip and Hult, 2012). The manufacturing companies that grow need to build sufficient capacity in their supply chains to serve the varying demand on the market. Acquisitions and mergers are two common growth strategies. However, companies that have grown using these kinds of growth strategies have difficulties to find economies of scale as they fail to integrate acquired entities into their businesses (Hitt, Ireland and Harrison, 2001; Ireland, Hoskisson and Hitt, 2008). In particular, the integration of IS is challenging (Sudarsanam, 2003) where partial and marginal integration seems less complex in a short term perspective and costly in a long term perspective (Johnston and Yetton, 1996; Wijnhoven *et al.*, 2006). There are great risks that these companies become too diversified making it difficult to handle their global production networks (GPN) effectively (Ferdows, 2014). These companies need to assure that they sustain a reasonable amount of flexibility in their GPN to achieve business robustness from a long term perspective (Wiendahl, 2007).

Mass customization is an enabler of answering to customers' varying demands in a cost-efficient way. By changing the business strategy, a company can alter the product and yet keep the cost and quality benefits from mass production (Joseph Pine II, Victor and Boynton, 1993). A typical approach to achieve customized products is to modularize the product and to introduce standardized components and interfaces to allow the customer to choose from a set of predefined options with a little cost penalty (Ulrich, 1995). As the trend of customized and even personalized products tends to increase (Um *et al.*, 2017; Wan and Sanders, 2017), manufacturing systems need to remain flexible enough to answer to dynamical and rapid changes in the market demands (ElMaraghy and Wiendahl, 2009; Wang, Törngren and Onori, 2015). Handling high levels of product variety in a manufacturing system is not an easy task. Product variety places a penalty on production performance as it tends to increase the amount of hours spent per product (MacDuffie, Sethuraman and Fisher, 1996; Fisher and Ittner, 1999), affect quality negatively (Fast-Berglund *et al.*, 2013) and introduce complexity at the work station (ElMaraghy *et al.*, 2012).

1.1.2 The vision

To overcome the challenges of handling high levels of product variety in assembly processes manufacturing companies have different strategies in place. The introduction of kitted material and sequenced material aims to simplify decision making for the operator by limiting the variety at the work station (Brolin, Thorvald and Case, 2017). Another way of handling product variety and the complexity it brings is to equip the operator with customer order specific assembly work instructions. Assembly work instructions are intended to support the operator's decision making by providing information at the right time, in the right place and in ensuring that there is an identified need for that particular information (Bäckstrand *et al.*, 2006).

As future product complexity remains unknown, improved methods for handling such complexity is needed in the manufacturing industry. According to Stork and Schubö (2010) the assembly task needs to be analyzed in the perspective of the cognitive process to support the operator. By introducing optimized and adapted assembly work instructions, the complexity of the assembly task could be handled. Many research activities have investigated operator support in manual assembly intensive industries. As an example, one study investigated how to increase the intention to use supplied assembly work instructions by making them mobile and more accessible at the work station though mobile devices (wearables). The experiments showed an increase in the usage of supplied information as well as improved assembly quality (Thorvald *et al.*, 2010).

In the future, assembly work stations will be equipped with more technology and smart devices providing the ability to both support the operator in different ways with different information sources, information carriers and information media and to enhance overall plant optimization (Cimini, Pinto and Cavalieri, 2017). To facilitate such work station improvements, new assembly information systems (AIS) are needed which can provide requested information. This is where industry 4.0 will play an important role. For this to happen, there are six particular stages covering the development of the capabilities required for Industry 4.0; computerization; connectivity; visibility; transparency; predictive capacity; and adaptability (Schuh, Anderl, *et al.*, 2017). However, case studies presented in this thesis show that there is a gap between those stages and the current state in the manufacturing industry. This thesis aims to address this gap.

1.2 Research objective

As global manufacturing companies grow bigger they base their businesses on large amounts of legacy spread across their GPNs. Acquisition based growth is one of the reasons why global manufacturing companies have hard times turning legacy into positive business value. These companies fail to integrate new businesses with former businesses (Hitt, Ireland and Harrison, 2001, p. 112; Ireland, Hoskisson and Hitt, 2008, p. 141). In large global manufacturing companies, integration of IS during an acquisition is challenging (Sudarsanam, 2003, pp. 7–8). Consequently, many manufacturing companies end up with partial or marginal integration of IS. Lack of common IS in the organizations makes it difficult to implement new standards and technologies into their IT infrastructures.

The research objective of this thesis is to increase the knowledge of the implications of an increasing digitalization in the manufacturing industry. The research objective is achieved by investigating current challenges of handing assembly information in the manufacturing industry. Additionally, the thesis will suggest focus areas where the manufacturing industry should concentrate their efforts when implementing new AIS.

1.2.1 Research questions

On basis of the research objective, three research questions are formulated:

RQ 1. What are the main challenges of handling assembly information for manual assembly tasks in global manufacturing companies?

RQ 2. What critical aspects exist when the manufacturing industry deploys new assembly information systems?

RQ 3. How can an ambition for enhanced future assembly information systems be validated?

The first research question is focused on identifying the challenges of current handling of assembly information in the manufacturing industry. This contribution is focusing on the development of assembly work instructions and the operational use of such information. The second research question addresses the critical aspects when deploying new AIS. This work is focused on aspects connected to the development, handling and use of assembly information in practice. The third research question builds upon the first two research questions by introducing an aspiration for future AIS to be validated.

1.3 Research context

The research presented in this thesis is divided in two parts, the licentiate thesis and the doctoral thesis. The research described in both the theses is linked together in a joint problem formulation concerning the development and handling of assembly work instructions in the manufacturing industry. The research context has been established based on the result reported in the licentiate thesis.

1.3.1 Licentiate thesis

The licentiate thesis, *Challenges in Global Multi-Variant Serial Production – A Study of Manufacturing Engineering Processes*, focused on developing assembly work instructions in global manufacturing companies (Johansson, 2016). In detail the licentiate thesis investigated current standardization levels of handling assembly work instructions and the challenges in manufacturing engineering processes in GPNs. The licentiate thesis concluded:

- Most of the respondents from the case studies stated that there are standards in place for handling of assembly work instruction. However, there is little to support that these standards are actually followed; instead, they are differently approached in different locations.

- Manufacturing engineering processes in the case company are executed differently depending on the organizational structure and location of the plants. Furthermore, commonality and holistic perspective is missing in the organization, which is needed to facilitate knowledge sharing in the whole GPN.

The results from the licentiate thesis are based on four different case studies conducted within one manufacturing organization using web questionnaires and semi-structured interviews. The result has been documented in four papers and one master thesis project report (Fast-Berglund *et al.*, 2014; Delin and Jansson, 2015; Johansson, Moestam and Fast-Berglund, 2015; Johansson, Delin, *et al.*, 2016; Johansson, Mattsson, *et al.*, 2016). The work described in the licentiate thesis contributes to the research objective of this doctoral thesis by identifying a research gap as described in section 1.2.

1.3.2 PhD thesis

This doctoral thesis, Future Assembly Information Systems – Redefining the Manufacturing Systems of Tomorrow, focuses on the challenges the manufacturing industry is facing in the context of digitalization and product customization. It takes its starting point from the licentiate thesis which mostly focused on current state analysis of manufacturing engineering processes. The doctoral thesis is continuing the research effort with an emphasis on large global manufacturing companies and the impact on assembly work instructions in complex organizations and IT infrastructures. The intended contribution of this thesis are six focus areas containing several critical aspects the manufacturing industry need to consider when deploying new AIS. These critical aspects are seen as enablers of smart AIS.

1.4 Delimitations

- The thesis is only considering manual assembly intense manufacturing companies.
- Manufacturing engineering is in this context only related to the process of developing assembly work instructions and making these available to shop floor operators.
- The thesis is only considering large, > 250 employees, and global manufacturing companies with plants in more than one country/location. The company size definition of the European Union (European Union, 2003) is applied.
- This thesis is focusing on AIS from the perspective of the operator and not on architectural or other technical aspects of an IS.

1.5 Disposition of thesis

1. *Introduction* describes the starting point for the research presented in this thesis and the vision in terms of future AIS. On basis of the background, the research objective is presented where three research questions are defined focusing on current state, solution and validation. The research context is presented focusing on the contribution from the licentiate thesis and the contribution from this doctoral thesis. The delimitation of this thesis is also covered.
2. *Frame of reference introduces* theory on data, information and knowledge. It continues to look into cognition in theory and practical use. Information technology as of industry 4.0 is covered. The chapter continues by looking in to different perspectives of IS; operators; engineers; and management. The chapter is concluded by a summary of presented theory.
3. *Methodology* presents the methodology for the overall thesis as well as for the three case studies conducted. The research validation aspects are presented as well as the data analysis.

4. *Summary of appended papers* present the contribution to the research questions from each of the five appended papers.
5. *Discussion* aims to provide the answers to the defined research questions. Three research questions are discussed as well as the academic contribution and the industrial implications. The chapter is concluded by reflections on quality and limitation of the studies made and suggestions for future work.
6. *Conclusion* presents the final remarks covering the three research questions and the overall ambition of this thesis.

2 FRAME OF REFERENCE

This chapter presents definitions of data, information and knowledge. It also presents aspects of cognition in the manufacturing context, Information Technology, Industry 4.0 and assembly information systems. It ends with an elaboration on different hierarchical perspectives and a summary.

2.1 Data, information and knowledge

As the introduction of this thesis states, information is a fundamental asset in an assembly information system and requires a proper introduction. Definitions of data, information and knowledge go far back. Data is a representation of properties of an object. The representation of properties itself is of no value if it is not given a meaning. By adding meaning to data, data is transformed to information (Ackoff, 1989; Stair and Reynolds, 2017). Information can take an unstructured, semi-structured or a structured shape as the semantic level between the information properties may vary (Batini and Scannapieco, 2016). Adding awareness and understanding to information, the state of knowledge can be reached (Rainer and Cegielski, 2011). In some context, wisdom is also added to this complex structure, referring to the mental function of judgment, adds value to the knowledge. Data and information is time dependent, while knowledge has a longer lifespan and wisdom considered as permanent (Ackoff, 1989). This thesis focuses mainly on data and information as they form the basis of knowledge and wisdom.

2.2 Manufacturing systems

Manufacturing, production and operations, there are different terminologies describing the actions taken between the order and delivery of a product or a service. The word manufacture originates from the mid-17th century e.g. from the Latin words *manu factum* and the Italian word *manifattura* (Stevenson, 2010). Manufacturing is defined as "The entirety of interrelated economic, technological, and organizational measures directly connected with the processing/machining of materials, i.e., all functions and activities directly contributing to the making of goods" (Segreto and Teti, 2014). A manufacturing system is a combination of resources connected by a common flow of information and material responsible for the making of goods (Chryssolouris, 1992). A manufacturing system can either be discrete (assembly) or continuous (process) (Scallan, 2003). To facilitate manufacturing in a systematic way, manufacturing engineering is responsible for "the planning and selection of the methods of manufacturing, development of the production equipment, and research and development to improve the efficiency of established manufacturing techniques and the development of new ones" (Matisoff, 1997, p. 1). A common task in a manufacturing process is the manual assembly task which "…comprises all kind of operations performed in order to permanently join components by manual methods to form subassemblies and products" (Lien, 2014).

2.2.1 Cognition in the manufacturing context

The operator is a critical asset in a manufacturing system which requires that certain preconditions be fulfilled to be able to perform the allocated assembly task. The cognitive load of the operator is dependent on work station design, product variant mix, assembly work instructions, cycle times etc. (Brolin, Thorvald and Case, 2017). Highly cognitive loads tend to increase the amount of assembly errors due to the complexity of components and assemblies and the difficultness to join them together (Swift and Booker, 2013). The assembly situation affects how the operator acts. The behavior of the operator can be described in three terms; skill-based, rule-based and knowledge-based (Rasmussen, 1983). Skill-based and rule-based behaviors are the result of situations where the operator is handling by intuition. Such intuition means that the operator makes quick and effortless decisions based on experience (Klein, 2003). When the situation requires more than intuition, the knowledge-based behavior takes over and intuition becomes reasoning. The process of reasoning is slower and only a smaller amount of information can be processed simultaneously (Evans, 2010). Therefore it is important that supplied assembly information is presented in such a way that it stimulates an active mindset e.g. skill- and rule-based behavior (Bäckstrand *et al.*, 2008; Thorvald *et al.*, 2008; Bäckstrand, 2009; Thorvald, 2011). Otherwise, there are great risks of production disruptions in the shape of assembly errors (Bäckstrand *et al.*, 2006). Additionally, when the task complexity increases, the success of information seeking decreases (Byström and Järvelin, 1995). To support intuition, five guidelines have been described in literature (Mattsson and Fast-Berglund, 2016):

- *Support active cognitive processes;* information must be given in such a way that it is easy to interpret on the basis of the experience of the operator.
- *Support mental models;* operators interpret information differently and act accordingly.
- *Support abilities and limitations;* benefit from natural abilities and instincts of the operator and at the same time consider natural limitations such as memory capacity etc.
- *Support individual preferences/differences;* operators are different and have different prerequisites and will need different types of information in a situation.
- *Support perception;* consider the placement of the information and supportive pictures where they are needed.

These guidelines are used to create assembly work instructions. The issue with assembly work instructions is that the operators are different in the perspective of skills, experience, age etc. This makes it hard to develop assembly work instructions that fit the needs of each specific operator (Menn and Seliger, 2016). The more complex the assembly work task gets, the more assembly work instructions are required which affects both the content and carrier of the instruction (Fässberg, Fasth and Stahre, 2012). Therefore, to make assembly work instructions more efficient, their design must emphasize knowledge about learning and comprehension from the cognition theory field as well as knowledge regarding technical writing and information design (Ganier, 2004). To assure good instructional design, digitized assembly work instructions and techniques such as responsive web design (Baturay and Birtane, 2013) should be considered. With new techniques and standards information carriers become more flexible and efficiently handled that more focus could be put on the information content instead.

2.2.2 Assembly information systems

An IS is a "set of interrelated components that collect, process, store and disseminate data and information; an information system provides a feedback mechanism to monitor and control its operation to make sure it continues to meet its goals and objectives" (Stair and Reynolds, 2017, p. 7). As the definition implies, the IS is vital for any company, the manufacturing company in particular. The manufacturing company handles large amounts of data, information and knowledge throughout their value chain. There is no doubt that IS quality (from a service viewpoint) is affected by the quality of the information it handles (Dedeke, 2014), but poor IS quality does also negatively impact the ability to maintain high information quality in an IS (Gorla, Somers and Wong, 2010). Many manufacturing companies are still failing to make decisions based on data and information due to that (1) data is not prepared and processed into information and (2) IS are not integrated across the company which hinders the usage of common data and information (Schuh, Anderl, *et al.*, 2017). As companies create, collect and store large amounts of data and information, they can lack certain characteristics to be of any use of value in a process. (Pierce, 2014). Manufacturing companies should focus on information quality rather than information quantity (Beynon-Davies, 2013). Quality measures of information can be defined by numerous of different attributes as addressed by Al-Hakim (2007) who refers to multiple sources of different information quality attributes in literature. Some of common quality attributes in literature can be summarized by the following attributes (Al-Hakim, 2007; Beynon-Davies, 2013; Batini and Scannapieco, 2016):

- Accuracy
- Relevance
- Completeness
- Consistency
- Currency

For manufacturing companies, IS quality, information quality and service quality should be of large concern as the quality domains have great organizational impacts (Delone and McLean, 2003; Gorla, Somers and Wong, 2010).

2.2.3 Instruction quality

Work instruction quality is an issue in many industries. As an extension of the term information quality, instruction quality relates to the matter of providing work instructions as tools for achieving higher quality outcome from the work task the instruction concerns (Haug, 2015). As most literature concerns information quality and not instruction quality, Haug identifies 15 quality dimensions (information quality) determining the quality of a work instruction. These 15 quality dimensions have been clustered in five categories as described in Figure and should be emphasized when developing assembly work instructions. These quality dimensions illustrate the need to consider both the intrinsic and extrinsic perspectives of the instructional information. Without these perspectives in mind, there are risks that poor assembly work instructions becomes an unmanageable barrier between engineering and the operators which potentially affects production quality negatively.

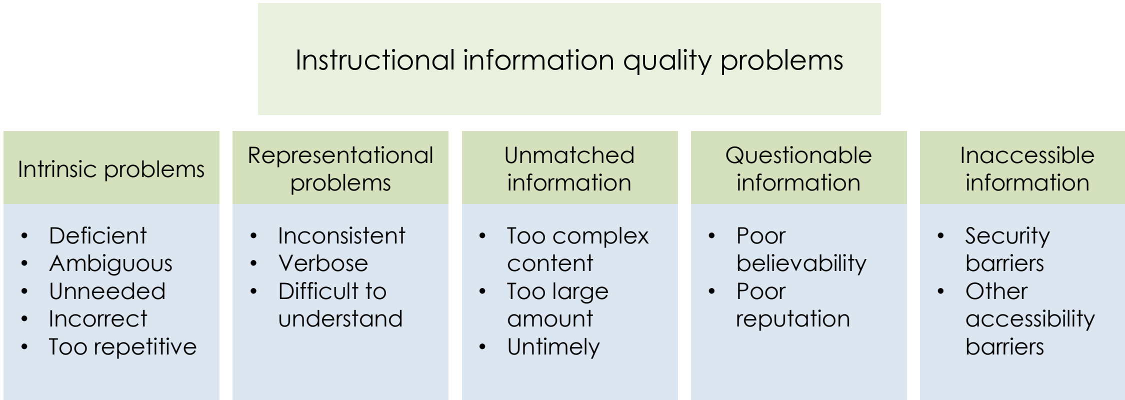

Figure 1: Instructional quality problems (Haug, 2015)

2.2.4 Information systems success

In 1992, DeLone and McLean (1992) presented an model for IS success, with the ambition of identifying the dependable variables which contribute to the success factor of an IS. Ten years later they updated their model on the basis of research contributions to the area (Delone and McLean, 2003). The IS Success Model as illustrated in Figure 2 consists of six dependable success variables:

- *System quality:* In system quality, qualities such as usability, availability, reliability, adaptability and response time are of concern by the end user.
- *Information quality:* the information content of an IS should be accurate, relevant, complete, consistent and current (Al-Hakim, 2007; Batini and Scannapieco, 2016).
- *Service quality:* the service given by an IS should emphasize assurance, empathy and responsiveness to guarantee the expected service.
- *Usage:* All interaction between the IS and the end user are covered by the usage variable addressing nature of use, navigation patterns etc.
- *User satisfaction:* The scope of an IS is to deliver the right information to the right stakeholder at a given time and in the correct amount and format (Rainer and Cegielski, 2011).
- Net benefits: The net benefits of an IS are the most critical variables measuring success. Net benefits include the previous variables of individual impact and organizational impact. The net benefits are directly determined by the contextual measures of a system such as productivity, production quality, FTT etc.

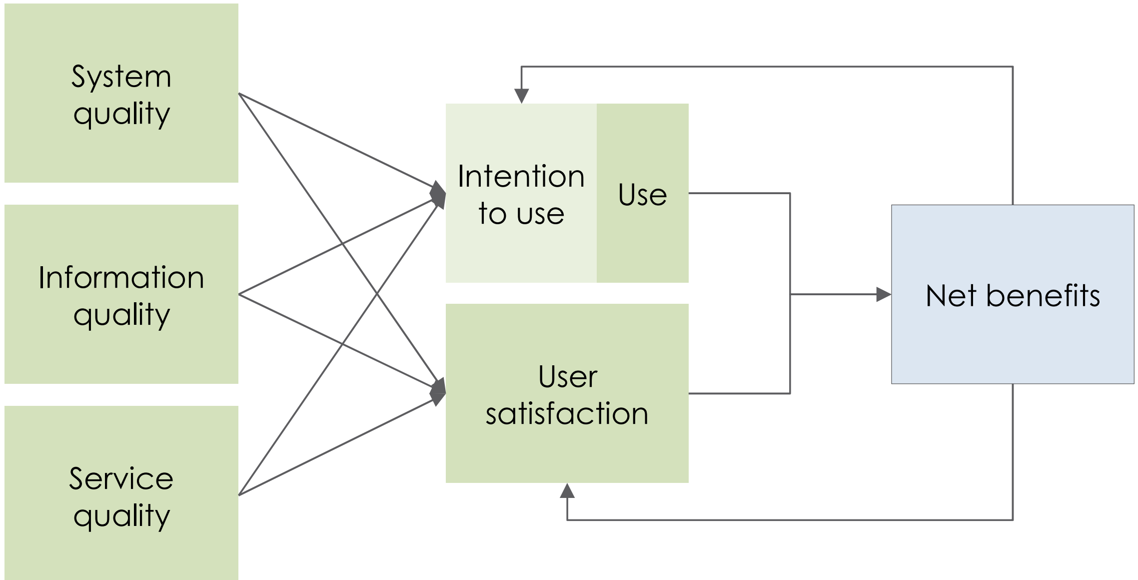

Figure 2: The IS Success Model by DeLone and McLean (1992; 2003)

In research methods theory, variables are classified as dependent or independent. A variable itself is a measure of the behavior of an object. The interdependent variable is a measure which affects the value of the dependent variable (McBurney and White, 2010). The IS Success Model has so far focused on identifying and describing the interplay between the dependent variables. In 2013, an ambition to identify and describe the independent variables (determinants) that affect the dependent variables of the IS Success Model was published, see Figure 3 (Petter, DeLone and McLean, 2013).

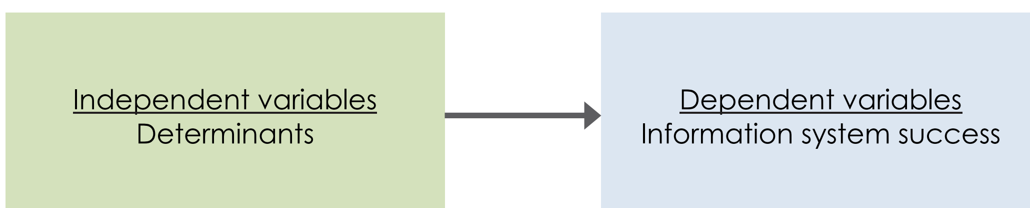

Figure 3: The interplay between independent and dependent variables

In their study, 43 independent variables were identified and grouped in five categories of determinants; Task; Individual; Social; Project; and Organizational. In Table 1, the most important determinants of IS success are presented. The identified determinants suggest a large focus on the user and the organization and are particularly covered in this Thesis. These important success factors have consistently been identified to influence IS success in many studies.

Table 1: Important determinants for IS success

<u>Task</u> • Task Compatibility • Task Difficulty	<u>Project</u> • User Involvement • Relationship with Developers • Domain Expert Knowledge
<u>User</u> • Attitudes Toward Technology • Enjoyment • Self-Efficacy • Trust • User Expectations • Technology Experience • Organizational Role	<u>Organizational</u> • Management Support • Management Processes • Extrinsic Motivation • Organizational Competence • IT infrastructure

2.3 Operators, engineers and management

The impact of effectiveness in a manufacturing company is affected by how human resources are managed (Slack, Brandon-Jones and Johnston, 2013). In operations management (OM) literature, an operation strategy is characterized by four perspectives; top-down; bottom-up; market requirements; and operations resources. The top-down perspective relates to three levels of strategy – corporate, business and functional whilst the bottom-up perspective relates to strategy established through incremental improvements based on operational experience (Slack and Lewis, 2011; Slack, Brandon-Jones and Johnston, 2013). These vertical perspectives typically describe the organizational behavior of a manufacturing company.

Within a manufacturing company, operators, engineers and managements have different perspectives on the needs of the manufacturing system. These perspectives emerge from different functions and roles that are connected and placed in an organizational structure on the basis of logical dependencies (Baligh, 2006). Management is focused on corporate, business and functional strategies whilst the engineer is focused on strategies based on operational experience. The responsibility of the operator is to realize such a strategy throughout the work task. To improve the outcome of a work task (performance as intended), the design of the job needs to emphasize two aspects to highlight self-esteem and personal development; work characteristics vs. motivation; and work motivation vs. performance (Slack, Brandon-Jones and Johnston, 2013). A typical job design model of such an approach is illustrated in Figure 4. The work task, including potential sub tasks, should therefore be designed in such a way, that it stimulates the mental states as indicated in the job design model. This suggests that provided assembly information needs to be a part of such an approach to contribute to work motivation. This approach suggests that work motivation is a part of assuring that the work task is conducted as defined.

Techniques of job design	Core job characteristics	Mental states	Performance and personal outcomes
• Combining tasks • Forming natural work units • Establishing client relationships • Vertical loading • Opening feedback channels	• Skill variety • Task identity • Task significance • Autonomy • Feedback	• Experienced meaningfulness of the work • Experienced responsibility for outcomes of the work • Knowledge of the actual results of the work activity	• High internal work motivation • High quality work performance • High satisfaction with the work • Low absenteeism and turnover

Figure 4: Behavioral job design model by Slack et al. (2013)

2.4 Industry 4.0

Industry 4.0 is an approach launched by the German authorities during 2011 as a project aiming for computerization of the manufacturing industry (Bundesministerium für Bildung und Forschung, 2018). A vision of Industry 4.0 is to establish worldwide networks of connected factories, logistic centers etc. and to share information between these entities in an intelligent way. These networks will be the base of smart factories where machines, products and humans are all connected to emphasize improvement potential throughout the whole value chain (Gilchrist, 2016). Internet of Things and Internet of Data and Services will be two of the drivers for future innovations. The technology development has become more mature providing large benefits at low cost. The spectra of various technologies creating synergies "lead to qualitatively different opportunities and impacts that ultimately come to be perceived as a revolution" (Kagermann, 2015), a fourth industrial revolution e.g. Industry 4.0. The main component of Industry 4.0 is the smart manufacturing system which is characterized by (Lu, Morris and Frechette, 2016):

- Digitization of each entity in a manufacturing system with interoperability and enhanced productivity
- Distributed intelligence and networked devices for real time control
- Collaborative supply chain
- Enhanced decision making for optimized resource efficiency
- Big data analytics enabled by smart sensor systems throughout the product lifecycle

Standards form the basis of achieving robust end results from repetitive processes and varying technological solutions. The introduction of smart manufacturing systems will require new standards going from hierarchical structures to distributed structures (Lu, Morris and Frechette, 2016). The RAMI 4.0 is a Reference Architect Model for Industry 4.0, see Figure 5. The intention of RAMI 4.0 is to grasp several aspects and perspectives of Industry 4.0 into one model. The model is intended to be used as a tool for further development of the concept of Industry 4.0 to identify and resolve different gaps and standard overlaps (Hankel, 2015). The three-dimensional model is comprised of a business layer, a functional layer, an information layer, a communication layer, an integration layer and an asset layer on the vertical axis. On the second axis, the product life cycle and value stream are located. The third axis focuses on functionalities and responsibilities (Adolphs *et al.*, 2015). The reference model visualizes the components of the Industry 4.0 concept and the integration of its properties.

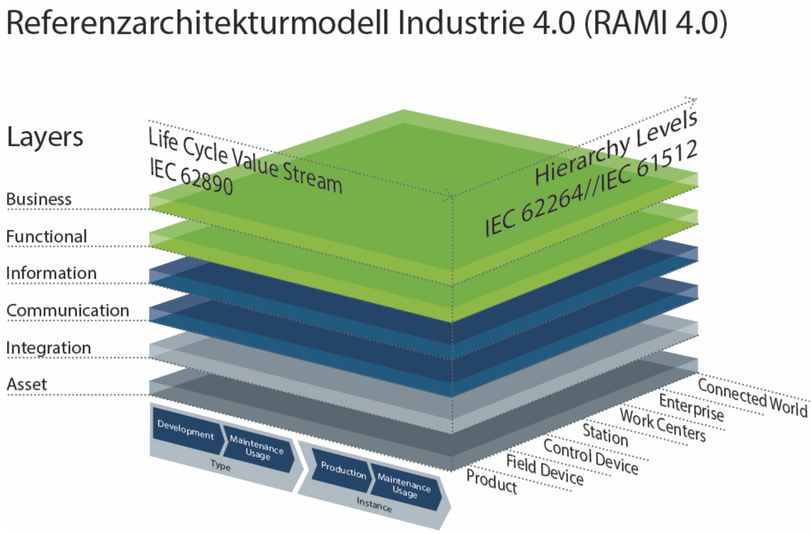

Figure 5: RAMI 4.0 (With permission from IFOK and Plattform Industrie 4.0)

2.4.1 Industry 4.0 maturity index

Despite rapid changes in both industry and society, the dream of Internet of Things and Internet of Data and Services are still far away to be fulfilled. One of the challenges organizations are facing is big data analytics as part of Industry 4.0. The organizations do not see the importance of visualization, they collect large amounts of data but spend little resources on analyzing it, they lack competence and have insufficient information systems to support big data analytics (Simon, 2014). This view is also shared by the German National Academy of Science and Engineering (acatech) who published an Industry 4.0 Maturity Index in 2017 with the ambition to highlight areas where further actions are required to facilitate the implementation of Industry 4.0 in reality (Schuh, Anderl, *et al.*, 2017). Their Industry 4.0 Maturity Index consists of six defined stages with an increasing value of each stage which also demonstrates the challenges in the manufacturing industry:

Digitalization

1. *Computerization:* Lays the foundation of digitalization in the manufacturing company. This is fulfilled by isolation of different information technologies within the company. Computerization provides benefits such as cheaper manufacturing, but to a lower cost and higher standards and precision.
2. *Connectivity:* By implementing connected components, previous isolation of information technologies can be removed. In this stage equipment become connected and enables interoperability in the manufacturing system. This will allow product data to be pushed down to the manufacturing process throughout the product realization process.

Industry 4.0

3. *Visibility:* As prices of sensors, microchips and network technologies decrease, real-time recording of states and events in the manufacturing system can now be moved to more parts of the manufacturing system than just the machining cell. This allows the manufacturing company to have a real-time digital model of the manufacturing system. The recorded data can be used to handle disruptions in the process to reduce its impact on the overall performance, KPIs.

4. *Transparency:* The fourth stage comprises identification and interpretation of recorded data to build semantic models. Adding engineering knowledge is required for rapid and complex decision making. This means that large amounts of data, big data, need to be analyzed to make decisions. Transparency allows the company to take predictive actions, e.g. maintenance.
5. *Predictive capacity:* On the basis of data recorded from the manufacturing process and from other IS, the manufacturing company can simulate scenarios for the future and plan those development steps in time. The predictive capacity is dependent on the rigorous actions taken in the previous stages.
6. *Adaptability:* An increased automation in IS is possible through proper capacity predictions. This enables quick adaptions to new business models. "The goal of adaptability has been achieved when a company is able to use the data from the digital shadow to make decisions that have the best possible results in the shortest possible time and to implement the corresponding measures automatically, i.e. without human assistance." (Schuh, Anderl, *et al.*, 2017, p. 18)

2.5 Summary

The operator in manual assembly is a vital link between the manufacturing company and the customer. Operators in manual assembly are facing highly customized products which affect the complexity of the assembly task. The operator interprets assembly information provided by engineering departments and performs the task accordingly. To increase the overall performance of the manufacturing system, the manufacturing company needs proper processes and resources to handle information and knowledge within the organization.

Many manufacturing companies have large sets of IS to transform and transfer information throughout different processes. As the performance of the manufacturing company is dependent on the information in the IS, the company should focus on information quality rather than information quantity. There are several attributes that describe information and instructional quality which needs to be emphasized when developing assembly work instructions. Additionally, as the manufacturing industry shows large interest in digitalization as the rest of the society, the industry will become even more dependent on the actual data and information stored in company IS.

The concept of Industry 4.0 targets to transform current manufacturing systems to smart manufacturing systems where all resources, humans and equipment, are connected through distributed networks. The Industry 4.0 should not be the target itself, but its concepts should be used to assure flexibility and scalability in the supply chain to fulfill cost, productivity and quality goals in the manufacturing company. The Industry 4.0 maturity index shows that there are several stages for a manufacturing company to implement to fully adhere to the concept. But to digitize documents is not the only part of becoming smart. The IS success model consists of dependent variables which all contribute to the overall performance of the company. Particularly, the information quality, IS quality and service quality have large impacts on the performance. IS success is of outmost importance as IS together with its information content is the backbone of the smart manufacturing system.

To gain success of Industry 4.0 initiatives, it is important for the manufacturing industry to properly consider the different roles and perspectives in an organization. The industry must continuously focus on corporate, business and functional strategies as well as on operational experience. Transparency and openness must replace silo thinking. The common goal must be clear and stimulate work motivation throughout the entire organization. To fulfill its mission, the organization must accept that it is composed by individuals and not a homogeneous task force and adjust its operational activities thereafter.

3 METHODOLOGY

This chapter presents the methodology used for this thesis. It covers the research approach, the research design of each of the cases studies conducted and elaborates on data collection, reliability and validity.

3.1 Research approach

This thesis is influenced by the systematic approach for empirical research introduced by Flynn et al. (1990) which covers six activities in the approach:

1. Theoretical foundation
2. Research design selection
3. Data collection method selection
4. Implementation
5. Data analysis
6. Publication

The six activities have been used to design the studies presented in this thesis. The theoretical foundation has been used to formulate study questions and for data analysis purposes. The defined study questions have impacted the choice of research designs and data collection methods. The studies presented in this thesis are based on both inductive and deductive reasoning. In inductive reasoning the researcher explores the elements of a system and seeks to understand the implications of changes in elements and properties of such a system. In deductive reasoning the researcher in opposite to inductive reasoning, looks upon the behavior of system and tries to find the underlying causes of its performance. This means that inductive reasoning aims to build theory upon the observation (bottom up), whilst the deductive reasoning uses a theory as a starting point of an observation to verify a theory (top-down) (Dekkers, 2017).

3.2 Case studies

This thesis is based on five appended papers reflecting on three conducted multiple case studies answering three defined research questions. In a multiple case study, data is collected from more than one location focusing on similarities and dissimilarities (Flynn *et al.*, 1990). In a case study, the researcher investigates a phenomenon or case in its natural setting (Swanborn, 2010). In such a study, the number of variables of interest will be larger than the amount of data points (Yin, 2013). Even though case studies per definition exclude surveys and statistical methods, they are in this thesis used within the case studies as additional data sources (Swanborn, 2010) to strengthen the reasoning and understanding of the phenomenon studied. This research approach uses the result from the licentiate thesis (Johansson, 2016) as a starting point. In Figure 6 the relation between the case studies and research questions are illustrated. The case studies are conducted in chronological order as indicated in the figure.

In this thesis, qualitative and mixed methods have been used to collect data. In qualitative research methods the focus is on a group or individual and their meaning, perception and understanding of a problem or phenomenon. In mixed methods the researcher collects data both with qualitative and quantitative methods and combines the data together to strengthen the understanding of the research problem (Creswell, 2013; Morse, 2016). The intention of such an approach is that the combination of both qualitative and quantitative methods will provide more rigid understanding of the research problem together than either method would do alone (Creswell and Plano Clark, 2011).

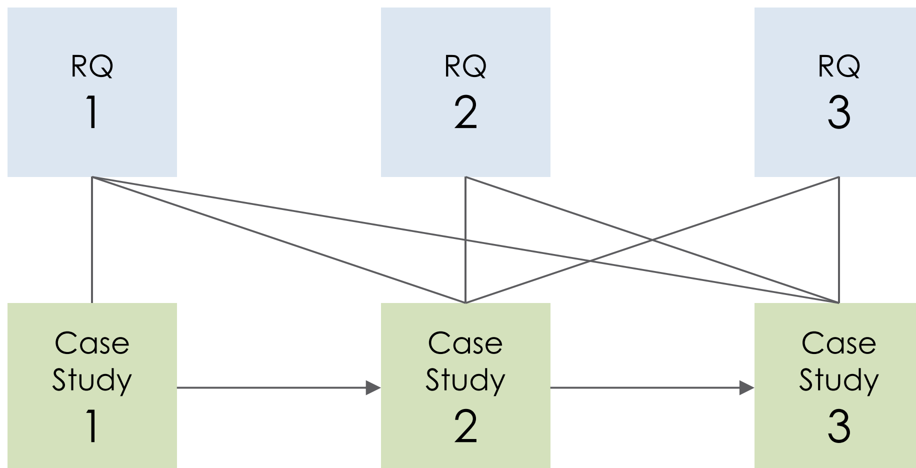

Figure 6: Relation between case studies and research questions

3.2.1 Case study 1

Case study 1 was carried out between the fall of 2016 and early spring of 2017. The study used the mixed method design combining both quantitative and qualitative data. The study has used an inductive approach as observations have led to the definition of the study and the theory construct, see Figure 7. An initial literature review was conducted to formulate the study questions. The study questions are based on findings presented in (Johansson, 2016). The case study investigated the usage of supplied assembly work instructions at 13 assembly and preassembly stations in 3 factories within a GPN. Furthermore, the information content of the assembly work instructions was rated on basis of importance on a Likert scale from 1 to 5 where 1 indicates that the information is not important for the operator to handle the assembly task, and 5 indicates that the information is very important for the operator to handle the assembly task. In total, 32 operators participated in the study together with 10 manufacturing engineers and production technicians. Importance was rated both by the operators and production technicians. At first, observations were made at all sample stations to understand the scope in each assembly station and to verify the interaction between operator and assembly work instructions. During the observations, the operators marked in their assembly work instructions which type of information content they use during an assembly task. They did also rate the importance of each type of information content from 1-5 as previously described. The gap between provided and actually used assembly information was calculated as well as the importance gap between the operators and production technicians and are presented in Table 3 in section 4.1. Secondly, semi-structured interviews were held with the manufacturing engineers to address the origin of the data and information in the assembly work instructions which improved the process mapping presented by Delin and Jansson (2015). Semi-structured interviews were also held with the production technicians to validate the statistical data. For the data analysis, a main literature review was conducted to interpret the collected data. The case study was conducted together with two master thesis students (Enofe, 2017; Schwarzkopf, 2017).

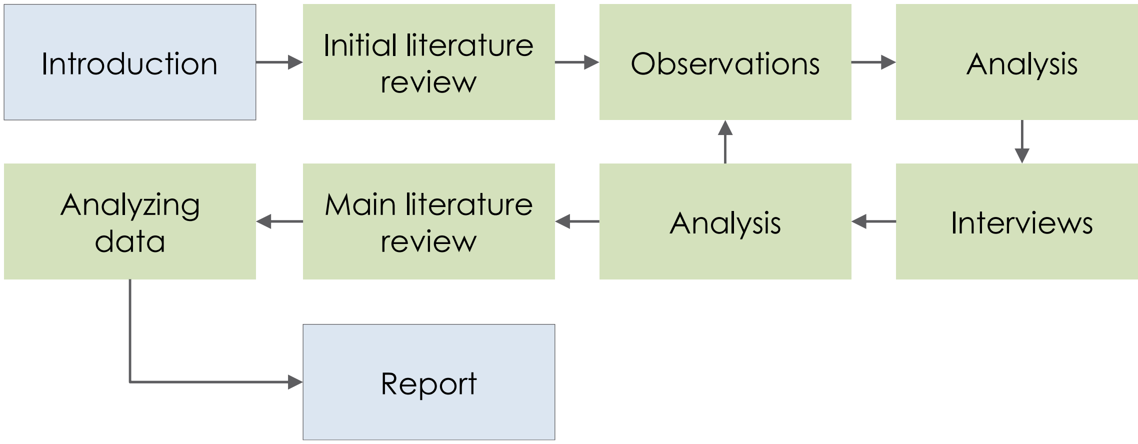

Figure 7: The research design of Case study 1

3.2.2 Case study 2

Case study 2 was carried out during the spring of 2017. The study used a qualitative method to collect data and an inductive approach as it sought to develop new theory. The study investigated current challenges in terms of working methods in the perspective of assembly information and focus areas for future AIS. The research design for this case study is illustrated in Figure 8. An initial literature review was made to establish the main study questions. The study investigated the same assembly and preassembly stations as addressed in Case study 1. Two sets of interview questions were composed (see APPENDIX A). In total, 25 operators were interviewed using a structured approach to answer the interview questions addressed. Additionally, structured interviews were also used during interviews with 7 additional engineering roles in the organization (e.g. manufacturing engineers, production leaders, production technicians and one IT function). The interviews were coded on keywords and the data from the operators were compared with the data from the engineers. A main literature review was conducted prior to the data analysis. The case study resulted in defined focus areas and problem areas which are described in section 4.2. The case study was conducted together with two master thesis students (Eriksson and Johansson, 2017).

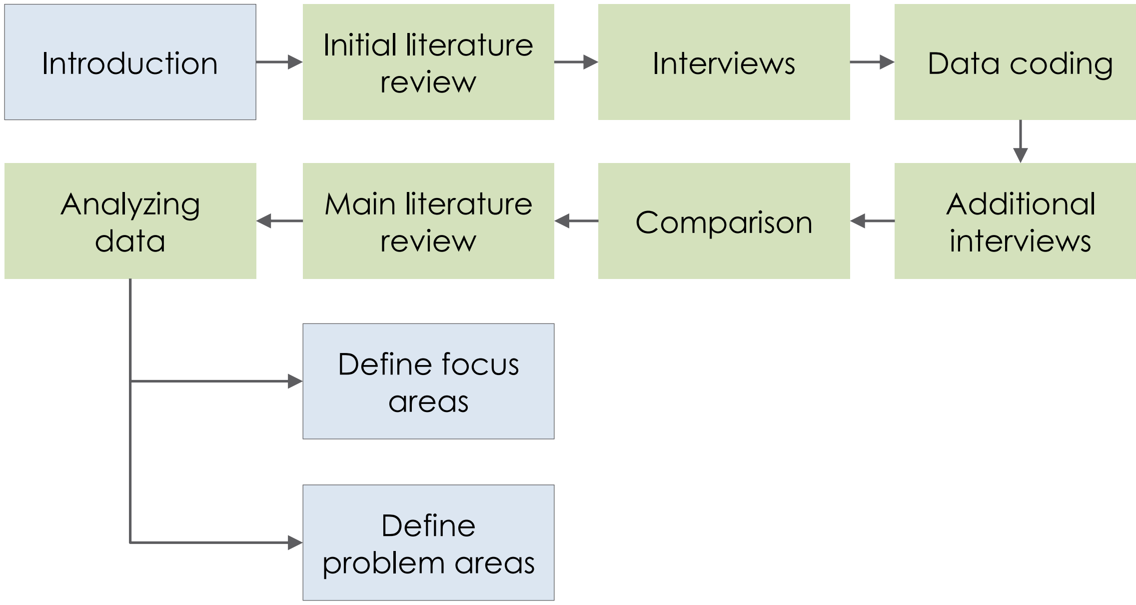

Figure 8: The research design of Case study 2

3.2.3 Case study 3

Case study 3 was conducted with the purpose to explore the research objective from a wider perspective seeking to generalize the research result. This study was performed with a deductive approach and qualitative method to collect data, see Figure 9. On the basis of the result described in the licentiate thesis (Johansson, 2016) and in Case study 1 and 2, a set of interview questions were composed, see APPENDIX B. To fit the scope of the research objective, a set of case companies were identified and contacted. In total, 15 manufacturing companies + 2 additional subsidiaries of the group company from Case study 1 and 2 participated in the study. The case companies were chosen based on three requirements: (1) they are categorized as large (European Union, 2003), (2) they conduct manual assembly tasks as a significant part of the manufacturing process, and (3) they have more than one manufacturing unit in their GPN. Structured interviews were held with plant managers, production managers, production technicians, manufacturing engineering managers and manufacturing engineers. The case companies represent both the automotive and non-automotive sector and comprise manual assembly in cycles from less than three minutes up to several days. In addition, interviews were also held with three industry experts with genuine knowledge about the industrial sector. The interviews were recorded and transcribed. The data coding is based on keywords connected to the research questions of this thesis. The data analysis was conducted after a major literature review.

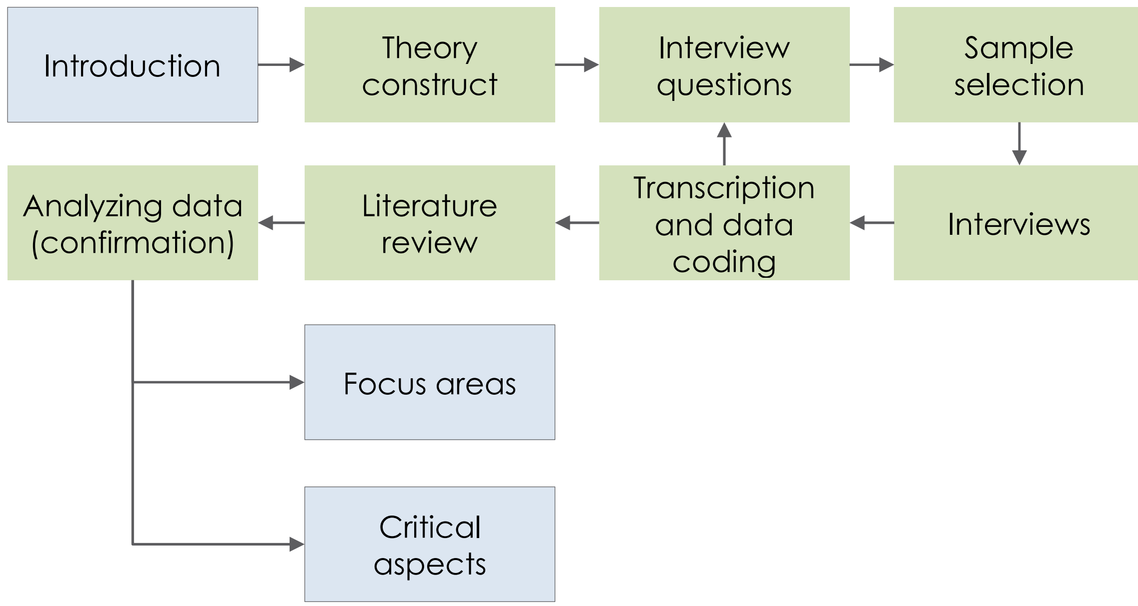

Figure 9: The research design of Case study 3

3.3 Data collection, reliability and validity

When performing qualitative research based on interviews, the researcher needs to account for the thorough preparations such as defining proper interview questions. The quality of an interview can be characterized by what is actually asked, what is not and the answer given as a response (Seton, 2006). During interviews, both structured and semi-structured interview approaches have been used. In case study 1, the semi-structured approach was used to keep the scope of the interview but to allow additional angles that sufficiently strengthen the reasoning and understanding of the study. Semi-structured interviews allow the researcher to gather additional and unexpected data during interviews that would improve the understanding of the research over following a strict interview scheme (Merriam, 2009; Hesse-Biber and Leavy, 2011; Galletta, 2013). To achieve high quality results from a semi-structured interview, the researcher needs to make thorough preparations, keep discipline and creativity during the interview session and reserve enough time for data analysis due to the broader perspective the interview structure takes than in fully structured interviews (Wengraf, 2001). To interpret the collected data from a qualitative study, data coding is conducted to categorize and to establish a framework and patterns of its ideas and meanings as part of the data analysis (Auerbach and Silverstein, 2003; Gibbs, 2008). A common approach to such data analysis is open coding. The researcher generates categories from the data to stimulate ideas. Open coding is followed by axial coding which focuses on connecting the different categories. Finally, through selective coding, a core category is defined which become the center of the developed concepts (Strauss and Corbin, 1998; Dey, 2013). The interviews in case study 1 and 2 have been conducted by two interviewers and have been recorded. One of the interviewers led the interviews whilst the second interviewer focused on taking notes during the sessions. Case study 3 was conducted by one interviewer who also took notes during the sessions. These interviews were also recorded. All data was coded according to open, axial and selective coding. Case study 1 followed a semi-structured approach, whilst case study 2 and 3 followed a structured interview approach to allow comparisons (Flynn *et al.*, 1990).

To make research results solid and of high quality, they have to be repeatable through generalizability, validity and reliability (Creswell and Plano Clark, 2011). Validity and reliability of a study is achieved by careful consideration of how data is collected, analyzed, interpreted and presented (Merriam and Tisdell, 2015). Validity of research as of quantitative matters is normally classified as internal or external. In internal validity, the researcher advocates that the result of a study is a cause from expected variable dependencies using empirical evidence and logics. For external validity, the researcher must advocate the generalizability of the research results (Newman and Benz, 1998; Taylor, 2013; Merriam and Tisdell, 2015). Triangulation is often used as a measurement to validate the result in a study (Mertens and Hesse-Biber, 2012). By using triangulation, a better understanding of a research problem or phenomenon can be gained using multiple approaches and methods (Burton and Obel, 2011; Bush, 2012). Validation through triangulation of the interview data from the case studies has been approached by interviewing different roles with different perspectives. For the observations, visits to several manufacturing units at different times have strengthened the validity of the data (Merriam and Tisdell, 2015).

Reliability is a measure of the repeatability of a study. On the contrary to quantitative research, qualitative research is mostly related to human behavior and cannot be seen as static. By using method triangulation (mixed method), reliability can be achieved to the extent of consistency and dependable data. In fact, a proper way to ensure reliability is to describe in detail how data was collected, how categories were defined and how decisions were made (Merriam and Tisdell, 2015). This is especially true for situations where the research design evolves during a study (Thyer, 2010).

4 RESULT

This chapter presents the result of the case studies covered by this thesis. The chapter introduces the appended papers and motivates their individual contributions to the research objective and defined research questions.

To address the three defined research questions, three case studies have been conducted. The result from the case studies have been reported in the five appended papers addressed in this thesis. In Table 2, the relation between appended papers, case studies and defined research questions are presented. Paper A is based on case study 1 and contributes to RQ1; Paper B is based on case study 2 and contributes to both RQ1 and RQ2; Paper C is based on case study 1, 2 and 3 and contributes to RQ1; Paper D is based on case study 2 and 3 and contributes to both RQ2 and RQ3; Paper E is based on case study 2 and 3 and contributes to RQ3.

RQ 1. What are the main challenges of handling assembly information for manual assembly tasks in global manufacturing companies?

RQ 2. What critical aspects exist when the manufacturing industry deploys new assembly information systems?

RQ 3. How can an ambition for enhanced future assembly information systems be validated?

Case study 1: Current challenges of handling data and information; usage and importance
Case study 2: Assessment based information needs within manual assembly processes
Case study 3: Interviews with external manufacturing companies to address RQ1, RQ2 and RQ3

Table 2: The link between appended papers, case studies and research questions

Appended papers	Case studies	Research questions
Paper A	Case study 1	RQ1
Paper B	Case study 2	RQ1 RQ2
Paper C	Case study 1 Case study 2 Case study 3	RQ1
Paper D	Case study 2 Case study 3	RQ2 RQ3
Paper E	Case study 2 Case study 3	RQ3

4.1 Paper A

Title: Data and Information Handling in Assembly Information Systems – A Current State Analysis

The aim of the paper was to identify common assembly information content and investigate how this information is handled from manufacturing engineering to shop floor operations. The paper comprises case study 1 as described in section 3.2.1 which was conducted in three different assembly plants. Plant A belongs to Organization A, whilst Plant B and Plant C belong to Organization B. In total, 13 assembly and pre-assembly stations were chosen as a sample based on common assembly tasks such as media routing, clamping, equipment-controlled assembly, hole pattern recognition, hidden assembly, bracket assembly and riveting. The sample selection was supported by global manufacturing process and technology specialists at the case company. The case study measured the usage rate of supplied assembly information as well as the importance of the same information. In total, 32 operators participated in the study and indicated what information they use in their assembly work instructions. They also rated the importance of the information in the assembly work instructions using a five-graded Likert scale. Responsible production technicians for the same sample stations rated the importance of the information in the assembly work instructions. In Table 3, the gap between available assembly information and actually used information is visualized. Information that is present in the assembly work instructions and used by all operators is indicated by a gap of 0, whilst a usage gap in levels of 50 % (0,50) or higher has been highlighted and indicates that 50 % of the operators do not use the supplied assembly information. Detected usage gaps indicate that the information supplied is not attended by the operators. Regarding the importance gap, any positive value has been highlighted as it indicates that the operators do find the information more important to the operator than the responsible technicians do. The reason for measuring the importance gap is to find a possible reason of why assembly work instructions are not attended despite the amount of assembly errors as reported in (Johansson, Mattsson, *et al.*, 2016). During the observations, operators' interactions with the assembly work instructions were minimal suggesting that the actual usage of assembly information could be even lower than measured. The study also investigated the origin of the information in the assembly work instructions. Organization A uses paper instructions while organization B has a solution for digitized assembly work instructions connected to a Manufacturing Execution System, MES.

Table 3: The usage and importance gap of information have been measured in case study 1

		Organization A		Organization B			
		Plant A		Plant B		Plant C	
Attribute	Information carrier	Usage gap	Importance gap	Usage gap	Importance gap	Usage gap	Importance gap
Product ID	Digital/Physical	0,08	-0,32	0,00	**3,80**	**0,67**	**1,13**
Procedure	Digital/Physical	0,24	-0,08	0,00	**1,40**	0,00	**0,73**
Part name	Digital/Physical	0,08	**3,36**	**0,50**	**0,33**	**1,00**	-2,20
Part number	Digital/Physical	0,12	-1,04	**0,50**	-0,47	0,33	-0,47
Quantity	Digital/Physical	0,20	**2,32**	0,00	-1,47	**0,67**	-3,07
Lamp	Pick-2-light	0,00	0,00	0,00	0,00	0,00	0,00
Part number	Pick-2-light	0,00	-4,00	0,25	0,00	0,00	**2,00**
Part name	Pick-2-light	0,00	**4,00**	0,25	0,00	**0,67**	-0,67
Quantity	Pick-2-light	0,00	0,00	0,00	-4,00	-	-
SOP	SOP	0,28	0,00	0,00	**2,00**	0,00	-1,67
Product type	Physical	**0,96**	-0,24	-	-	-	-
Sequence number	Physical	**1,00**	0,00	-	-	-	-
Serial number	Physical	**1,00**	0,00	-	-	-	-

Attribute	Information carrier	Organization A Plant A Usage gap	Organization A Plant A Importance gap	Organization B Plant B Usage gap	Organization B Plant B Importance gap	Organization B Plant C Usage gap	Organization B Plant C Importance gap
Assembly line	Physical	**1,00**	0,00	-	-	-	-
Instruction ID	Physical	**1,00**	0,00	-	-	-	-
Additional instructions	Physical	**0,60**	-0,80	-	-	-	-
Packaging	Physical	**1,00**	0,00	-	-	-	-
Use point	Physical	**1,00**	0,00	-	-	-	-
Cycle time	Physical	0,32	0,00	-	-	-	-

4.1.1 Contribution to research questions

The case study has shown that large amounts of the supplied assembly information are rarely used by the operators for several reasons. The most common reflection made by the operators is that the assembly work instructions contain too much information which makes it difficult to identify relevant information in time. This shows that the structure and content of assembly work instructions are not optimized for the actual end user. The discovered importance gaps show that there are disparities in the provided assembly information. The importance gap shows that operators and engineers have different perspectives on which information is important in which situation. The intention of the importance measure is not to define which information attributes that are seen as the most important ones, but to show that operators have different needs for assembly information for various reasons. As organization A and B use different information carriers they also have different processes (Johansson, Delin, *et al.*, 2016) and IS where the assembly information is used to compose the assembly work instruction. The divergent result from case study 1 contributes to RQ1 with current issues related to both processes and IS. Paper A combined with Johansson, Delin, et al. (2016) provides a current state analysis of developing assembly work instructions and the usage of such instructions in manual assembly. The paper shows that there is no common strategy in the case company for handling information in their AIS which could potentially harm the service quality towards the operators.

4.2 Paper B

Title: Assessment based information needs in manual assembly

The aim of this paper was to assess the information needs in production using a bottom-up approach. The paper is a result of case study 2 as described in section 3.2.2 in which 25 operators and 7 production technicians, production leaders and manufacturing engineers have been interviewed. The case study was conducted at the same assembly plants and sample stations as addressed in Paper A. On the basis of the result reported in the licentiate thesis (Johansson, 2016) and Paper A, a set of interview questions were defined, see Appendix A. On the basis of the interviews, four problem areas and three focus areas were identified as illustrated in Figure 10.

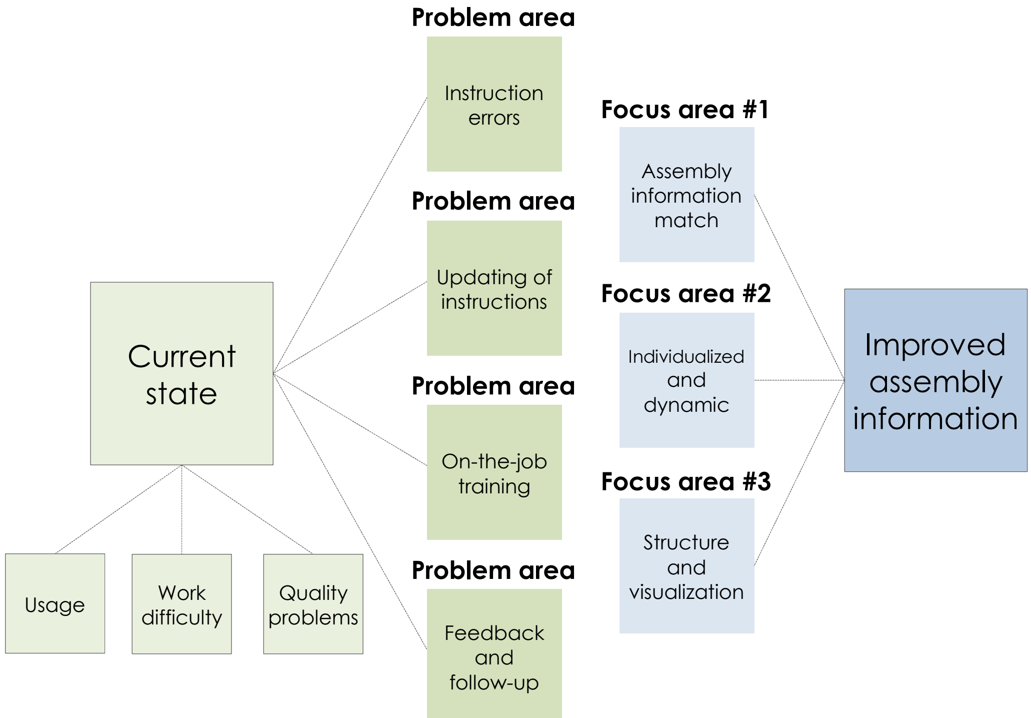

Figure 10: Four problem areas and three focus areas have been identified in case study 2

The first problem area defined relates to instruction errors. 44 % of the operators stated that assembly work instructions contain misleading or incorrect information. Despite the effort of improving instruction and information quality, only 56 % of the operators stated that they mostly trust the assembly work instructions.

When assembly work instructions are updated, it takes three weeks until the operator has the updated assembly work instruction in the hand. This lead time is a consequence of that instructions are linked to the material ordering system which means that assembly work instruction content is frozen at the same time as the production sequence. This means that even if errors in assembly work instructions have been updated there are still risks that similar errors will occur during this freeze phase. To minimize the risk of new assembly errors, the production technician generates temporary instructions, which gives double work for the technician.

On-the-job training was defined as the third problem area as the interviews suggest that there is no common strategy for operator training in place in any of the three assembly plants. All training takes place at the assembly work station and is conducted (mostly) by experienced operators. Most of the operators find this situation unsatisfactory. In total, 48 % of the operators claimed variety in how training is conducted. Due to the variety in the training process, the operator obtains different types of knowledge. 56 % of the operators reported that they lack general knowledge of the assembly tasks they conduct.

The fourth problem area addresses issues with feedback and follow-up of assembly errors etc. Operators report that little useful feedback is provided. At Plant B 58 % of the operators stated that feedback is sporadic or not provided.

The first focus area is addressed as assembly information match. The main questions during the interviews have focused on identifying the operators' assembly information needs. As the production setup differs among the different assembly plants (different cycle times), the information needs vary. Much of the information currently available relates to basic information such as bill-of-material. Real time-based information, sequenced, where to assemble, how to assemble, common issues, general product and process knowledge, and mobile information are different examples of requested information. The main information request focused on providing the right amount of information when it is needed. Operators also requested more images in the assembly work instructions and feedback functionality in the AIS.

The second focus area considers individualized and dynamic assembly information. As the operators have different experiences information needs to be scalable to fit the individual needs of the operators. The satisfaction level of the assembly information is in general low. Several operators suggested that the operator should be able to choose the amount of information to be visualized, whilst other operators suggested that only information that departs from the standard should be shown. To only present non-standardized task information will require proper operator training.

The third focus area considers structure and visualization of assembly information. In plant A, most operators were not satisfied with structure, logic and visualization of assembly work instructions. The instructions contain amounts of information that are too large and are of little use to the operators which makes it time consuming to find the relevant information. In plant B and C, the operators are in general satisfied with the amount of information and its structure. However, the instructions in plant B and C are also difficult for newly trained and novice operators to interpret.

4.2.1 Contribution to research questions

The case study presented in this paper introduces four problem areas which further contribute to RQ1. The interviews with the operators at three assembly plants have provided future requests on future AIS. The three focus areas previously described contribute to RQ2 by providing directions on how assembly information should be controlled, formulated, structured, and visualized.

4.3 Paper C

Title: Challenges of Handling Assembly Information in Global Manufacturing Companies

The aim of the paper was to broaden the perspective of challenges of handling assembly information in global manufacturing companies. The paper covers the results from the licentiate thesis (Johansson, 2016) and case study 1, 2 and 3 presented in this doctoral thesis. The third case study (see section 3.2.3) sought to generalize the research result by expanding the perspective to other manufacturing companies as well. The result presented in the paper is based on surveys with 93 respondents and 88 structured and semi-structured interviews conducted since 2014. The participants represent operators, production technicians, production leaders, production managers, plant managers, manufacturing engineers, manufacturing engineering managers and industry experts. The paper builds upon the conclusions from Paper A and B and six focus areas have been defined which cover the different challenges the manufacturing industry currently is facing. The six focus areas, as illustrated in Figure 11, incorporate previous problem areas and focus areas as described in Paper B. The focus areas consist of IT challenges, process challenges, assembly process disturbances, information availability, technology & process control, and assembly work instructions. This new setup of focus areas provides a more comprehensive view of the current challenges in the manufacturing industry of handling assembly information.

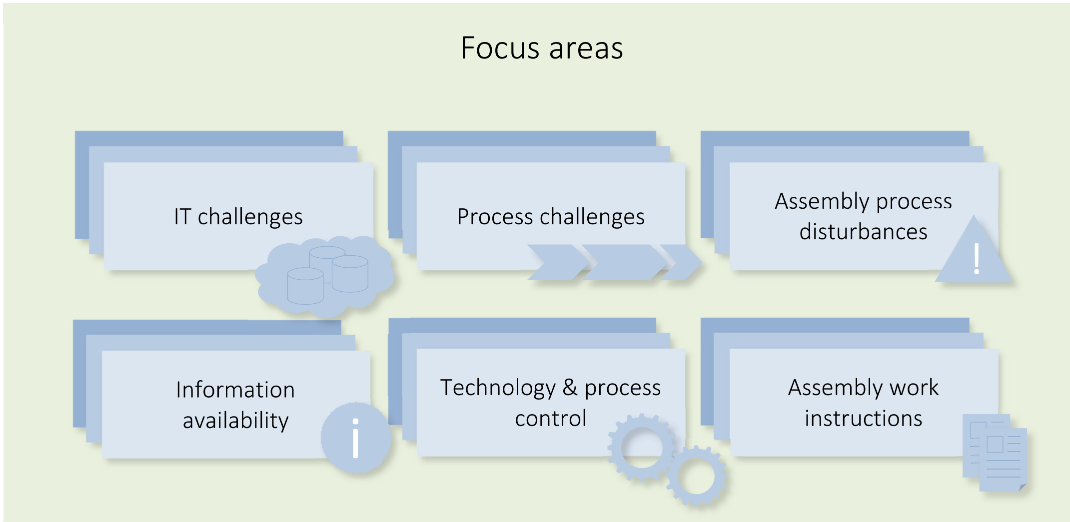

Figure 11: Based on case study 1, 2 and 3, six focus areas have been defined

IT challenges

Based on case study 1, 2 and 3 it has been shown that it is common for manufacturing companies that are global and consist of several manufacturing units to have several IS within their manufacturing systems. Some of the interviewed companies have centralized IT strategies whilst others have decentralized strategies which basically means a redundant setup within the company. A consequence from a decentralized IT strategy is that the companies have difficulties in sharing information within the company and between different organizational functions. Many of the interviewed companies have IS that are inflexible and dated. In one of the companies, an IS could not handle numbers above a certain value due to poorly defined system requirements in the past. Many of the companies (52 %) stated that assembly information is stored in more than one system. A majority also argued that there is lack of IT support within their manufacturing organizations. Most efforts are put on non-manufacturing IS.

Process challenges

Most companies argue that they have standardized processes for developing assembly work instructions. As much of the work is manually conducted, the result is dependent on the individual manufacturing engineer or production technician. It is also stated that it is too time consuming to develop high quality assembly work instructions. As the companies interviewed are handling high levels of product variety, the operators need proper training to make proper decisions during the assembly work. However, most training activities are carried out by fellow operators with more experience directly at the assembly work stations. The training outcome is varied as the experiences of the trainers are differing.

Assembly process disruptions

Interviewed manufacturing companies with lower product variety and short assembly cycles reported little disruptions due to assembly errors. For the manufacturing companies with higher product variety and long assembly cycles it is more common with assembly errors. One of the reasons is that operators neglect assembly work instructions and make wrong decisions such as choosing the wrong components, or they miss assembly steps. In some cases, it was reported that the reason why operators neglect the instructions is that they lack customer order specific information, the instructions are unstructured or contain too much information and there is not enough time to read through them. One of the industry experts argued that it is common that assembly work instructions do not actively stimulate the information seeking process of the operator or that information is just not easily accessible at the assembly work station.

Information availability

As previously mentioned, it is common that assembly information is stored in several IS. Much of the information is made available to the operator but it takes an extra effort to access the information in different IS or different physical spaces on the shop floor. Much of the information is analog and not traceable. Observations during case study 1 revealed aged assembly information on the shop floor. It has been verified by one of the industry experts that it is common to find old and uncontrolled information on the shop floor. As the available information does not necessarily fit the operator's need for information, much of the assembly information remains unused. It is costly for the manufacturing company to develop assembly work instructions which are not often used.

Technology & process control

In most of the studied manufacturing companies it is not common to find process control on the shop floor. Only few of the interviewed companies stated that they have invested in process control to monitor and steer the manufacturing process. In those cases, the system hinders unfinished products to leave the assembly work station. In a few of the companies the digital assembly work instructions are controlled by an IT system. In only a few cases examples of electric nut runners or presses were mentioned, in all other cases analog tools are the standard. Some of the industry experts argued that in general, the automotive industry lies ahead of the rest of the manufacturing industry in terms of technology on the shop floor.

Assembly work instructions

Assembly work instructions differ among the case studies. In case study 1 and 2, both paper-based instructions and digital instructions were found. Instructions contained, in some cases, too much information and in some cases too little information. In case study 3, most assembly work instructions were paper based. In most of the cases where the information is digital, the assembly work instructions consisted of digital documents. In case study 3 it was reported that assembly work instructions were not always customer order specific. Instead, the operators are provided with product specifications without instructions. From Paper A it was learned that there is a bias concerning importance of the content of the assembly work instructions. As most of the supplied assembly work instructions are physical or digitally fixed, the varying operator experience and skills cannot be properly managed.

4.3.1 Contribution to research questions

Paper C summaries the challenges of handling assembly information in global manufacturing and contributes to RQ1 by presenting six different focus areas where challenges have been identified in the manufacturing industry. A current state analysis may support the manufacturing industry to make proper prioritizations in both continuous improvement programs and in future investments. The intention is to highlight challenges that make it difficult or even impossible to implement new technology, methods and tools without increasing the amount of manual work in current processes. The paper shows that the manufacturing industry could be in better shape as much of the challenges are caused by lack of holistic perspectives.

4.4 Paper D

Title: Critical Aspects of Assembly Information in the Deployment of Future Assembly Information Systems

The aim of paper D was to further develop the six predefined focus areas, by identifying critical aspects for each of the focus areas. These critical aspects are considered important to emphasize when deploying new AIS. The paper is based on the same data as in Paper C. The critical aspects for each of the focus areas are shown in Table 4. The critical aspects are suggested to positively contribute to the manufacturing industry's transformation effort to be digitalized and to realize Industry 4.0.

Table 4: Critical aspects have been derived within each focus area

IT challenges	Process challenges	Assembly process disruptions
• Standardization • Accessibility • Functionality • Competence	• Task standardization • Task automation • Competence	• Standardized assembly tasks • Standardized assembly work instructions • Feedback • Operator training
Information availability	**Technology & process control**	**Assembly work instructions**
• Availability • Accessibility • Information sharing • Information quality	• Scalability • Connectivity • Information control • System automation	• Purposeful assembly work instructions • Immersive technologies • Accessibility

IT challenges

For IT challenges, four critical aspects have been identified; Standardization, Accessibility; Functionality; and Competence. To adhere to the concept of Industry 4.0, standardized infrastructures and processes are necessary. Standardization makes it easier to share functionalities, information and services across the GPN of the company. Standardization is a first step to establish seamless information flows between different organizational units both inside and outside the company walls. As one of the current challenges is the amount of IS within a company, accessibility is a critical aspect. Companies must assure to keep the amount of IS to a minimum and decrease the complexity to access information in the IS. Today it takes a long time for the stake holders to find the information and get access to it. Many companies argue that they lack IT resources within operations. The companies should focus on functionality. As they lack resources, they miss opportunities of new functionalities in both engineering and manufacturing processes. Without new functionalities, smart manufacturing will be difficult to achieve. The fourth critical aspect for IT challenges is competence. The IT competence in manufacturing companies is too low. To realize Industry 4.0, the companies must address new roles and new competences in the entire companies.

Process challenges

For process challenges, three critical aspects have been identified; Task standardization; Task automation; and Competence. As large parts of the manufacturing industry manufacture products of high customization level, it is vital that the companies are focusing on the correct tasks. Task standardization enables best practice to be spread across the GPN and improves decision making. Non-standardized tasks are a source of inconsistent outcomes (McIntyre, 2009). As most companies argue that it is too time consuming to develop high quality assembly work instructions, task automation should be considered in future AIS. This would allow fast and accurate decision making based on data. It would also reduce the amount of manual work such as moving data from one system to another which is unfortunately common in the manufacturing industry. Manufacturing companies lack competence within the cognition field, both for operators and engineers. As Industry 4.0, offers new opportunities with smart and connected manufacturing, it will require new competence to enable the best solutions for human cognition.

Assembly process disruptions

Assembly process disruptions consist of four identified critical aspects; Standardized assembly tasks; Standardized assembly work instructions; Feedback; and Operator training. With high levels of product variety and little process control in assembly, assembly tasks become less standardized. A modular approach in terms of standardization would limit the impact of assembly disruptions. Manufacturing industry should focus on implementing standardized assembly tasks. Much of the supplied assembly work instructions are dependent on the individual production technician or manufacturing engineer. To reduce variance in content and quality, the manufacturing industry should focus on establishing standardized assembly work instructions and processes for developing them in a standardized manner. With modern IS, real time communication is possible. The manufacturing industry should focus on implementing proper feedback process to take preventative actions and to make problem solving more efficient. To take advantage of new technologies and functionalities in future AIS, the manufacturing industry needs to focus on establishing standardized training processes for operators. Immersive technologies are offering training before the operators are actually entering the real assembly work stations.

Information availability

For information availability, four critical aspects have been identified; Availability; Accessibility; Information sharing; and Information quality. Manufacturing companies should focus on information availability. There is currently a mismatch in what information that is made available to operators in manual assembly. Making the correct information available is a key to enable task automation for decision making. Manufacturing companies must also focus on information accessibility. They must assure easy access to information as high lead times hinder proper use of requested information. To avoid redundant work and to share best practices, the manufacturing industry needs to focus on information sharing. Information sharing is a fundamental feature of smart manufacturing systems in the future. Too much information has been identified as being of poor quality. The manufacturing industry must focus on information quality when more of the business processes become integrated.

Technology & process control

For technology and process control, four critical aspects have been identified; Scalability; Connectivity; Information control; and System automation. As flexibility and scalability of a manufacturing system is important for the ability of the manufacturing company to comply with market demands, future AIS must allow scalability on a system level to fit local requirements. Present IS are inflexible and difficult to adjust to fit local prerequisites. Manufacturing companies must prioritize connectivity on the shop floor as part of smart manufacturing. Connected tools will support the operator at the assembly work station and require certain amounts of information from the AIS. Manufacturing companies must focus on information control. As much assembly information is uncontrolled it becomes difficult to assure that valid information is available. An improvement of information control will boost transparency in the manufacturing process. System automation should also be considered when designing new AIS. As more information becomes available and accessible, there is potential for real time quality assurance through smart algorithms and sensor systems during the assembly task.

Assembly work instructions

For assembly work instructions, three critical aspects have been identified; Purposeful assembly work instructions; Immersive technologies; and Accessibility. As many interviews address, the information content in assembly work instructions is varying. The manufacturing industry must focus on providing purposeful assembly work instructions. When designing new AIS, it must enable assembly work instructions that are, activity focused, operator focused, customer focused, work station focused, and plant focused. Immersive technologies should be considered in terms of assembly information. Future AIS must be more flexible allowing new types of information usage. With immersive technologies, operators can be supported in an augmented fashion which changes the overall assembly experience. The manufacturing industry should also focus on information access when deploying new AIS making the information exchange between system and intended end-user (e.g. operator) effective and efficient.

4.4.1 Contribution to research questions

Paper D builds on the contribution from Paper C by addressing 22 critical aspects for six focus areas for future AIS as a contribution to RQ2. The critical aspects will support the manufacturing industry in prioritizing activities necessary for the digital transformation. The paper provides a broad perspective on the manufacturing industry by looking into discrete manufacturing within different industry sectors. It also contributes to RQ3 by using the critical aspects as design requirements for an industrial demonstrator to show how an AIS may function in the future from an assembly work station perspective.

4.5 Paper E

Title: Enhancing Future Assembly Information Systems – Putting Theory into Practice

The aim of Paper E was to use the critical aspects from Paper D to define design requirements for an industrial demonstrator to test an ambition for enhanced AIS. The purpose of the industrial demonstrator is to show how an assembly work station could be designed and function in the future if the AIS is altered. Much of the technologies emphasized are well known, but for several reasons, little of the technologies have been successfully deployed in the manufacturing industry. The demonstrator is based on the industrial application scenario within the learning factory concept as it uses a real manufacturing environment and authentic products (Abele *et al.*, 2015). The functionalities (design requirements) of the demonstrator are listed in Table 5. The functionalities are in line with the first two stages of the Industry 4.0 Maturity Index as they emphasize computerization and connectivity.

Table 5: The design requirements are based on Paper C and Paper D

Functionalities (requirements)	I 4.0 Maturity Index	References
Digital assembly work instructions	Stage 1	(Fässberg, Fasth and Stahre, 2012; Hold and Sihn, 2016; Syberfeldt, Danielsson, *et al.*, 2016; Brolin, Thorvald and Case, 2017; Schuh, Franzkoch, *et al.*, 2017)
Dynamic assembly work instructions	Stage 2	(Syberfeldt, Danielsson, *et al.*, 2016; Johansson *et al.*, 2018)
Product variant driven assembly work instructions	Stage 1	(Claeys *et al.*, 2016; Johansson *et al.*, 2018)
Responsive assembly information layout	Stage 1	(Baturay and Birtane, 2013)
Mobile assembly information	Stage 1	(Thorvald *et al.*, 2010; Mattsson, Fast-Berglund and Li, 2016)
Experience based assembly information	Stage 2	(Mattsson, Fast-Berglund and Li, 2016; Johansson *et al.*, 2018)
Operator optional settings as text size, language and layout	Stage 1	(Mattsson, Fast-Berglund and Li, 2016; Johansson *et al.*, 2018)
Real time reporting on assembly disruptions	Stage 2	(Johansson *et al.*, 2018)
Traced reading receipts on change notices, warnings and other messages during an assembly cycle	Stage 2	-
Connected tools through easy set up (plug & produce)	Stage 2	(Arai *et al.*, 2000; Schuh, Anderl, *et al.*, 2017)

The demonstrator is based on four authentic assembly work stations where a crossbeam member is assembled. The demonstrator consists of a product fixture, material racks, touchscreen monitor, electric nut runner, PLC controlled nut runner and a barcode scanner. The assembly work instructions are digital and dynamically controlled. The assembly information is experience based and presented through a web browser enabling a responsive layout which fits the information to the size of the screen. The assembly work instructions are also accessible in any mobile device with a reasonable screen size (e.g. smartphones and tablets).

Demonstrator use cases

To overcome challenges of experimental tests with limited complexity and product variety (Li *et al.*, 2016; Lušić *et al.*, 2016), two use cases have been defined. Use case 1 consists of one crossbeam member for a 6x4 truck (configuration with three axles) and use case 2 consists of two crossbeam members for a 10x4 truck (configuration with five axles). These kinds of crossbeam members are positioned in-between the frame rails that constitute the base module of the truck and are placed above the rear axle installation, see Figure 12. Each of the product variants will be manually assembled in a 4-assembly work station setting.

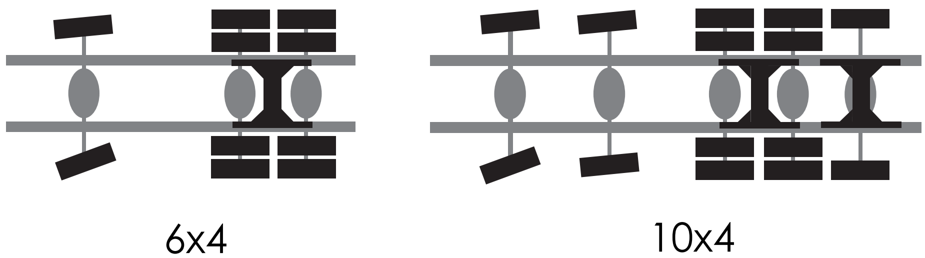

Figure 12: Use case 1 consists of a 6x4 truck and use case 2 of a 10x4 truck

Demonstrator user tests

The demonstrator is designed to be tested by real operators in an authentic manufacturing environment. The sample of operators will consist of novice, inexperienced and experienced operators. The assembly information will be shifted during the tests from current assembly work instructions on paper to the experienced based assembly work instructions. The main hypothesis for the tests is that the enhanced assembly information and the human-machine interface (HMI) will improve user satisfaction, increase usage of provided assembly work instructions and production quality, accordingly to the IS Success Model (Delone and McLean, 2003). The tests will be used to validate if the implemented functionalities, which address parts of the identified critical aspects for future AIS, will reject the null hypothesis (no relation) and accept the main hypothesis.

4.5.1 Contribution to research questions

Paper E builds on the result from Paper A to Paper C and contributes to RQ3 by proposing an industrial application scenario for validating an ambition for future AIS. The suggested operator tests will allow systematic evaluation of hypothesized relationships. The proposed validation case may also contribute to the exploration of determinants for IS success as suggested by Petter et al. (2013).

5 DISCUSSION

This chapter discusses the result in chapter 4 and presents the answers to the research questions as defined in chapter 1. It discusses the academic contribution, the industrial implications and the quality and limitations of the studies conducted.

"There are many ways of going forward, but only one way of standing still."

– Franklin D. Roosevelt

The manufacturing industry is struck by the digitalization wave. The benefits of introducing digital technologies in the manufacturing systems have become more evident as technology becomes mature and more accessible to reasonable costs. However, large parts of the manufacturing industry are still heavy on traditional methods in operations. In many cases, assembly work instructions are still paper based. As an example, at one of the plants in case study 1 and 2, the amount of paper has been reduced by 19 kg per operator and year in one of the preassembly sub flows just by removing unattended and unnecessary information from the assembly work instructions. If the assembly work instructions would be fully digitized, the reduction of paper used would be an additional 133 kg per operator and year. But the transformation of the manufacturing industry to enable smart manufacturing is more than just digitizing documents and connecting equipment to network switches. The transformation will require organizational changes, new IS, new processes and new competence in the manufacturing industry. Despite the transformation ambition, there are still challenges in how this transformation should be conducted and what the scope of the transformation is. This chapter aims to answer the three defined research questions introduced in chapter 1.

5.1 RQ1: What are the main challenges of handling assembly information for manual assembly tasks in global manufacturing companies?

This thesis has sought to bridge the gap between current assembly information handling in the manufacturing industry and the targeted state of smart manufacturing systems. In appended paper A, B and C, shortcomings and challenges of properly handled assembly information have been reported. On the basis of the three case studies conducted, the result has been formalized as six focus areas as addressed below:

- IT challenges
- Process challenges
- Assembly process disruptions
- Information availability
- Technology & process control
- Assembly work instructions

Many of the investigated manufacturing companies in the cases studies have insufficient IS. Implemented IS are rigid and inflexible to changing requirements from the manufacturing organization. Many of the large and global companies have grown based on acquisitions and mergers. This growth results in an increasing amount of IS which have not been properly integrated with each other. IS integration is difficult and often results in coexistence of IS with similar capabilities (Johnston and Yetton, 1996; Sudarsanam, 2003; Wijnhoven *et al.*, 2006).

As the product variety increases, the ability to handle the subsequent complexity must increase. Many of the interviewees from case study 3 stated that they spend too much time on creating high quality assembly work instructions. Much manual work is invested on the engineering side. Each manual step makes the result dependent on the individual engineer or production technician resulting in varying instruction quality. The instruction quality should be emphasized as addressed by Haug (2015) who proposed 15 quality dimensions of instructions. This goes also hand in hand with the neglecting of assembly work instructions as addressed in Paper A. As the assembly work instructions contain unrequested and unneeded information it becomes difficult for the operator to distinguish the relevant information from the peripheral information under time pressure (Brolin, Thorvald and Case, 2017). This situation has been reflected upon by Case et al. (2008) who argue that there are four states of information need versus demand; there is a need but no demand; there is a need and a demand; there is a demand but no need; and there is no demand and no need. These situations will directly affect the usage and user satisfaction according to the IS success model (Delone and McLean, 2003).

The manufacturing industry manufactures innovative and highly technical products. Despite the high technology value in produced goods, the technology level in the manual assembly process is rather low among the investigated manufacturing companies. Few of the investigated manufacturing companies control the information flow on the shop floor. This means that assembly work instructions are analogically distributed and handled. During observations old information was discovered. Most tools used in manual assembly are still analog making it impossible to track tool performance and real torque values. The manufacturing industry misses opportunities which contribute to the overall competitive advantage by neglecting technical solutions in manual processes.

5.2 RQ2: What critical aspects exist when the manufacturing industry deploys new assembly information systems?

Current challenges of handling assembly information as addressed in RQ1 can be seen as a critical point for the manufacturing industry. Without proper actions, there are great risks that the development of the manufacturing industry will stand still, and the competitive advantage will be lost over time. In paper D, 22 critical aspects have been defined and addressed within the 6 formulated focus areas presented in paper C. These critical aspects should be seen as initiative proposals for the manufacturing industry.

IT challenges

As Industry 4.0 seems promising for the future development of the manufacturing industry, it also puts requirements on the IT development in the industry. The manufacturing companies must focus on standardization (Salkin *et al.*, 2018) and stepwise integration of IS as addressed by Johnston et al. (1996) and Wijnhoven et al. (2006). Without proper interfaces between different IS, there will be lack of sufficient information sharing and usage which hinders data driven decision making as addressed by

Schuh et al. (2017). Full integration of IS in the manufacturing company will also allow easier access to information for all stakeholders. But the manufacturing industry must prepare for competence extension. Industry 4.0 means need for new roles within the manufacturing organization of the company (Benešová and Tupa, 2017; Pinzone *et al.*, 2017; Waschull, Bokhorst and Wortmann, 2017).

Process challenges

As the concept of Industry 4.0 is based on standardization of communication and transfer of information across the supply chain (Hankel, 2015; Lu, Morris and Frechette, 2016), the manufacturing industry will also be required to conduct certain standardization tasks. Task standardization is commonly known to allow consistent quality from a process (Liker and Meier, 2006; McIntyre, 2009). Without proper process standardization, it will be troublesome to assure sufficient information quality in the company IS. Additionally, from case study 3 it has been reported that it takes too much time to develop high quality assembly work instructions. As the intention of Industry 4.0 is to allow data based decision making (Schuh, Anderl, *et al.*, 2017), the manufacturing industry must change their processes to enable task automation to a higher degree, which can be realized through task standardization, to concentrate the engineering efforts on infrequent cases. To improve user satisfaction and instruction utilization, the competence within manufacturing engineering need to include cognition theory, technical writing and information design as proposed by Ganier (2004).

Assembly process disruptions

Assembly process disruptions will remain as a prioritization in future manufacturing organization. As product variety continuous to increase (Um *et al.*, 2017; Wan and Sanders, 2017), manufacturing companies need sufficient support processes to prevent disruptions and to efficiently limit the impact of an occurred disruption. Both standardization of assembly tasks and assembly work instructions should be considered as they lay the foundation of well-functioning training process of operators. The utilization of operators actually following standardized assembly tasks would be improved by enhanced AIS. Manufacturing companies must also prioritize proper feedback to operators on performance which requires that assembly deviations need to be reported directly when detected.

Information availability

In terms of information availability, there is no question regarding the importance of information availability in the manufacturing industry. According to Cantor et al. (2009), individuals tend to have different perceptions on information availability depending on the actual amount of information made available to them. This finding suggests that proper rules need to be applied to control information availability in future AIS. This is supported by Marusich et al. (2016) who found that an increasing amount of task-relevant information did not improve human decision making. When the amount of information is increasing it is necessary with autonomous or semiautonomous IS to support engineers' and operators' decision making. Even if information is made available, it has been found through case study 3 that it can be time-consuming to get access to the relevant information both from operators and engineers. Accessibility is in literature addressed as one of the quality dimensions of information quality (Kehoe, Little and Lyons, 1992; Wang and Strong, 1996). In an information dependent future, it is important to endorse easy information access in new AIS. Additionally, for information dependency, it is important that the manufacturing industry make information quality a prioritization to gain from the digitalization ambition (Hedman and Almström, 2017). This has also been addressed in the IS success model (Delone and McLean, 2003) and by Gorla et al. (2010).

Technology & process control

From case study 3, it was found that the technology level in the manual assembly intense manufacturing industry is rather low. Pneumatic tools are more common than electric tools which are more costly and enable assembly assurance control during the assembly task. Even though there are manufacturing companies with process control, analog assembly systems are more common. The manufacturing industry should emphasize scalability in both manufacturing systems and in AIS. New AIS will be more flexible in their structures and have the ability to expand the functionalities over time. As Industry 4.0 is in focus, resources such as the equipment, operator, product and support systems at the assembly work station, should be connected to allow real-time information exchange with other IS such as ERP systems (Schuh, Anderl, *et al.*, 2017). In such a way it is possible to realize self-optimization through the vertical integration as addressed by Gilchrist (2016) and Salkin et al. (2018). Today, much assembly information is analogically spread across the shop floors of the manufacturing industry. With future AIS it is possible to control the information flow, both to other IS and stakeholders such as operators and engineers. This will also contribute to improved service quality according to the IS success model (Delone and McLean, 2003). With improved technology and process control within manufacturing systems it is also possible to introduce IS automation through smart algorithms and sensor systems which interchange information with other information repositories in the cloud (Schuh, Anderl, *et al.*, 2017).

Assembly work instructions

Applying the IS success model (Delone and McLean, 2003) on a manual assembly system, the operator is seen as the user. By improving IS quality, information quality and service quality the usage and user satisfaction can be increased which gives positive effects on production performance. Operators need sufficient support systems and tools to make decisions during the assembly task, particularly in complex assembly situations. Case study 1, 2 and 3 have shown that the quality of assembly work instructions differs in the manufacturing industry. In some parts of the industry, instructions are more general, whilst in other parts of the industry the instructions are customer order specific. Petter at al. (2013) have proposed a set of independent variables that affect IS success. The assembly work instruction plays one of the main parts of such success. It is important that future AIS enables the stakeholders in the manufacturing system, such as the operators, to get purposeful assembly information. Flexibility needs to be emphasized to assure that the AIS can be changed over time as needed due to instruction quality (Haug, 2015), intuition support (Mattsson, Fast-Berglund and Li, 2016) or other changes that affects the design and functionality of the AIS.

When deploying new IS, the manufacturing industry should consider flexibility in terms of future use of information content and information carriers. Many immersive technologies change the method of how assembly information can be communicated to the operator. Syberfeldt et al. (2016; 2016) show the ability to present information through augmented reality based on the experience level of the operator. In another study, mobile information has successfully been tested to boost the information use as the information becomes more accessible (Thorvald *et al.*, 2010). But assembly information can also be used prior to real assembly. Information can also be used for computer-based training which outperforms traditional operator training (Malmsköld, Örtengren and Svensson, 2012, 2015).

5.3 RQ3: How can an ambition for enhanced future assembly information systems be validated?

In paper E, an industrial demonstrator was introduced where several of the critical aspects defined in paper D are emphasized. The paper proposes use cases and user tests as methods to validate some design principles for future AIS. User tests will be conducted with novice operators, non-experienced operators and experienced operators. Two product configurations will be assembled during the tests. Furthermore, the information content will be shifted during the tests, adjusting the amount of details in the information such as step-by-step instructions and supportive images. Through user tests, determinants for IS success will be tested through both quantitative measures (Likert scales) and qualitative measures (semi-structured interviews). The introduced product variance and complexity in the assembly tasks will provide better quality of the tests as suggested in previous research (Li *et al.*, 2016; Lušić *et al.*, 2016). The industry 4.0 maturity index (Schuh, Anderl, *et al.*, 2017), determinants for IS success (Petter, DeLone and McLean, 2013) and instruction quality dimension (Haug, 2015) will serve as the basis of the measures and will be used during the analysis of the result of the user tests. The actual assembly time and the amount of potential assembly errors will be measured during the tests.

5.4 Quality and limitations

This thesis is based on both quantitative and qualitative data. Case study 1 and 2 were conducted within the GPN of one case company. Case study 3 expanded on the result from case study 1 and 2 and has been focused on other case companies that have not been previously studied. This third case study has allowed a broader perspective on manual assembly intense manufacturing companies. Case study 1 and 2 focused on the plants within the GPN with highest product variety to assure that the studies are not limited due to low production complexity. Case study 3 has been conducted with large and global manufacturing companies to allow comparisons between the three case studies. Large manufacturing companies and small and medium-sized (SME) manufacturing companies do not necessarily share the same prerequisites. Smaller organizations with only one few factories might highlight other risks than large organizations. SMEs should therefore be considered for further investigations.

To handle validity and reliability in qualitative research methods, triangulation has been used in all case studies by observing the assembly process at different types of assembly work stations and interviewing different types of stakeholders at different types of assembly work stations and different plants at different times which is proposed by Merriam and Tisdell (2015). Case study 3 has been conducted through telephone and online meeting services. The methods used in all case studies have carefully been selected to assure high reliability and validity of the results.

The validation as presented in paper E is planned to be conducted during the spring of 2018, and the validation result is therefore not included in this thesis construct. The validation is however based on previous models as described in Section 4.5 and contributes by further investigate independent variables for IS success. The validation will allow conclusions to be drawn concerning relations between determinants and usage and user satisfaction. The result will further support the manufacturing industry to understand the interplay between dependent and independent variables in manufacturing systems. In this case, it is important to include experienced operators in the validation process to strengthen the validity of the results. As the amount of experienced operators available is limited, semi-structured interviews will be used to improve the data collection.

5.5 Academic contribution

The result of this doctoral thesis contributes to the knowledge of current challenges of handling assembly information in a manual, assembly intense manufacturing industry. Even though the Industry 4.0 maturity index is based on workshops and case studies (Schuh, Anderl, *et al.*, 2017), the proposed stages to achieve the targets of Industry 4.0 are still abstract for many manufacturing companies. The analysis of the data from case study 1, 2 and 3, shows that the manufacturing industry is currently facing several challenges which affect both the ability to transform, but also to gain from the main components of a smart manufacturing system.

The result also contribute to the knowledge of IS success by contributing to the validation of determinants for IS success as introduced by Petter et al. (2013). To build better IS in the future, there are still determinants that have not yet been tested. The instruction quality dimensions introduced by Haug (2015) will also be validated through the industrial demonstrator introduced in paper E.

The critical aspects as introduced in paper D and addressed through RQ2, contribute to the design of future AIS. They can also be used to develop standards for future AIS which enables the intended functionalities of smart manufacturing systems and solves several of the reported challenges in the current manufacturing industry. This work seeks to contribute to close the knowledge gap of how to realize the digitalization transformation of the manufacturing industry as proposed by the Industry 4.0 maturity index (Schuh, Anderl, *et al.*, 2017).

5.6 Industrial implications

The current manufacturing industry is characterized by its ability to manufacture valuable products by applying its experience, knowledge and technology. As technology emerges the manufacturing industry has fallen behind the general service and technology development in society. Manufacturing companies consist of expensive equipment, complex IT infrastructures and supply chains. The ability to rapidly adjust to changes on the market becomes a key qualification for competitiveness (ElMaraghy and Wiendahl, 2009). This work has shown through RQ1, the challenges the manufacturing industry is facing today in the perspective of handling assembly information in manual assembly intense manufacturing companies. The challenges have been categorized into six focus areas to be more accessible for the manufacturing industry. In total, 22 critical aspects have been defined on basis of data from case study 1, 2 and 3 and have been grouped in the six focus areas.

The intention behind the identified critical aspects is to support manufacturing companies to prioritize initiatives which step by step will improve their production performance over time. As the intention of the Industry 4.0 maturity index is to provide a guidance of how to proceed with the digital transformation (Schuh, Anderl, *et al.*, 2017), this work will support the industry to concretize actions to prepare for taking the proposed transformation steps. As the manufacturing industry is facing challenges which limits and sometimes makes it impossible to realize smart manufacturing systems. The result from this thesis is presented as critical aspects as several dimensions of challenges are linked together and makes them difficult to grasp and therefor difficult to solve. Especially when different roles in an organization have different perspectives on processes and roles (Baligh, 2006).

5.7 Future work

The three case studies have been conducted with global and large manufacturing companies. Therefore, future studies should also consider SMEs. As the industrial demonstrator does not consider all critical aspects in the scope, future work should be focused on adding the omitted aspects to the experiments. The developed demonstrator focuses on functionality before information design; future experiments should therefore focus more on the information design and instruction quality as proposed by Haug (2015). Future work should also be focused on developing an IS to demonstrate the functionality on the engineering side as the developed demonstrator is currently doing on the operations side.

6 CONCLUSION

This thesis presents three cases studies conducted within the manufacturing industry focusing on manual assembly. The thesis addresses challenges of handling assembly information in manual assembly intense manufacturing industries. Six focus areas have been identified on the basis of the identified challenges. On the basis of the identified focus areas, 22 critical aspects have been proposed to the manufacturing industry to consider when deploying future assembly information systems. The critical aspects are intended to support the manufacturing industry to prioritize their initiatives to start the transformation to become digitalized and to build smart manufacturing systems:

- *IT challenges:* Standardization, Accessibility; Functionality; and Competence. Future AIS need to be equipped with standardized interfaces to allow smooth data and information transfer. The IT competence must be strengthened in manufacturing organizations.
- *Process challenges:* Task standardization; Task automation; and Competence. More engineering tasks should be standardized to allow more automation within manufacturing engineering to free up resources for more specialization activities. To build improved support systems for the operators, the competence within cognition, technical writing and information design must be improved.
- *Assembly process disruptions:* Standardized assembly tasks; Standardized assembly work instructions; Feedback; and Operator training. Assembly tasks should be standardized to improve production quality. Assembly work instructions should be standardized in terms of information content. Standardized operator training will allow consistent training results.
- *Information availability:* Availability; Accessibility; Information sharing; and Information quality. When designing future AIS, the manufacturing industry needs to assure that the actual information is easily accessible by the stakeholders and that the information quality is high to allow proper decision-making.
- *Technology & process control:* Scalability; Connectivity; Information control; and System automation. Future AIS must allow an increased technology level on the assembly work station and improved information control.
- *Assembly work instructions:* Purposeful assembly work instructions; Immersive technologies; and Accessibility. Future AIS must be flexible enough to not constrain the information design in the assembly work instructions. The instructions must be adaptable to the specific needs of each individual operator. They must also ensure that assembly work instructions can be presented in non-conventional ways, e.g. immersive technologies.

The results from the three case studies have been used to develop a demonstrator case where an ambition for enhanced assembly information systems has been implemented. This demonstrator will be used for validation of the enhanced assembly information systems during the spring of 2018.

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APPENDIX A

Assessment based information needs in manual assembly

(for operators)

Demographic and general questions

1. Are you employed by the company or through a staffing agency?
2. For how long have you been working at the company?
3. For how long have you been working at this assembly work station?
4. How long is your total work experience?
5. How old are you?
6. What is your general technical experience? (Low/Average/High)
7. Which is your highest educational degree?
8. Did you get any training before working at this assembly work instruction?

Main questions

9. How do you know what to do when conducting an assembly task?
10. Do you follow any assembly work instructions when you conduct the assembly task?
11. Do you use the assembly work instructions on a daily basis?
    a. If no, how often do you use the assembly work instructions?
12. How long do you look at the assembly work instructions each time?
13. Do you consider the assembly tasks conducted at this assembly work station to be difficult?
    a. In which way?
    b. Are the supplied assembly work instructions helpful or do you trust your own experience?
14. Do you consider there to be enough time to read the assembly work instructions?
15. What kind of information are you looking for in the assembly work instructions?
    a. How do you use that assembly information?
    b. What purpose does the assembly information fulfill?
16. Do you feel supported by the supplied assembly work instructions?
    a. If yes, in what way?
    b. If no, what do you miss?
17. Do you feel supported by the assembly work instructions in terms of feedback during and after the assembly task?
    a. If yes, in what way?
    b. If no, what do you miss?

18. Do feel supported by the assembly work instructions in terms of decision making of what to do?
    a. If yes, in what way?
    b. If no, what do you miss?
19. Do feel supported by the assembly work instructions in terms of learning the assembly process of a new assembly work station?
    a. If yes, in what way?
    b. If no, what do you miss?
20. Is there anything else that you consider as good or bad with the assembly work instructions related to this specific assembly work station?
21. Do you experience assembly disruptions (quality problems) at this assembly work station?
    a. If yes, what kind of problems
        i. How do you get information of eventual quality problems?
22. Do you trust the content of the assembly work instructions?
    a. If yes, what do you trust more, the assembly work instructions or other operators?
    b. If no, why not?
        i. How do you handle such a situation?
        ii. How do you trust instead?
23. Do you participate in the development of the assembly work instructions used at this assembly work station?
    a. If yes, in what way?
    b. If no, why not?
24. How does the information need differ between novice operators and experienced operators?
25. How would assembly work instructions containing 3D-models affect the assembly work? (A picture of such an instruction is shown)
26. How would wearables (immersive technologies) affect the assembly work? (A picture of such situation is shown)
27. How would mobile assembly work instructions affect your work? (A picture of such a situation is shown)
28. How would assembly work instructions in the format of videos affect the assembly work?
29. How would audio-based assembly work instructions affect the assembly work?
30. How would a collaboration situation with a collaborative robot affect the assembly work? (A picture of such a situation is shown)
31. For questions 25-30, what do you find as good or/and bad with these types of assembly work instructions?
32. Is there anything else you would like comment on which has not been covered?

Assessment based information needs in manual assembly

(for technicians, production leaders and engineers)

Demographics

1. Are you employed by the company or through a consulting firm?
2. What kind of experience of Volvo did you have before your current position?
3. For how long have you been employed by the company?
4. For how long have you been working at this position?
5. How old are you?
6. What kind of academic education do you have?

Main questions

7. Can you give an overall explanation of how SPRINT and MONT are structured (IS)?
8. Can you explain what kind of support tools and assembly work instructions that you have today for the operators?
9. What do you think of the current assembly work instructions?
10. What are you allowed to do with the current assembly work instructions?
11. Can you describe the procedure of developing new/ updating the assembly work instructions?
12. Are the operators involved in the development of new assembly work instructions?
13. How much of the feedback that you get from the operators are implemented?
    a. About sprint: Why does it take 3 weeks before the system is updated?
    b. About sprint: Why do you still use paper based assembly work instructions?
    c. How often are the assembly work instructions updated?
14. What kinds of problems are connected to current assembly work instructions?
15. How much quality problems is there at the assembly work stations today?
    a. How could you reduce them?
    b. Could quality problems be reduced by changing the information provided to the operators?
16. What kind of information is important, from your point of view, which the operators get during the assembly work?
17. In what kind of situations do the operators need more help?
18. In what way is the different kind of assembly work instructions intended to be used during assembly?
19. Is there anything that would potentially support the operators, but is not used/exists today?
20. What kind of limits exists today?
21. How would you like to design the assembly work instructions of the future, without current restrictions?
    a. What would they contain?
    b. How would they be presented?
    c. How would the interaction between operator and carrier look like?
    d. What is important in the future?
    e. How would the digitalization help?
22. What is important for the technicians when you work with the assembly work instructions?
    a. Are there any problems that occur when developing or updating the assembly work instructions?
    b. Do you have any demands for the future?

23. What do you think of the trade-off between product variants and quality? Is it affecting the development of the assembly work instructions?

APPENDIX B

Current challenges in handling assembly information and prerequisites for future assembly information systems

(for companies)

Demographic and general questions

1. In which product segment do you work?
2. Can you shortly describe your current role?
3. How long have you had your current role?
4. How long is your work experience in production?

Engineering

5. Can you describe the organization in terms of process owner, process developer, system owner and system developer within manufacturing engineering; how is the work distributed?
6. Who makes directional decisions in terms of processes and systems within operations?
7. How are directional decisions made in terms of processes and systems within operations?
8. Have you implemented standardized work similar to Toyota Production System?
9. Are manufacturing engineering processes centralized or decentralized?
10. Is the product preparation conducted on site or in central functions?
11. Are current information systems used for manufacturing engineering centrally or locally chosen and controlled?
12. Please describe the following:
    a. How is a product prepared for production?
    b. How are assembly work instructions developed?
13. How does the operator get assembly information at the assembly work station?
14. Are assembly work instructions analog or digital?
15. Is the provided assembly information on a customer order level or on a general level (standardized)?
16. Is the operator supported by any equipment at the assembly work station such as electric nut runners or other system-controlled equipment?
17. How is the general technology level within manual assembly?
18. Are there any rules that states when certain support tools should be used?

Production

19. Of the products you manufacture how large is the amount that are of standard types and how large is the amount that are rarely recurring types?
20. How much do standard types and rarely recurring types differ in terms of work content and components?
21. How many products of each type were manufactured last year in this factory?
22. How many factories does your global production network consist of?
23. Please rate the complexity of your products from low (1) to high (5) in terms of:
    a. Product variants
    b. Work content and competence
    c. Station layout
    d. Tools and support systems
    e. Assembly work instructions
24. Describe the necessity of competence, experience and internal training to assemble your products.
25. Which is the current takt time in the factory?
26. How often do you rebalance the production line?
27. How much of eventual assembly disruptions could be referred to:
    a. Component quality
    b. Assembly errors
    c. Errors in assembly work instructions
    d. Malfunctioning system-controlled equipment
    e. Missing competence

Future

28. Regarding challenges:
    a. With which quality issues do you currently work?
    b. Do you experience any deviations from current processes or assembly steps?
    c. Do you experience any limitations from current processes in engineering or assembly?
    d. Do you experience any limitations in current information systems?
29. What kind of development goals o you have within the next five years in terms of assembly information systems?
    a. What do you want to achieve?
    b. What functionalities need to be implemented?
    c. What kind information must an assembly information system contain?
30. What is your vision for future assembly information systems unlimited in time perspective and resources?
31. What is your view on future development of operator support?
32. What is your view on digitalization within your production?
33. How can digitalization support your manufacturing engineering processes?
34. How can digitalization support your operators?
35. How can you benefit from digitalization in operations in general?
36. What is your view on competence within operations in terms of digitalization?

37. Do you have any ideas on how manual assembly will change in the coming 10-15 years?
38. Do you have any additional comments?

Current challenges in handling assembly information and prerequisites for future assembly information systems

(for industry experts)

Demographic and general questions

1. Which research area do you work in?
2. Can you shortly describe your current role?
3. How long is your work experience within production?

Engineering

4. What is your general view on centralization and decentralization within the manufacturing industry?
5. How much of the work within the industry is standardized?
6. How well does inter and intra organizational collaboration work in the industry?
7. Are industrial and engineering processes harmonized if the company has multiple factories?
8. How is assembly information provided to operators in general?
9. Are assembly work instructions analog or digital?
10. Do the assembly work instructions contain customer order specific informations?
11. What is the general technology level in the manufacturing industry?
12. Is the manufacturing industry following strict processes of when to implement technical support systems?

Production

13. What is most common for the manufacturing industry: standard products or customization?
14. What is your general view on complexity in terms of:
    a. Product variants
    b. Work content and competence
    c. Station layout
    d. Tools and support systems
    e. Assembly work instructions
15. Which are the most common assembly disruptions in the manufacturing industry?

Future

16. Regarding challenges:
    a. Are current processes limiting the competitiveness of the manufacturing industry?
    b. Are current information systems limiting the competitiveness of the manufacturing industry?
17. Do you consider current technology levels in the manufacturing industry to be satisfactory?
18. What kind of functionalities must future assembly information systems emphasize?
19. What kind of information must future assembly information systems contain?
20. What is your view on the development of operator support?
21. How would digitalization impact manufacturing engineering?
22. How can the manufacturing industry benefit from digitalization in operations in general?
23. What is your view on competence within operations in terms of digitalization?
24. What is the status of Industry 4.0 in the manufacturing industry?
25. What is the most important step for the manufacturing industry to prioritize?
26. Is the digitalization crucial for the industry's future?