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INDUSTRY 4.0

Where are Swedish manufacturers in the transition towards Industry 4.0?

Master's Thesis in the Master's Programme

Quality and Operations Management

MARCUS ANTONSSON

Department of Technology Management and Economics
Division of Supply and Operations Management
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Tutor, Chalmers: Mats Winroth

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Department of Technology Management and Economics
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Chalmers University of Technology

SE-412 96 Gothenburg, Sweden
Telephone: + 46 (0)31-772 1000

Chalmers Reproservice

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Marcus Antonsson

ABSTRACT

It is commonly suggested that the industry is facing a new revolution, namely the 4th industrial revolution. The new revolution is often denominated as Industry 4.0, and referring to the emerging technologies such as Internet of Things, automation, connectivity, sensors as well as to the market demands on shorter lead-times and increased individualization of products. The definition of Industry 4.0 is however, despite a great amount of research, still vague. The research commonly focuses on defining the technologies and the benefits of using them, which implies that a holistic view of the concept is lacking.

This study aims to assess the Industry 4.0 maturity level of Swedish manufacturing companies. The companies in scope of the study are eleven Swedish manufacturing companies, all with an annual revenue of > 0,5 billion SEK and all with a high complexity in their production processes. To enable assessment of the maturity level, it was necessary to define what concepts and ideas that constitute Industry 4.0 in the manufacturing area as well as a framework describing Industry 4.0, that could be used for the assessment. This was needed since a clear definition was lacking and since existing assessment frameworks required the assessed companies to have good insight in Industry, which was not the case in this study.

The study result consists of two parts; (1) a definition and a framework enabling assessment of the industry 4.0 maturity level and (2) an assessment of the maturity level of Swedish manufacturing companies. The definition of Industry 4.0 was developed based on input from various sources and has been used as basis for the study. The assessment framework consists of two parts. The first part measures the technological implementation of twelve use-cases (applications) and calculates a total score per company as well as an average score for the industry as whole. The second part measures the other dimensions needed to assess the maturity; management attention, priority given to topic and existence of strategy. The two parts are used jointly in the analysis, where the technological implementation level is compared with the view upon the topic.

The assessment concludes that the general Industry 4.0 maturity level in Swedish industry is low. This since the total implementation level of the use-cases of Industry 4.0 was concluded low. There are however some use-cases, where the implementation level in the industry as whole is high, these comprise material transparency and real-time performance management. Further it has been concluded that there seems to be a mismatch between the belief in positive effects from Industry 4.0 and the efforts that are put into realizing such benefits. Since even that all companies believe in positive impact of Industry 4.0, almost half of the companies lack a strategy for Industry 4.0 implementation and more than 60% of the companies prioritize the topic only low to medium (in a scale ranging between low-medium-high-top).

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1 INTRODUCTION

1.1 Background

It is commonly suggested that the industry is facing a new revolution, namely the 4th industrial revolution (Posada et al., 2015; Kagermann et al., 2013; Haddara and Elragal, 2015; Lasi et al., 2014). The 1st industrial revolution introduced mechanization and the use of steam and water power, the 2nd introduced electricity and the 3rd developed electronics and IT to further automate the production (Haddara and Elragal, 2015). Maynard (2015) describes the 4th industrial revolution as a movement trying to exploit and converge several emerging technologies. Examples of emerging technologies are Internet of Things and Services, industrial automation, connectivity, cybersecurity and big data analysis (Posada et al., 2015). The new technologies will provide solutions to satisfy market demands on shorter development times, individualization of products, higher flexibility and resource efficiency (Lasi et al., 2014).

Several governments have embraced the 4th industrial revolution. The most famous initiative is the German Industry 4.0. The term Industry 4.0 was coined 2011 at the Hannover Fair in Germany. It is a result from a high-tech strategy project of the German government (Haddara and Elragal, 2015). In the U.S., a similar strategy is named the Industrial Internet (Lee, 2015; Posada et al., 2015). When the Swedish government launched their strategy for the new industrialization in 2015, Industry 4.0 was emphasized as one out of four areas of particular importance (Swedish Ministry of Enterprise and Innovation, 2016). Common for all these initiatives is the belief that digitization of the manufacturing sector is necessary to stay competitive as a high-wage country. The notion Industry 4.0 has in Europe become synonymous with the notion the 4th industrial revolution. From now on the notion Industry 4.0 will be used in this report.

Previous studies show that a successful transition to Industry 4.0 can help companies to realize significant benefits. Industry 4.0 can make manufacturing systems more flexible, allow for optimized decision making due to smart and transparent machines and enable more efficient resource utilization (Kagermann et al., 2013). Studies also show that Industry 4.0 will have a positive financial effect. Triathlon Group (2016) expects productivity gains of 20% and revenue growths of 10-15% over five years.

Even though most of the early Industry 4.0 initiatives have focused on defining the concepts and the benefits, there is still no clear definition of the concept Industry 4.0. Posada et al. (2015, p. 28) state that "*although there is some criticism regarding certain vagueness in the term Industrie 4.0 […] it is now widely accepted that the vision and the related technologies of Industrie 4.0 have already had a real impact in industrial manufacturing systems*". This implies that even though a clear definition is missing, Industry 4.0 has already started to gain foothold. In addition to the lack of a definition, Sommer (2015) further claims that, despite the perceived importance of Industry 4.0, there is a lack of understanding of the qualifications needed to be part of the transition. This statement is supported by a survey conducted in Germany, the U.S. and Japan that shows that only 16% of the companies have a strategy for Industry 4.0 in place, despite that most companies believe in the significant impact of Industry 4.0 on their industry (McKinsey Digital, 2016). It is reasonable to believe that the situation is similar in Sweden, but no similar study has been found during the initial literature study.

Therefore, there is a need to investigate where Swedish companies are in the transition towards Industry 4.0.

This study is concerned with investigating where Swedish manufacturing companies are in the transition towards Industry 4.0, and the thesis aims to assess the Swedish companies' Industry 4.0 maturity level. Industry 4.0 is expected to impact most functions in a company, such as sourcing, manufacturing, distribution, sales and product development. This study will focus on manufacturing and manufacturing processes, since it will play a crucial part in Industry 4.0 (Kagermann et al., 2013).

1.2 Purpose

The purpose of this thesis is to assess the Industry 4.0 maturity level in the Swedish industry. Since there is no clear definition of Industry 4.0, a framework will be developed describing the concepts and ideas of Industry 4.0. The framework will enable the Industry 4.0 maturity level of the Swedish industry to be assessed.

1.3 Problem Description and Research Questions

The term Industry 4.0 is very novel, and vagueness exists regarding its principles (Posada et al., 2015). To enable assessment of the maturity level it is necessary to first define a framework for Industry 4.0 by aggregating already existing concepts for the manufacturing sector. This leads to the first research question (RQ).

> **RQ 1:** *What concepts and ideas constitute Industry 4.0 in manufacturing, and how can Industry 4.0 be described in a framework?*

RQ 1 will give a framework of Industry 4.0 in manufacturing. This enables an assessment of the current situation in Swedish manufacturing companies to be done. The framework will enable answering the second research question, which is the major question of the thesis.

> **RQ 2:** *What is the current Industry 4.0 maturity level in the Swedish industry?*

1.4 Delimitations

The thesis will examine the Industry 4.0 maturity level within the companies' manufacturing processes. No attention will be paid to other company functions, such as product development, sales or aftermarket. Further, only large Swedish companies with high complexity in their manufacturing processes will be examined, since it is expected that those have best potential to benefit from Industry 4.0 since they are presumably the most advanced companies.

1.5 Context of Study

The study has been conducted in collaboration with Chalmers University of Technology and a Swedish management consultancy firm. The firm is headquartered in Gothenburg and has expertise in all areas included in a company's value chain, e.g. product development, aftermarket and production. In this study, the firm's production management group has supported with relevant expertise from the industry. The study was conducted in the fall of 2016.

2 LITERATURE REVIEW

This chapter will present the literature review that has been conducted to provide a theoretical basis for the study. First, the chapter explores the background of Industry 4.0 and different definitions and frameworks. Second, the chapter presents different Industry 4.0 scenarios and applications discussed in the literature. Third, initiatives related to digitalization of manufacturing in different countries are examined. Lastly, the chapter presents and analyzes existing Industry 4.0 maturity models.

2.1 Industry 4.0 Definitions and Frameworks

In this section, the background of Industry 4.0 is explored and different definitions and frameworks from the literature are presented.

According to Posada et al. (2015), there is a worldwide movement trying to improve productivity and efficiency in industrial manufacturing. Lasi et al. (2014) mean that worldwide movement has two major drivers: an application-pull and a technology-push.

The application pull derives from general changes in social, economic and political aspects. The changes are forcing companies to reduce development periods, individualize products, be more flexible, enable decentralized decision making and produce more resource efficient (Lasi et al., 2014). Also Haddara and Elragal (2015) state that the development is driven by a need to react to market requirements and improve manufacturing by reducing cost, increasing product flexibility and decreasing the reaction time to changes in the market.

The second driver is the technology-push. The latest advancements in information and communication technologies are being implemented into the manufacturing systems. Examples of the technologies are the Internet of Things, industrial automation, connectivity and ubiquitous information (Posada et al., 2015). Lasi et al. (2014) stresses that new technologies are making their way into industrial systems, and three different trends are appearing in industrial systems: further increasing mechanization and automation, digitalization and finally networking and miniaturization.

The term Industry 4.0 was first coined in 2011, and "*is often understood as the application of generic concept of cyberphysical systems (CPSs) to industrial production systems*" (Drath and Horsch, 2014, page 56). Similarly, Zhou et al. (2015) state that Industry 4.0 "*encapsulates future industry development trends to achieve more intelligent manufacturing processes, including reliance on Cyber-Physical Systems (CPS), construction of Cyber-Physical Production Systems (CPPS), and implementation and operation of Smart Factories*" (page 2147). Further, they write that Industry 4.0 is mainly based on integration of information and communication technologies in industrial settings, with the goal to achieve intelligent manufacturing.

A commonly quoted publication is the final report of the Industrie 4.0 working group in Germany (Kagermann et al., 2013). The report is often referred to as the Industry 4.0 manifesto. In the report, the working group argue that so called smart factories have started to appear, where "*Cyber-Physical Systems comprise smart machines, storage systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently*" (Kagermann et al, 2013, page 5).

Lee et al. (2015) argue that introducing cyber-physical systems into industrial production would transform existing factories into Industry 4.0 factories, which is the next generation of manufacturing. A Cyber-Physical System has been defined as "*transformative technologies for managing interconnected systems between its physical assets and computational capabilities*" (Lee et al., 2015, page 18). A structure has been developed, that is useful as a step-by-step guide for implementing a CPS. The structure consists of 5 levels, depicted in Figure 1. The 5 levels are: connection level, conversion level, cyber level, cognition level and configuration level. The idea is to equip objects with sensors for collecting data and go via conversion of data into information to the higher levels where the information is shared and interpreted to gain deeper understanding of the system. In the ultimate stage, the manufacturing processes can self-compare, self-maintain and self-configure.

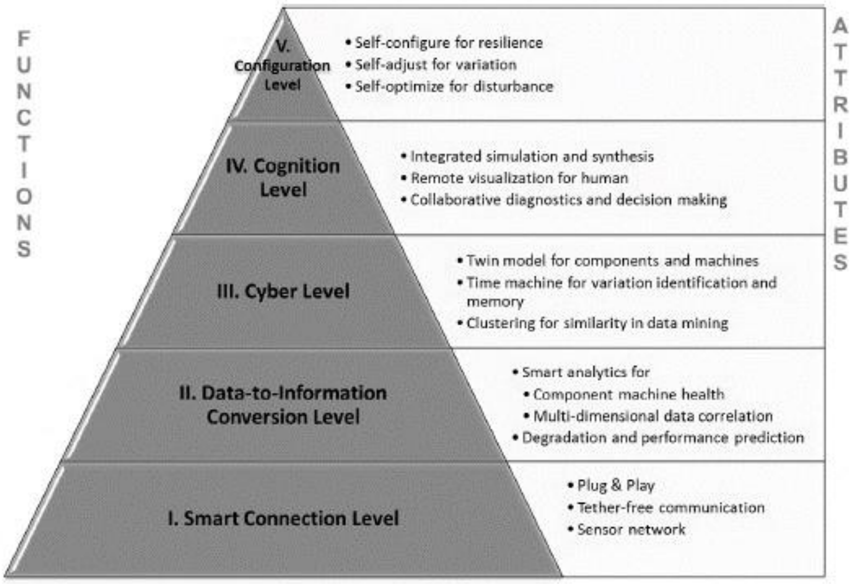

Figure 1, 5C architecture for implementation of Cyber-Physical System (Lee, 2015, page 232)

By incorporating cyber-physical systems into production, integration in three different dimensions can be achieved (Kagermann et al., 2013):

Vertical integration within the factory
Refers to the integration of various IT systems at different hierarchical levels. Data accessibility is a core principle in Industry 4.0, and to achieve that the different levels from sensors and actuators up to manufacturing and execution level must be integrated.

Horizontal integration over the supply chain
Refers to the integration of IT systems in different stages of the manufacturing and business planning process. The range of the integration stretches not only over different functions within a company, but also over company boundaries between different companies.

End-to-end engineering over the entire life cycle of the product
Refers to the integration over the product's life-cycle. The entire value chain, from product design via manufacturing to aftermarket and sales, should be integrated and use the same set of data models.

The visions of Industry 4.0 promises prosperous future states. Several benefits can be achieved, such as a more resource efficient production, profitable batch size one production, last-minute changes to production and delivery, optimized decision making and new ways of creating value and novel business models (Kagermann et al., 2013). Similarly, the new technologies can enable the following key objectives to be reached: (Posada et al., 2015)

- IT-enabled mass customization of manufactured products
- Automatic and flexible adaption of production chain
- Tracking and self-awareness of parts and products
- Improved human-machine interaction paradigms
- Production optimization due to Internet of Things enabled communication
- Radically new services and business models contributing to changing ways of interaction in the value chain

A discussed question is which type of companies that will be able to benefit the most from Industry 4.0, and which type of companies that might be victims in this revolution. A German study conclude that the Industry 4.0 awareness and capability to adapt the new concept is heavily dependent on the company size, where small companies are more likely to be victims in the revolution (Sommer et al, 2015).

Even though some authors have tried to define Industry 4.0, several authors argue that a clear definition is lacking.

Hermann et al. (2016) conclude that no clear definition of Industry 4.0 exists. They mean that the key promoters of Industry 4.0 only describe the vision, benefits and enabling technologies, but there is no definition. The authors have created a framework consisting of four design principles. Design principles help practitioners in implementing Industry 4.0 and support academics by focusing their research of the topic. The design principles have been developed by a quantitative text analysis and a qualitative literature review. Figure 2 below shows the four identified design principles:

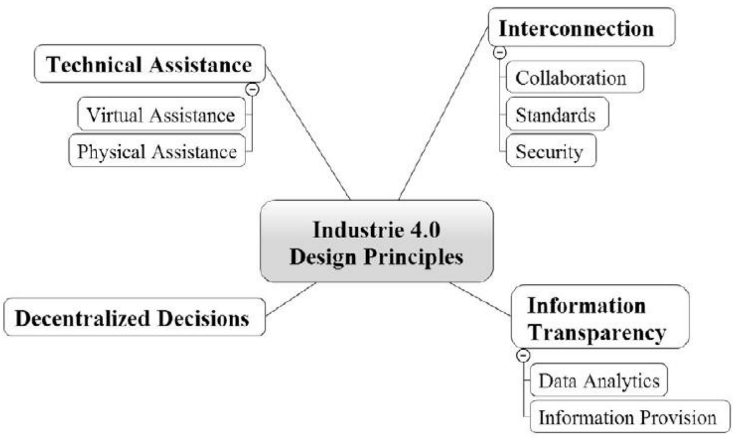

Figure 2, Four design principles of Industry 4.0 (Hermann et al., 2016, page 3932)

The four Industry 4.0 design principles are further elaborated on below:

Interconnection: Machines, devices and sensors will use wireless communication technologies to communicate with each other over the Internet of Things. Communication standards play an important role in enabling the communication. Also, cyber-security issues will be of increasing importance since the number of harmful attacks will increase when valuable information is transferred in the network and stored in the cloud.

Information transparency: By having interconnected objects and people, more information will be available. By having access to all the information, a virtual copy of the physical world can be created. Equally important as having the information, is to provide the information to the right people or objects.

Decentralized decisions: When objects and people are interconnected and the information is transparent, decentralized decisions can be made by utilizing both local and global information. Only in certain cases, the decision must be delegated to a higher level.

Technical assistance: Due to the increased complexity of production, technical assistance will be of major importance. There are two main types of assistance systems. First, decision support systems that will support people in decision making by aggregating and visualizing information for people. The second main type is physical assistance. Advances in robotic technology will enable new types of physical assistance on the factory floor.

Qin et al. (2016) argue that the criteria for achieving Industry 4.0 is unclear, and that there is a lack of a roadmap for a transition towards Industry 4.0. To close the knowledge gap, the authors have created a categorical framework of Industry 4.0 applications in manufacturing. The framework is shown in Figure 3.

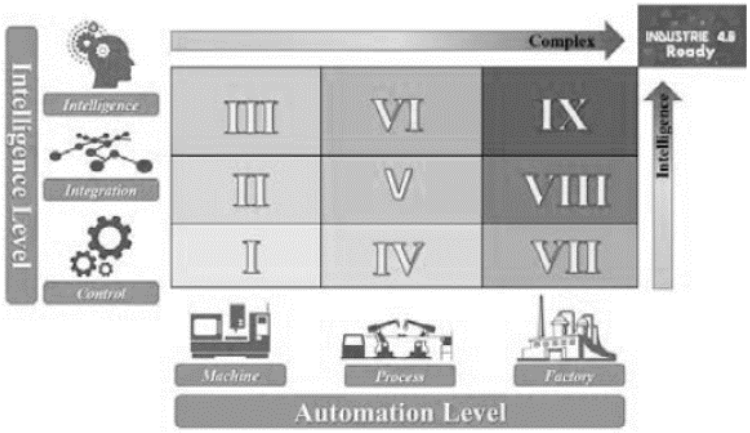

Figure 3, Categorical framework for Industry 4.0 applications in manufacturing (Qin et al., 2016, page 177)

In the model, Industry 4.0 applications are classified based on the advancement in two dimensions:

The automation level: stretches from single automated machines to totally integrated and automated factories.

The intelligence level: starts at control functions, such as programmable logic controlling, and goes via integration of information to intelligent systems that can self-aware, self-optimize and self-configure.

It requires accomplishment on the lower levels to reach the higher levels in the framework. It means that to reach an automated process, the machines in the process must be automated, and an automated factory requires automated processes. Similarly, to reach the highest level of intelligence, the factory must first have control functions that steer the machines and collects data. Subsequently the information can be distributed, shared and integrated with other machines, humans and processes before it ultimately becomes self-aware and can self-configure.

Lasi et al. (2014) mean that Industry 4.0 is a term "*whose clear classification concerning a discipline as well as their precise distinction is not possible in individual cases*" (Lasi et al., 2014, page 240). Instead, the authors have listed 7 fundamental concepts of Industry 4.0:

1. **Smart Factory:** By using smart technology and holistically digitalized factory models of products and factories, smart factories that are autonomously controlled will appear.
2. **Cyber-physical systems:** The real and the digital world are merging why the physical and the digital world cannot anymore be differentiated in a reasonable way.
3. **Self-organization:** A shift will happen from traditional production hierarchy to decentralized self-organizing systems.
4. **New systems in distribution and procurement:** Various channels and connected processes will increase the individualization of procurement and distribution.
5. **New systems in the development of products and services:** Approaches of open innovation and product intelligence will be of major importance when products are becoming individualized.
6. **Adaption to human needs:** Humans will be in focus and manufacturing systems will be primarily designed to follow the human needs.
7. **Corporate social responsibility:** Fundamental framework conditions for succeeding products are sustainability and resource efficiency.

2.2 Industry 4.0 Scenarios and Applications

In this section, different examples of Industry 4.0 applications and scenarios will be described. The aim is to capture concrete examples and applications of how the Industry 4.0 vision will be realized in manufacturing.

Industry 4.0 will be characterized by a new level of socio-technical interaction (Kagermann et al., 2013). Different manufacturing resources, such as machines, robots and warehousing systems, will be self-controlling and autonomous. Tomorrow's manufacturing structure will not be fixed and predefined. But instead there will be a set of defined IT configuration rules that can be used to automatically build a specific structure, which will allow for a more flexible and dynamic manufacturing structure and shop-floor. Similarly, Lasi et al. (2014) say that manufacturing will consist of autonomous manufacturing cells who independently control and optimize manufacturing in various steps.

Haddara and Elragal (2015) mean that the core of Industry 4.0 is based on connected systems that create a fully digital and integrated value chain, and that the systems eventually will be intelligent. The goal is to achieve a faultless interaction between machines and their surrounding systems. According to the authors, sensors are a core aspect of a smart factory. Sensors are capable to feed data models with more information than humans can do, and by having sensor data the data models can monitor and control the physical unit.

Stock and Seliger (2016) present a state of the art review of the concept Industry 4.0, based on developments in academia as well as practice. The smart factory is broken down into five different constituents, so called value creation factors. Stock and Seliger describes trends and future expectations for each of the value creation factors:

> **Equipment** - the manufacturing equipment will be characterized by high level of automation. The equipment will be highly flexible and enable collaboration between man and machine.
>
> **Human** - the role of human will change in the smart factory. Simple and repetitive work tasks will be automated. Instead, workers will perform more knowledge work and tasks that are hard to plan.
>
> **Organization** - due to the increasing complexity in manufacturing systems, they cannot be controlled from a central instance. Instead, decisions will be made decentralized by workers or equipment using methods from the field of artificial intelligence.
>
> **Process** - additive manufacturing technologies will help in creating more complex, stronger and lightweight geometries. Additive manufacturing will also create a resource efficient production.
>
> **Product -** customers of the future will require individualized products. There will be a shift towards mass customization where products are produced in batch size one.

According to Lee et al. (2015), tomorrow's smart factory differs from the traditional factory in several ways. Objects will become self-aware. By utilizing big data analysis and sharing information between machines, it will be possible to determine the machine health and expected remaining life-time. Further, when systems are increasingly complex, different types of simulations will be used to gain a deeper understanding of the system and to be able to manage the systems. Ultimately, by having a thorough understanding of the system it will be possible to create machines and systems that can self-configure, self-adapt and self-optimize.

Hermann et al. (2016) write that in the smart factory, smart products will be aware of their current state and production history. The smart products will be able to actively steer their way through the production by instructing machines to perform required manufacturing tasks. This will lead to a decentralized control of the production, a shift away from the today's centrally controlled factories. Further, the authors state that information transparency is a central part of Industry 4.0, and that process-critical information should be distributed in real-time. Process-critical information can be for example information enabling early detection of discrepancies and deviations that might affect the outcome of the production.

A general trend in the smart factory is that the manufacturing equipment will be further automated (Stock and Seliger, 2016). The equipment will be more flexible and adaptable to changes of other objects and of equipment on the shop floor. For example, robots will be sensitive to workers' behavior, enabling robots and workers to work collaboratively on joint tasks. Additive manufacturing is predicted to be increasingly deployed in manufacturing since the price has decreased over last years together with an improved performance. The greatest benefit of additive manufacturing is the possibility to create more lightweight, complex and strong geometries, in a quick and resource efficient way using batch size one.

Jagrit (2016) has through a peer-sharing initiative identified ten future digital supply chain scenarios. The scenarios represent different capabilities and areas that will be of major importance in the digital manufacturing era. Three out of ten scenarios are related to the internal processes of a factory. The three internal scenarios are:

Digital factory design and simulation – digital models will be used for factory layout design, process simulation and material flow simulation

Digital manufacturing planning and execution – manufacturing systems with real-time enables monitoring of KPIs and early detection of disruptions

Flexible automation and additive manufacturing – flexible automation systems and additive manufacturing technologies support customized or small batch production

According to Stock and Seliger (2016), the in-house transports will be characterized by autonomously operating transport equipment, such as Automated Guiding Vehicles (AGV). To enable automatic transport of equipment, all material in the factory must be traceable at all time, i.e. it must be possible to identify and localize the material in real-time. Even material stored by the line side or material on a carrier should be traceable. Different technologies are available for this purpose, Radio Frequency Identification (RFID) tags or Quick Response (QR) codes are two examples of such.

Boston consulting group (2016) has identified eight different Industry 4.0 topics. The topics, that are based on the application areas of Industry 4.0 technologies, have been used to ask companies about the status of adoption of each topic. The eight topics are:

- Digital factory logistics, supply chain and warehousing
- Predictive maintenance
- Electronic performance boards
- Mobile and real-time performance management
- Smart shop-floor, production control, and digital factory design
- Augmented reality for training
- Autonomous robots and assistance systems
- Social business media

A McKinsey & Co report (McKinsey Digital, 2016) has investigated different Industry 4.0 applications that have been prioritized by manufacturers in Germany and the U.S. The 5 most prioritized applications are Real-time supply chain optimization, Digital quality management, Remote monitoring and control, Digital performance management, and Predictive maintenance. The study has also investigated in what applications that the companies have made progress in and concluded that progress had been made in the application areas; Digital quality management, Smart energy consumption, Remote monitoring and control, Digital performance management and Predictive maintenance.

In a Vinnova report conducted by Roland Berger (2016), 10 different technology areas have been identified. Within these areas, many new solutions are expected to emerge in the digital manufacturing industry. The ten technology areas are:

- Additive manufacturing
- Smart electronic systems
- Social networks
- Man-machine

- Visualization
- Cyber-security
- Wireless communication
- Big data analytics
- Systems of system
- Simulation and modelling

The SmartFactoryKL is often mentioned as a pioneer within the development of smart factories and Industry 4.0 in manufacturing. In a demonstrative video (SmartFactory KL, 2016), several concepts and applications of Industry 4.0 is explained. A major feature is the smart assistance systems, such as screens or smart glasses, that provide instructions and information to operators. In the video, the assistance systems are demonstrated by providing standard operating procedures and machine service instructions to operators. Another feature of the SmartFactoryKL is the modular design of the manufacturing line. The line consists of several modules from different manufacturers, and the modules are coupled by standard interfaces. The manufacturing line can also self-configure, meaning if a module is removed or replaced the line automatically configures the settings to adapt to the new set up.

2.3 Digitalization initiatives in different countries

The digitalization of manufacturing is a hot topic. Many governments have embraced the technological development in different initiatives to strengthen the competitiveness of the countries. This section will provide a brief overview of some initiatives trying to exploit the new opportunities offered in manufacturing.

O'Sullivan (2016) has reflected on the different initiatives and perspectives in some important manufacturing countries. The conclusion in the article is that most of the major economies have research and innovation efforts related to the digitalization of manufacturing. The emphasis and focus of the initiatives differ depending on the national industrial strengths and established capabilities of the countries. In the U.S., a large part of the research focuses on the digital thread. The digital thread is an integrated approach to manage information related to a specific product. In Germany, the focus is on connectivity, embedded systems and smart factories, with the aim to strengthen the many small and medium sized companies in the country. The focus of the Japanese initiatives is on exploiting the new opportunities given by Internet of Things. The country has a long tradition of strong advancement in robotics, and by using Internet of Things to incorporate robotics the country aims to realize new benefits.

Like O'Sullivan, Drath and Horsch (2014) have also described other initiatives similar to Industry 4.0, such as the Industrial Internet in the U.S. The authors state that various, but still similar, initiatives have caused confusion rather than brought clarity into the term. Further, Drath and Horsch (2014) argue that even though the enabling technologies for Industry 4.0 are available and more widespread in other areas (such as consumer industry), Industry 4.0 in manufacturing is still in the future due to the low level of implementation.

2.4 Existing Maturity Models

In this section, different existing maturity models will be presented.

Schumacher et al. (2016) have examined existing maturity and readiness models for Industry 4.0. They have identified five different models, and the models have been compared based on the number of dimensions and factors that they consider. It is showed that it is often unclear what factors that are considered by the models. The authors argue that it is difficult to compare and validate the models due to the lack of details in existing models regarding the development process, structure and assessment-methodology.

To fill the gap, the authors have developed a new model for assessing a company's Industry 4.0 maturity, by transforming abstract concepts of Industry 4.0 into distinct and measurable items. The main contribution of the model is that it does not only focus on technical aspects, but also on organizational aspects such as strategy, leadership and people.

The structure of the model developed by Schumacher et al. (2016, page 164) is based on 72 previously published maturity models from other authors. The model consists of 62 items distributed on 9 dimensions, where each item is assessed on a 5-levels scale. The nine different:

- Strategy
- Leadership
- Customers
- Products
- Operations
- Culture
- People
- Governance
- Technology

When assessing a company's Industry 4.0 maturity, Schumacher et al. (2016) using the model in a three-step approach. First, the progress of each item is measured by a questionnaire. Second, the progress of each item is used to calculate the maturity of the nine dimensions. Third, the result is presented in a maturity report and visualized in radar charts.

The authors of the model emphasize that "*the questionnaire can only be answered properly, if all respondents have a basic understanding of the concepts of Industry 4.0*" (Schumacher et al., 2016, p. 164). The authors do also conclude that currently most companies do not possess the required basic understanding. This why the model may be difficult to use in this thesis.

3 METHODOLOGY

This chapter aims to clarify and reinforce how this study has been conducted. According to Alänge (2016) three important concepts that must be decided on when conducting a study, namely: research strategy, design and method. This chapter will specify how the study has been realized with respect to each of the three areas.

3.1 Research strategy

The research strategy decides on the general orientation of the research, which can be either quantitative or qualitative (Bryman and Bell, 2011). This study was realized with a qualitative research strategy, where findings are based on case studies with interviews and observations. There are various perspectives on the roles of theory in research, a deductive approach tests theory to prove a hypothesis whilst an inductive approach uses observations and findings to create theory (Bryman and Bell, 2011). In an inductive approach theory is the outcome of the research (Bryman and Bell, 2011). This study has been realized with an inductive approach, first creating a framework, then collecting data through interviews and at last populating the framework with empirical data to analyze the result and draw conclusions. The conclusions (i.e. developed theory) are the outcome of an inductive study.

3.2 Research design

The research design provides a structure for the execution of the data collection, but also for the following analysis of the collected data (Bryman and Bell, 2011). The research design does however not describe what technique to use when collecting the data, this is described by the research method.

There are five generic research designs in qualitative research (Bryman and Bell, 2011):

- **Experimental**: Does not have a typical form since it is an experiment.
- **Cross-sectional**: Using data from more than one case, during a single point in time, to analyze and identify association patterns. Normally a large amount of quantitative data is needed from a large amount of cases.
- **Longitudinal**: Little used in business and management research. Typically used to identify change over time.
- **Case study**: Commonly used in business and management research. Analyzes a single case in depth. A case may be a single organization. Several companies can be analyzed in a multiple case study.
- **Comparative**: Applies the same research method on several cases, in the same point in time, to enable comparison of results between several cases. For a comparison to be possible it is essential that data is collected in the same way, using the same tools.

This study has been conducted using two types of designs. A multiple case-study was conducted to answer the main research question; the Industry 4.0 maturity of Swedish manufacturing companies are. But the study has also used a comparative design, in order to enable comparison between both the interviewed companies and the different use-cases.

3.3 Research method

The research method is the technique used to collect data (Bryman and Bell, 2011). There are various methods available; interviews and observations are two examples.

The study has been conducted in three partially overlapping phases. Figure 4 outlines the three phases and describes main activities in each phase.

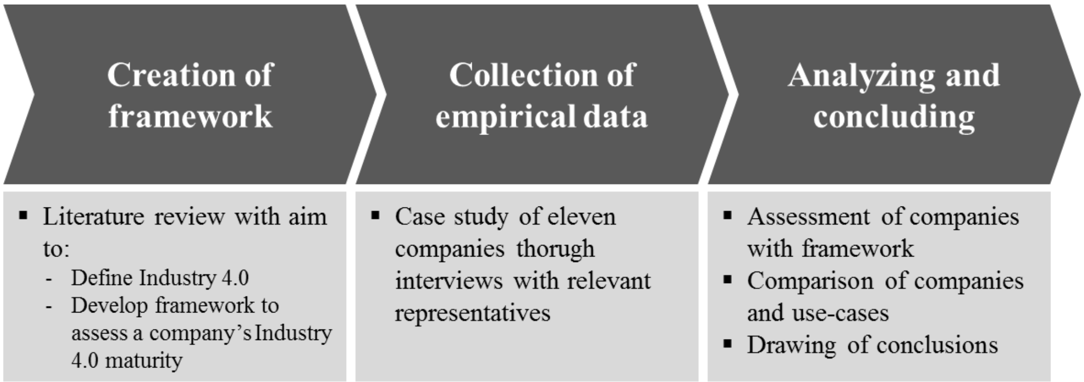

Figure 4, The three phases of the project and main activities in each phase

Two different data collection methods have been used. A literature review was conducted in the first phase to create the framework. In the second phase, empirical data was collected by company interviews.

3.3.1 Creation of framework

A framework was created in the first phase of the project. This was done through a literature review. The framework was created for two reasons:

- Define the concept Industry 4.0
- Develop a framework to enable assessment of companies' maturity in Industry 4.0

Chalmers database Summon was used for relevant academic publications. In addition to academic publications, consultancy reports have been used in order to find different Industry 4.0 scenarios and applications. The key words used when searching for publications are listed below:

- Industry 4.0
- Industry 4.0 framework
- Fourth industrial revolution
- Smart factory
- Industry 4.0 maturity model
- Industry 4.0 assessment

An Industry 4.0 framework was created after the literature study. The framework includes twelve technological applications, so called use-cases. The twelve selected use-cases are commonly discussed in the literature. The twelve use-cases are not mutually exclusive, nor collectively exhaustive. Nevertheless, they are representative for the vision of Industry 4.0 in manufacturing. They do also enable discussion with companies that have no prior knowledge of Industry 4.0, which is important since the knowledge level of the topic was expected to be low in the industry. The framework must be possible to apply on all companies, not only those with high Industry 4.0 knowledge, to give a fair result of the general maturity in Swedish industry. When the twelve use-cases were selected, questions were formulated for each of the use-cases to enable discussions with the interviewees, see *Appendix A – Interview Guide* for a list of the questions.

It was found in the literature study that the maturity cannot only be measured based on the technological implementation level. The assessment must also cover more aspects, such as management's attention and priority given the topic. Therefore, in addition to questions related to the twelve use-cases, more general questions were added to examine more dimensions that the technological implementation level. Some examples of the questions are:

- How do you think Industry 4.0 will affect manufacturing in our industry?
- What priority has the implementation of Industry 4.0 in your company?
- Do you have a strategy for implementing Industry 4.0?

3.3.2 Collection of empirical data

Empirical data to populate the framework was collected in the second phase of the project.

The empirical data was collected through semi-structured interviews with representatives from eleven companies. Each interview, that was realized in person, lasted for around two hours. The interviews were recorded and then transcribed by the interviewer. This was done to ensure that no information was missed since there was only one person interviewing the company representative. All interviews were held during a three-week period to enable comparison of answers.

The eleven companies included in the research were selected upon following criteria:

- Manufacturing company
- Annual revenue > 0,5 billion SEK
- Located in Sweden
- Production process with high complexity

Eleven companies were included in the study. The companies will not be presented by name, due to a willingness to remain anonymous. The companies operate in different industries, such as automotive, aerospace, food, material handling and furniture. The 2015 annual revenue of the company's ranges from 0.5 to 100 billion SEK.

From each company, a relevant representative was selected and interviewed. Targeted interviewees had a role relevant for the development of manufacturing and manufacturing processes. The interviewees hold the following positions: Plant manager, Production manager, Head of operations, Manager industrial strategies, Global development manager, Technical manager, Director information architecture. Some of the interviewees worked at a specific production site, whilst some belonged to the company group.

3.3.3 Analyzing and concluding

In the third phase, the developed framework was populated with the empirical data in order to analyze the maturity level and draw conclusions.

The analysis was done in five steps:

1. First, the interviewer created scales and did a qualitative judgement of the companies answer to the general questions. Classifications were possible to the questions regarding priority of topic and existence of strategy, but not for how it will affect their industry. Instead, a selection of answers to the last questions are presented to exemplify different types of answers.

2. Each company was assessed individually with respect to their maturity and importance level of each of the technological use-cases. Each use-case was assessed with a score from zero to four, see Figure 5. For the maturity scale, use-cases with the highest maturity were given a four, implying that they were fully implemented at the assessed company. For the importance scale, use-cases with the highest importance were given a four, implying that they were classified as crucial for the company to stay in the business. The maturity level was assessed by the researcher after the interview whilst the importance level was assessed jointly by the researcher and the interviewee, during the interview.

Scale to classify the maturity level

0	1	2	3	4
No plans to implement	Implementation plans exist	Pilot project	Partially implemented in factory	Fully implemented

Scale to classify the importance level

0	1	2	3	4
Will not improve performance	Potential to slightly improve performance	Potential to improve performance	Potential to significantly improve performance	Crucial to stay in business

Figure 5, Two scales have been used to classify the maturity and importance of each use-case

3. When the use-cases had been assessed for all studied companies, a matrix was developed for each of the use-cases. The two assessed scales maturity and importance represented one axis each in the matrix, see Figure 6. Each matrix included a maturity-importance level of the studied use-case for each company. This matrix was developed in order to provide data for the analysis of the Industry 4.0 maturity of the Swedish industry.

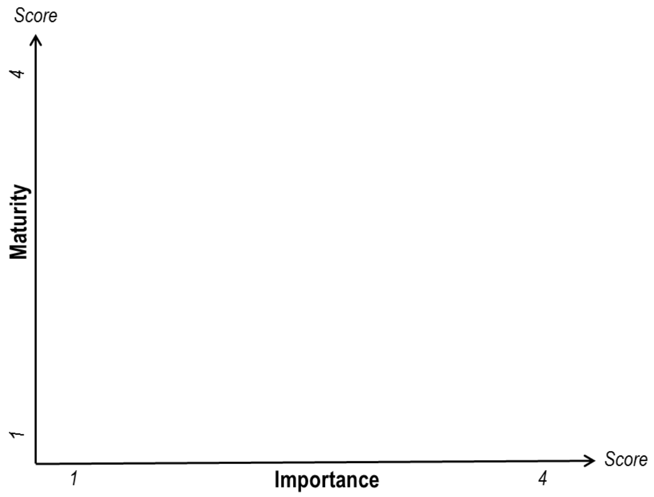

Figure 6, Matrix to visualize the maturity and importance of the use-cases

4. A total score for the Industry 4.0 implementation level was calculated for each company, see Figure 7. The total score for a company was calculated by adding the maturity score of each of the twelve use-cases. This was done in order to see patterns for the Industry 4.0 maturity of the Swedish industry.

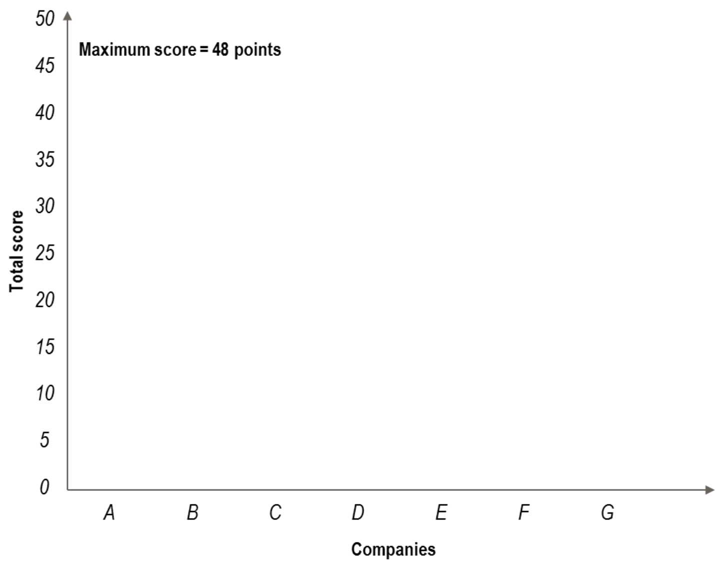

Figure 7, Chart used to plot the implementation score for each company

5. Finally, the empirical findings were analyzed. An average score was calculated for each use-case based on the scores of each company. The average score of each use-case was then plotted into a matrix with the same axis as Figure 6 including all use-cases. This was done to identify patterns for the use-cases. The hypothesis was that the maturity might be higher for some use-cases, and that it might be possible to find industry patterns for what use-cases that are most respective less advanced in the Swedish industry. Several other hypotheses were also tested to find correlations, for example the correlation between existence of strategy and high maturity implementation level.

3.4 Research quality

The criteria need to be considered to evaluate the quality of business research: reliability, replication and validity (Bryman and Bell, 2011). An overview of each criteria is presented below, followed by a description of how the criteria have been considered in this study.

3.4.1 Reliability

Reliability aims to evaluate whether the results of the study are repeatable, i.e. whether the same result will be obtained if repeating the study, using the same measures (Bryman and Bell, 2011). Reliability is particularly important for quantitative research.

All companies were assessed using the same framework and the same questions. If assessing the same companies again, and interviewing the same persons, the result would be the same why the study is considered reliable.

The selection of interviewees has an important role in the reliability of this study. The answers will differ depending on the interviewee's position in the company, and the result will not be trustworthy if selecting interviewees with roles not connected to the researched topic. This why selected interviewees need to have good insight in strategical questions as well as the production, where the Industry 4.0 use-cases are applied. Since similar types of role was selected from each company, the assessments of the different companies are comparable.

This multiple case study assesses the Industry 4.0 maturity of companies at a certain point in time. If measuring the maturity at a later point in time the companies may have developed, why the result cannot be expected to be the same and why the research would not be considered as replicable. However, this fact offers an opportunity of assessing the same companies at a later point in time, using the same method, to conclude on the development over time.

3.4.2 Replicability

Replicability is closely connected to the criterion reliability. The criterion evaluates whether the findings of a research are replicable by someone else (Bryman and Bell, 2011). To enable someone else to replicate the study it is important that the researcher describes the research process in detail. Replication may be desired if the findings are questioned.

The research is replicable in the sense that the research process, participating companies and the literature framework are described in detail. All evaluation criteria in the framework are thoroughly presented, and the full interview guide is included in this report.

Due to the many different definitions of Industry 4.0, it becomes very important to clearly describe on what literature basis the study has been conducted. The literature framework has been clearly described, and a clear definition of Industry 4.0 in this study has been presented.

3.4.3 Validity

Validity aims to evaluate the correctitude of the conclusions generated from the research findings (Bryman and Bell, 2011). The criterion validity includes both external and internal validity. External relates to the possibility to generalize the results. Internal relates to the correctitude of the conclusions (Bryman and Bell, 2011) and whether the right concepts have been studied for the given purpose (Wallén, 1993).

The limitations of the research, in terms of time and resources, allowed for interviews with eleven companies. This is considered sufficient to argue that the conclusion of the research, the companies' general maturity of Industry 4.0, is possible to generalize. The same conclusion, that maturity is low within Swedish manufacturing companies, should hence be the same if selecting other companies with the same selection criteria. However, the research does not claim to conclude on the Industry 4.0 maturity of any specific Industry, but only for the Industry as whole. Noteworthy is that the framework is applicable on all companies, regardless if the company have knowledge of Industry 4.0 or not. This is a major contribution, since the assessment is based on the situation of all companies, not only those possessing knowledge of the concepts.

The internal validity of the research is considered high since a clear definition of the concept Industry 4.0 was developed and used in a framework when assessing the companies. The framework is extensive and is by the researcher argued to include all important application areas of Industry 4.0, necessary to assess the maturity of Industry 4.0 in manufacturing. A few application areas have however been disregarded due to their low degree of usage within manufacturing and time limitations of interviews.

4 FINDINGS

This chapter is divided into two sections. In the first section, findings from the literature study are summarized and presented. In the second section, the empirical findings from the company interviews are presented.

4.1 Theoretical findings

The findings from the literature study are presented in this section. First, a findings regarding different Industry 4.0 definitions, frameworks and existing maturity models are summarized and concluded. Lastely, the twelve selected use-cases constituting the framework of the study are presented and elaborated upon to give the reader an understanding of the framework used in the research.

4.1.1 Summary Industry 4.0 definitions and frameworks

From the literature, it can be concluded that there is no clear definition of Industry 4.0. Some authors have tried to reach a consensus, for example Hermann et al (2016) by deriving four design principles of Industry 4.0 or Qin et al (2016) by creating a categorical framework for Industry 4.0 applications. However, there efforts should rather be seen as a first effort to reach a common understanding of the definition and the scope of Industry 4.0 rather than the final definition that the academia has agreed upon.

Since no clear definition or framework exist, an aggregated view of the different Industry 4.0 views will be applied. In this study, the following interpretation of Industry 4.0 has been used:

> *Industry 4.0 is a development mainly in two directions: increasing intelligence in manufacturing systems and increasing automation. A successful transformation towards Industry 4.0 requires proper development in both directions. To create a more intelligent and automated production, so called cyber-physical systems will be developed. A cyber physical system is a system where the physical world feeds data to the virtual world that analyzes, monitor and controls the physical units. The integration of new information and communication technologies will play a major role in this development.*

4.1.2 Summary existing maturity models

Based on the literature review performed by Schumacher et al (2016), it can be concluded that there exist only a few maturity models today. Also, the lack of details regarding the existing models make it hard to compare and validate these models. To solve this problem, a model has been developed by Schumacher et al (2016) that offers the necessary transparency. The developed model requires basic knowledge of Industry 4.0 concepts from the respondents.

In this study, it is assumed that all companies are not familiar with Industry 4.0. Hence, the model developed by Schumacher et al (2016) is not applicable. To only include companies with prior knowledge of Industry 4.0 would not give a representative result since they are expected to be more mature than the average company. The conclusion is that a new maturity model must be developed.

Even though Schumacher et al’s model cannot be used as a whole, elements from the model are applicable and useful. The main learning from the model is that an Industry 4.0 maturity model should not only focus on technical aspects, but also on other organizational dimensions such as strategy and leadership. The model must also concretize the abstract concepts of Industry 4.0 to enable an interview and assessment of companies' current state.

4.1.3 Synthesis of Industry 4.0 framework

In this section, the framework used in the study is explained. The selected use-cases are derived from descriptions of Industry 4.0 scenarios and applications found in different publications. In total, 12 different use-cases have been selected. The use-cases are presented and further described below:

1. **Smart assistance systems**

To cope with the increasing complexity and speed in manufacturing, smart assistance systems will become an important part of Industry 4.0 in manufacturing. The assistance systems can be applied in various functions, for example to provide assembly operators with standard operating procedures, technicians with service and maintenance instructions, or as a decision support for inspectors to judge quality defects. The information is provided automatically to the operators. Different technologies can provide the information, such as television screens, smart glasses or tablets.

2. **Predictive maintenance**

The main goal of predictive maintenance is to foresee a breakdown before it occurs. By equipping machines with sensors, the condition of a machine can be monitored and the machine alarm when a threshold is exceeded. The sensors measure for example the power supply, vibrations or heat. If the data is stored over time, big data algorithms can be applied to not only monitor the current condition of the machines, but also to predict future condition of a machine by calculating the current health and expected remaining lifetime.

3. **Smart products**

The smart product realizes a decentralized coordination and control of the production. Parts and products will carry their own process requirements, and the requirements are communicated directly to the machines, operators and other objects. The products will become self-aware, meaning they know their history and remaining steps before they are completed. In relevant cases, the products will control their own way through the manufacturing process by calling for different tasks to be performed.

4. **Additive manufacturing**

3D-printing is the most common form of additive manufacturing, but other methods are also deployed. Additive manufacturing offers a more resource efficient way to produce parts, and it enables new geometries to be produced. To date, additive manufacturing has mostly been deployed for prototyping in product development, but there are various application areas also in manufacturing, for example production of tools for in-house equipment, production of low volume batches, production of new lightweight parts or production of spare parts for aftermarket applications.

5. **Mobile production modules**

Increasing flexibility in the production is one of the often mentioned goals with Industry 4.0. An increasing product mix and ever changing market condition requires agile production.

Mobile production modules offer a way to react to changing requirements and creates a dynamic shop-floor with changeable setup and configurations of machines.

6. Collaborative robots

A collaborative robot can physically interact with humans, meaning that human and robots no longer need to be separated from each other. The robots are sensitive to human behavior, and there is no risk associated with working side by side with the robots. The collaboration between human and robots offers great potential since more low value adding work tasks can be automated. The price level of collaborative robots is lower than a traditional robot. This implies that even production of lower volume batches can profitably be automated.

7. Autonomous material handling

Autonomous material handling refers to automated and autonomous internal logistics. AGVs and automatic warehouse systems will be increasingly deployed, which is a way to further automate the manufacturing processes.

8. Full material transparency

New sensor technologies enable that all material can be identified and localized in the factory, not only in the warehouses but also the material stored line side or material on different carriers. Different technologies are available, such as bar codes, QR codes or RFID tags. Full material transparency is increasingly crucial due to higher requirements on traceability. It is also a prerequisite for autonomous material handling.

9. Real-time performance management

As stated by several authors, information important to monitor and control processes must be provided in real-time. In this study, real-time performance management is equivalent to collecting and processing production KPIs in real time, and the KPI must be visualized for operators on shop-floor or production control. Various types of KPIs can be measured such as Overall Equipment Efficiency (OEE), output, and planned versus actual produced orders.

10. Virtual reality and simulation

Applications of virtual reality and simulation is expected to be increasingly deployed. The applications will be used for introduction of new products, to simulate material flow, factory designs, design reviews, etcetera. The main benefit is that it offers a cheaper and faster way of working, since the number of physical experiments can be reduced.

11. Self-optimizing machines

By utilizing big data analytics and artificial intelligence (AI) machines will be able to self-optimize. A perquisite is that machines are equipped with sensors and that vast amounts of historical data is stored. The machines can optimize themselves based on different predefined criteria, for example shortest lead-time or lowest cost.

12. Integrated suppliers

The suppliers must be integrated to achieve the horizontal integration, and different systems must communicate with each other. Solutions using Electronical Data Interchange (EDI) are applied for this purpose.

4.2 Empirical findings

This section presents the empirical findings from company interviews. First, findings from the general questions are presented. Second, the findings from the questions related to the use-cases are presented.

4.2.1 Findings from Answers to General Questions

In this section, empirical findings from the general questions in the framework is presented.

4.2.1.1 Impact of Industry 4.0 in their industry

To capture the current impression of Industry 4.0, it is interesting to investigate the expected impact of Industry 4.0. It will also measure if there is a sense of urgency and awareness of the topic.

Question asked: *How do you think Industry 4.0 will affect manufacturing in your industry?*

Due to the many diverse answers from the interviews, no quantification of the answers was possible. Instead, the answers have been qualitatively judged. A selection of answers is presented below:

> *”A must to be competitive in the future”*
>
> *“Positive development for all manufacturing companies”*
>
> *”Great potential to make production more efficient”*
>
> *“Will help us meet the increasing demand for individualized products”*
>
> *“Can help us enable new business models”*

Common for all interviewees is that they believe that Industry 4.0 will have a positive impact on their industry. As seen from the answers above, the expected impact differs. Some companies believe that the concepts of Industry 4.0 will help in making the operations more efficient. Some companies believe that the impact will be even bigger, and that totally new business models will emerge. One company believe that improved operations based on Industry 4.0 will help them increase the attractiveness to the customers. By targeting more flexible processes, they can respond to the shorter product life-cycles of today. This will enable them to launch a new selection of products in stores within shorter time intervals than today.

Based on the reasoning above, and the answers during interviews, it can be concluded that there is a perception among companies that Industry 4.0 will have a positive impact on manufacturing.

4.2.1.2 Priority of Industry 4.0

From Schumacher et al (2016) model it was concluded that more factors than the implementation level of different technologies must be measured in order to determine the maturity level. Therefore, the companies have been asked about what priority questions related to Industry 4.0 have in their companies. The priority is an indicator of the management’s attention and commitment to the topic, since high priority implies high investments and willingness for change.

Question asked: *What priority has the implementation of Industry 4.0 in your company?*

The researcher has done a qualitative judgement based on the answers from the interviews. The companies have been classified in 4 groups, ranging from *Top priority* to *Low priority*. The result in shown in **Figure 8**.

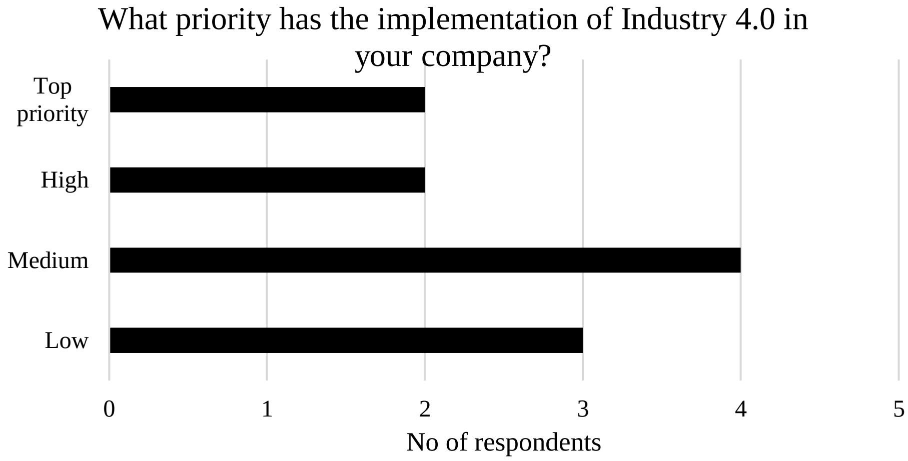

Figure 8, Priority of Industry 4.0 implementation

It was found that the priority of implementing Industry 4.0 is rather low. 64% of the companies (7/11=64%) put the implementation of Industry 4.0 as a low or medium priority, and 36% of the companies (4/11=36%) give Industry 4.0 a top or a high priority.

Many companies stated that specific technical solutions often are highly prioritized when they appear as a solution to a problem. However, the overall priority is lacking. Several interviewees have also stated that they as individual person put high priority on the topic, but the companywide priority is still very low. One mentioned reason for this is that people find it hard to convince the management team to make the necessary investments. There is a challenge to convince the management teams since the promised benefits of Industry 4.0 are often very difficult to quantify.

Two companies put the implementation of Industry 4.0 as the top priority for future competitiveness. Characterizing for these companies is a strong sense of urgency; they are feeling that they most radically improve their performance to stay competitive in the future. Both these companies also mention that Industry 4.0 can help in keeping production in Sweden instead of off-shoring production to other countries. Keeping production in Sweden, or in other high-wage countries, means keeping production closer to the major markets implying several benefits. Another common thing for the two companies is that they in early initiatives have managed to show successful result in terms of economic benefits. This have made it easier to get more investments from the management team.

Two companies put the implementation of Industry 4.0 as a high priority. These companies believe in the benefits offered, but they rather see it as one out of several things that can help them and have just started their Industry 4.0 initiatives.

4.2.1.3 Industry 4.0 strategy

Another aspect related to the Industry 4.0 maturity that have been examined is the existence of strategies for the implementation of Industry 4.0.

Question asked: *Do you have a strategy for implementing Industry 4.0?*

After the interviews, the answers have been categorized by the interviewer. Four different categories have been identified. The first category, *Explicit strategy for Industry 4.0*, includes answers such "*we have a strategy to achieve the smart plant*" or "*we have a five-year plan for Industry 4.0 in our factory*". Common for both companies in this category is that they explicitly have addressed Industry 4.0 or corresponding initiative in their factory, with the overall goal to achieve the three dimensions of integration. The second group, *Industry 4.0 elements embedded in general manufacturing strategy*, includes companies that have stated that they have addressed specific elements of Industry 4.0, but they have not explicitly mentioned it is an Industry 4.0 initiative. Instead, they have considered the elements to be part of their general manufacturing strategy. The third group, *Draft of strategy*, includes one company that have started to discuss and drafted a strategy for Industry 4.0, but so far no decision has been made whether to execute the strategy. The fourth category, *No strategy*, include companies that do not have an explicit strategy, nor have they a plan or roadmap for elements of Industry 4.0.

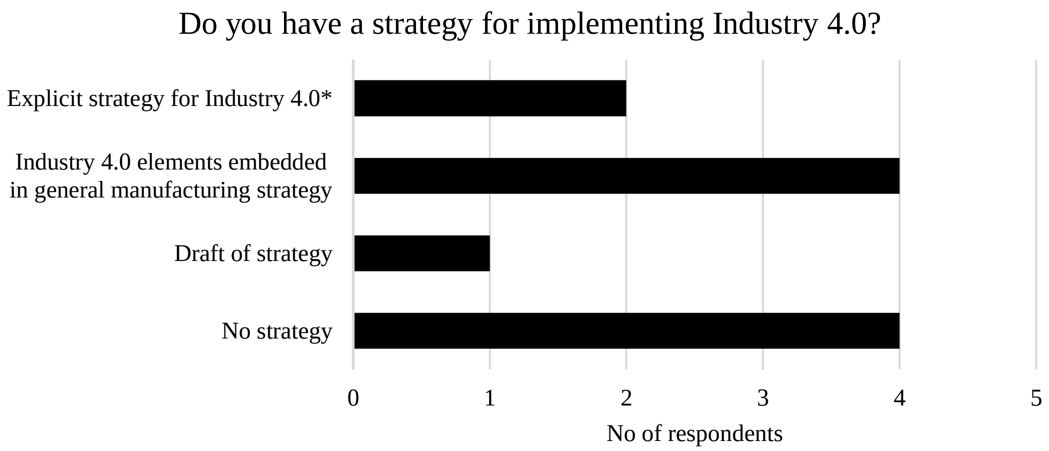

Figure 9, Distribution of companies on the four different groups of Industry 4.0 strategy

As can be seen in Figure 9, the companies are at different levels when it comes to having a strategy for implementing Industry 4.0. Four of the studied companies do not have a strategy. Out of the companies having a strategy, most have embedded elements in their general manufacturing strategy but they are lacking the holistic Industry 4.0 approach.

4.2.2 Maturity and importance of Industry 4.0 use-cases

In order to investigate which of the Industry 4.0 use-cases that are most advanced, an assessment was done of the maturity and importance of each use-case. Also, the total implementation score for each company was determined to find trends and patterns of what companies that are most advanced.

4.2.2.1 Implementation level and importance of each use-case

The maturity and importance were assessed for each use-case in all studied company. Both the maturity and the importance scales ranged from zero to four, were four represents the highest maturity/importance and zero the lowest. The result was plotted in twelve matrices (one for each use-case), and each matrix contains the importance-maturity scores of all companies in the study.

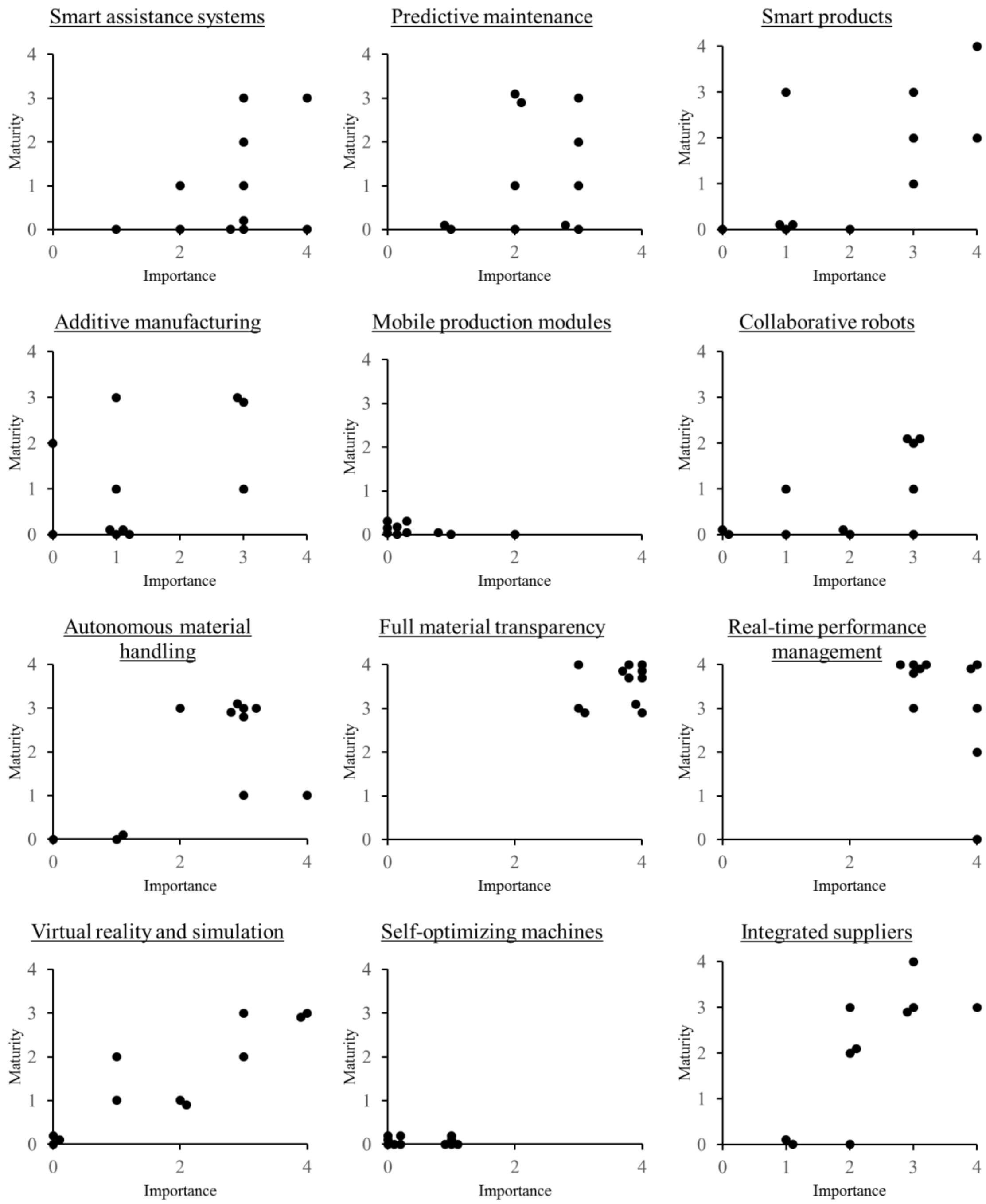

Figure 10, Matrix with maturity and importance for the use-cases. Each dot in the chart represents one company

As can be seen in Figure 10, there is a big difference between the maturity and importance of the different use-cases. For some use-cases, both the maturity and the importance seem to be very high, for example *Real-time performance management* and *Full material transperancy*. For *Self-optimizing machines* and *Mobile production modules*, the situation is the opposite. These use-cases have very low level of implementation for all companies, and no company considers the use-cases to be important to implement. For the rest of the use-cases, the result differs between the companies; there are examples of a companies that have reached a high level of implementation, but there are also companies that have not started to implement the use-case. The perceived importance of the use-cases also differs between the companies, where some companies believe that the use-case has great potential to imporve the performance and some companies do not believe that the use-case would have no or very small impact on their performance.

The results for each use-case is further ellaborated on below.

Smart assistance systems – Most companies believe this to be important, and several companies have stated that wish to implement this. However, the current implementation level is low, since the systems require extensive efforts for set up and maintenance.

Companies that have implemented smart assistance systems have experienced several benefits in terms of more efficient communication to operators. Current applications provide operators with standard operating procedures. One company mentioned that after implementation of a system providing SOP to assembly operators, more application areas were discovered and the system have been extended to also include communication between operators.

There are various technologies and systems available on the market, for instance tv-screens, smart glasses and mobile devices. Several companies have mentioned that they are testing and exploring different technologies at the moment. A recurring comment from interviewees is that a benefit with smart glasses compare to the other technologies is that they free up the hands of the operators. However, the technology of smart glasses is considered as immature and not ready to be implemented.

Interviewees see potential of various application areas for smart assistance systems. As mentioned, it can be used to provide SOP to operators, but also for material picking information, maintenance and service instructions.

Predictive maintenance – At this stage, advanced companies are applying condition based maintenance, meaning that sensors monitor critical components in machines. When a threshold is surpassed, for instance vibration, heat or power usage, the machine alarms. One manager of service and maintenance for an OEM expressed that mechanical defects can easily be detected today, but it is impossible to predict problems in electrical components.

Companies with high level of implementation are companies where up-time has high impact on the productivity. By applying predictive maintenance, the up time can be increased by a few percent.

Many companies are applying preventive maintenance, and they consider it to be good enough. However, the companies that have previously applied preventive maintenance and now have implemented predictive maintenance have experienced benefits in terms of reduced costs since previously they performed redundant services.

Smart products – the result for this use-case is very diverse. A vague correlation indicates that companies with high product mix consider this use-case to be important and have started to implement it.

In production, smart products are expected to enable manufacturing of customized products while maintaining a high-degree of automation. The product unique requirements are communicated directly to the machines without involvement of operators.

It also leads to a decentralized control of the production. An example of this the plans of a company who are planning to let the products call for instructions themselves, and partially control their own manufacturing process. The calls can be for example “take me to this station” or “perform this task on me now”.

Different technologies for the communication is applied, for instance RFID and QR-codes. One company has recently invested in a laser printing that will engrave a QR-code on the product with the purpose of identifying the product and enabling product-to-machine communication.

One interviewee mentioned that they want to have smart products in order to reach production of batch-size one, but the challenge is that it requires very short or no set-up times. Otherwise, it will become counterproductive.

Additive manufacturing – additive manufacturing is not yet applied in mass production. One company is using additive manufacturing technology to produce large components in their serial production, but in very low volumes. Other companies see potential application areas in production of spare parts to after market, it would reduce stocks and the need to save tools for production of the spare parts. Currently, the most common area for additive manufacturing is 3D-printing of tools and parts for inhouse machines. It could be for example to produce a sparepart to remove the leadtime for ordering a new part or for continuous development of machines. Speed, material restrictions and unknown material properties are the biggest blockers for additive manufacturing.

Noteworthy is that the most common area of application for 3D-printing is rapid protptyping in product development. It has not been inlcuded in this study since it focuses only on manufacturing processes.

Additive manufacturing is believed to have great potential to create totally new and complex geometries, geometries that are not possible to make with traditional manufacturing technologies. But it is only for low volumes, no company see additive manufacturing as feasible for mass production of high volumes in the next five years.

Mobile production modules – No company have mobile production modules today, the manufacturing lines are very static. Many large machines cannot be moved due to size and requirements on precision. It is also easier to let the material take alternative routes instead of reorganizing the lines. A different strategy is often applied, with the goal of enabling many different types or variants of a product on the same line instead of changing the lines.

Therefor, in general this use-case is not considered as important to implement. One company sees some potential in having smaller tools on production line mobile. It would enable the workstations on the line to be balanced differently from day to day based on the product mix.

Even though mobile production modules are not considered as important, other types of modularity have been discussed during interviews. For example, two companies have plans to break the lines and one company is working with modular machines to cope with the shorter product life-cycles.

Collaborative robots – One of the studied companies have a collaborative robot in production, and two companies have pilot projects running. From these numbers it can be concluded that this very new technology is still not widely applied in the industry. When discussing the topic with companies, many of the interviewees expect that the applications will be rapidly growing during the next years, as soon as the technology matures and can be proven by succesful cases.

Front-runners are companies with high degree of manual work, e.g. assembly operations. This comes naturally since these are the companies with the highes potential to increased productivity, since the labor cost can be reduces by automating the assembly processes. The most advanced application are assembly operations of smaller parts, less than 0,5 kg. This since the robots cannot perform task with larger forces, and also that safety matters appear if the robot handle larger products since they can hurt the operators.

Collaborative robots are mentioned as one way to further automate production. The robots will not replace traditional robots and manual work in total, instead companies see it as a complement to these way of working. Several benefits with collaborative robots are mentioned, in addition to reduced cost. The robots are very flexible, since they are smaller and easier to program than a conventional robot. This enables many new applications. An example of an application is that the robot can be placed on a wagon, and the robot becomes a mobile resources in the production that can easily be moved based on the demand of the day. Also the low price for the robots enable lower volume batches to be profitably automated.

Autonomous material handling – Many companies are applying AGVs for inhouse transportation. The use of AGVs are expected to increase due to new technology in steering systems, e.g. radar or laser steering. This will increase the flexibility in the system.

A main driver for using autonomous material handling is reduced cost. Several companies mention that AGVs have potential to significatnly reduce cost due to lower labor cost. In many cases, companies have been good at automating single process steps. Now, autonomous material handling has the potential to take the development one step further, and automate the entire flow.

Automatic warehouse system is another part of autonomous material handling. However, all companies do not like this application. The advocates think that it has potential to increase flexibility and reduce cost, while the opponents think that the systems becomes less flexible and sensitive for disruptions. In general, companies have moved reduced the amount of these applications. Many new types of applications are also expected to emerge with the new technology, for examples applications where the material comes to the picker instead of vice versa.

Full material transparency – All companies are to some extent working on this use-case, and all companies have made progress. Full material transparency is considered important to have control of and understand processes. It is also a prerequisite for autonomous material handlling.

Today, the most most common application is to have a barcode on the material och carrier. The barcode is scanned by the operator and the systems updates automatically. A few applications have been notices where there is a RFID tag placed in the carrier. The benefit of RFID, or any other sensor, is that the information can be transferred automatically, even with limited sight. However, the choice of technology is not seen as a matter. Instead, the major question is in what processes that it should be applied.

For some of the studied companies, legal requirements have driven the development of this use-case. Due to different restrictions companies must be able to trace the products in all of their processes.

The most advanced companies in this regard, i.e. the ones that have achieved full material transperancy in the factory, are now investigating how to extend this information flow outside the boundaries of the factory. One example is to be able to track the deleveries from the supplier, and being able to know exactly where the material is and when it is expected to be delivered.

Real-time performance management – Most companies have some kind of real-time performance management, and it is the second most advanced use-cases. It is important in order to understand processes and detect deviations in an early state.

Current applications of real-time performance management measure one machine or one process. The Information is often visualized on screens in production, and in some cases even accesible remotely on for example phone apps.

All companies believe this is important, and it will most likely become even more important since everything is expected to happen faster in the future. In some cases it is requested to have more integrated inforamtion. Today, information chains are divided per department, and the sourcing organization may for example have information that is important but not accesible for the production organization. Also, integrated systems enables to get more complex information such as economic aspects for follow up and controlling.

A challenge related to this use-case is knowing what inforamtion to have in real-time, what information that really makes a difference. It is no use in having all information in real-time. On the contrary, too much information can even make decisioning more complex.

Virtual reality and simulation – One of the use-cases with highest variation between companies. A couple of companies, with highly complex production processes, believe that differetn types of simulation will be crucial in order to survive as a company in the future.

The importance of simulation will also become increasingly important since the production systems become more complex. It makes it difficult for operators to overview the processes. Simulation can also be an aid in decision making, since it is difficult to understand how a decision in one process will impact the entire value chain. Also, some companies are struggling with shorter product life cycle which forces them to have more frequent introductions of new products on the market. They see different types of simulations as necessary in order to reduce the time to market and to reduce the development cost by reducing the amount of prototypes.

Today, simulation and virutal reality is used for simualting material flow and designing new factory layouts. Virtual reality is used for design reviews for example. A couple of pilot projects have also been conducted where ergonomic aspects have been simulated on a workstation.

Companie are also starting to make plans for how to create a digital twin of the real factory in the cyber space. Several benefits are mentioned to this. First, by having a updated digital twin of the factory, a simulation can be conducted at disruptions in the production, for example delayed delivery from supplier. A simulation can easily provide the best possible alternative production plan based on the current situation in terms of material and orders. Also, by having a digital twin adjustments in the factory can be tested and verified virtually before they are implemented in reality.

Self-optimizing machines – No company is working on this use-case today, and it is not considered as important within the next 5 years.

There are mainly two reasons explaining the low maturity. First, the technology is not mature enough. Self-optimizing machines or machine learning are based on artificial intelligence, and the technology is not ready. Even though many companies are watching the development, none of them are willing to drive the development. Second, the companies do not consider to be ready to implement this, there are many other lower hanging fruit to address prior to this use-case.

Integrated suppliers – A trend can be seen here that the maturity is higher for companies with more complex information flows. Also a trend that companies that are producing to customer order have higher maturity due to higher demands on shorter leadtimes.

Even though different EDI solutions have been available for many years now, the technique is still not widley applied. One reason could be that many companies are experiencing problem with the integration of data, that even though they have EDI solutions in place they still have to make many manual adjustments.

The prospect of this use-case is that it will become more important in the future due to requirements on shorter leadtimes, higher flexibility and customized products. Additionally first tier suppliers believe this will be a prerequisite to deliver to OEMs in the future, since they will increase their demands on material transperancy in the entire supply chain.

4.2.2.2 Implementation level of Industry 4.0

In addition to investigate the maturity of the different use-cases, it is also interesting to investigate the maturity of different companies. Therefore, for each company a total score of the implementation level of Industry 4.0 was calculated. The calculations were done through addition of the maturity scores for each assessed use-case.

$$Total\ score = (Score\ usecase\ 1) + (Score\ usecase\ 2) + \cdots + (Score\ usecase\ 12)$$

The maximum possible score in the study is 48 (12 use-cases and maximum score of 4 for each use-case).

Figure 11 presents the total score for each studied company.

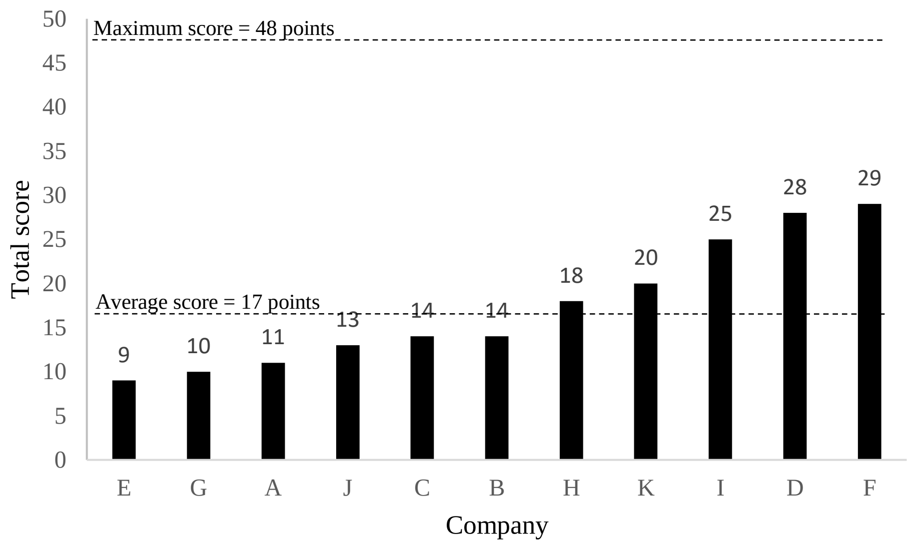

Figure 11, Total implementation score for each company

It can be seen from the figure above that the implementation level of the use-cases is low. The average implementation score is 17 points out of the maximum 48 points. It is also a big difference in score between the company with highest score (29 points) and the company with the lowest score (9 points). Also, the company with the highest implementation score has not yet reached full implementation of the use-cases, they are rather just partially implemented.

ANALYSIS

This chapter will analyze the maturity of Industry 4.0 in the Swedish industry. First the implementation level within Swedish companies will be analyzed, then the relationship between the existence of strategy and high implementation level of Industry 4.0 will be analyzed. Lastly, the different use-cases will be analyzed with the aim to identify industry patterns and especially advanced use-cases.

4.3 Implementation level of Industry 4.0

Based on Figure 11 in section 4.2.2.2, following conclusions can be drawn:

- Most companies have a low Industry 4.0 implementation level. The average implementation level is only to 35% of the maximum level (17/48=0,35). More than half of included companies have a lower implementation level than the average level of interviewed companies.
- The company with the highest implementation level has reached a level of 60% (29/48=0,6). This implies that the company still has a long way to go to finalize its Industry 4.0 implementation, but that it is well underway.
- The implementation level of Industry 4.0 varies greatly between the companies. The company with the highest implementation level has a 220% higher score (29/9-1=2,2) than the company with the lowest implementation level.

The conclusion is that the implementation level of Industry 4.0 is low in the Swedish industry. It can be concluded that the implementation level differs greatly between companies. However, even though the company with the highest implementation level (total score: 60 points) is well underway to implement Industry 4.0, there is still a long way to go to finalize the implementation.

4.4 Relation between revenue and maturity

An attempt has been made to investigate what companies that are the most advanced. One hypothesis is that the size of the company, in terms of revenue, could be one explaining factor. In order to examine a correlation, the implementation level was plotted against the size of the company, see Figure 12.

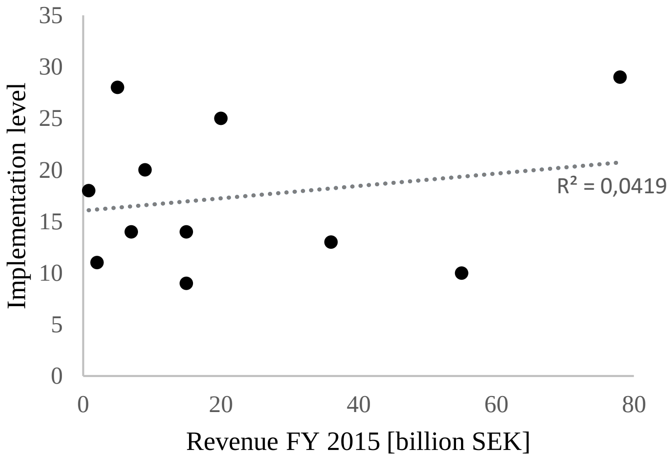

Figure 12, Diagram showing the correlation between implementation level and revenue

There is no clear relation between revenue and Industry 4.0 implementation level. The R^2-value is 0,0419 which is very low, indicating that no correlation exists between revenue and implementation level. Both large and small companies are among the forefront runners in Industry 4.0 maturity, with high scores of the implementation level.

Even though a relationship would have been possible to identify, the sample size (i.e. number of studied companies) is not considered large enough to draw a conclusion on the relationship between the implementation level and the revenue. It could however give an important identification and provide knowledge for further research of the topic.

This finding contrasts with Sommer's (2015) conclusion. Sommer conclude that in general, the readiness and capability to adapt Industry 4.0 is heavily dependent on the company size. An reason for the different conclusions could be that Sommer conducted his study on SME's. In this study, only large companies (i.e. an annual revenue of <0,5 billion EUR) have been included. If also smaller companies would have been included, identification of such a correlation might have been possible to identify.

4.5 Priority and strategy versus implementation level of Industry 4.0

As have been showed in section 4.2 Empirical findings, the priority of the implementation of Industry 4.0 is low and many companies lack a strategy for the implementation. The percentage of companies that give the Industry 4.0 low or medium priority amount to 64%, see Figure 8. Further, as can be seen in Figure 9, almost half of the studied companies lack an implementation strategy for Industry 4.0. These facts might be two explaining factors why the Industry 4.0 implementation level of Swedish companies is low.

Figure 13 has been developed to examine the correlation between implementation level and existence of strategy. The companies have been segmented based on the existence of a strategy. For each segment, the average implementation score for has been calculated for the companies in the segment. The result is presented in Figure 13.

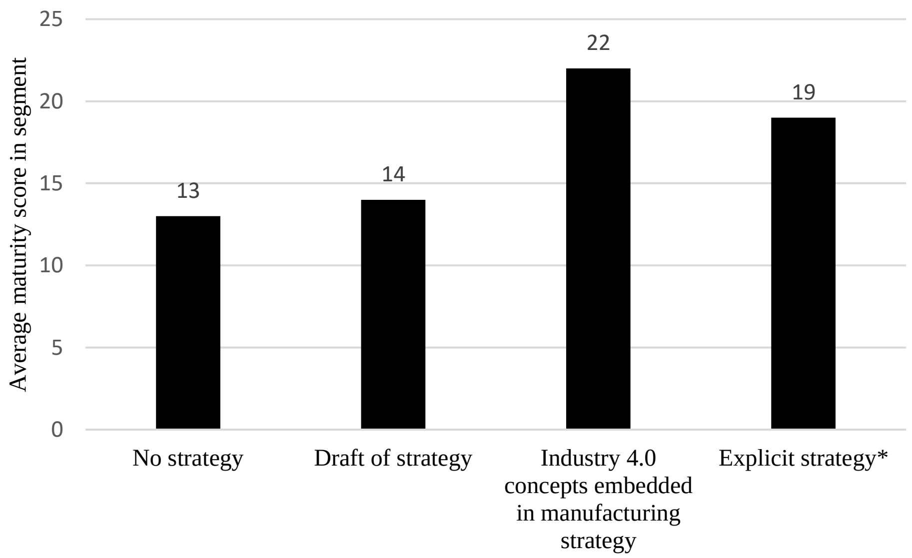

Figure 13, Average implementation score for companies based on the existence of strategy

The Industry 4.0 maturity is highest for the companies that have a strategy for Industry 4.0. The average score for companies with an explicit Industry 4.0 strategy is 19, and the average score for companies that have Industry 4.0 concepts embedded in the general manufacturing strategy is 22. If compared to the companies with no strategy, or draft of strategy, their average score is 13 respectively 14.

From the figures, it can be concluded that the companies that have a strategy also have higher implementation score. This result indicates that it is possible today to start implementing Industry 4.0 by putting priority on the topic and create strategies.

4.6 Mismatch between belief in positive effects and priority given to the topic

The findings in section *4.2.1.1 Impact of Industry 4.0 in their industry* show that all companies believe that Industry 4.0 will have a significant and positive impact in their industries. Even though they believe in the benefits of Industry 4.0, Figure 8 shows that the companies have not yet started to prioritize the topic. This emphasis on a great gap between the expectations of Industry 4.0 and the actual actions/priority taken to implement Industry 4.0. This gap can be explained by that the topic is still quite new, and that companies have high expectations but that they have still not understood enough to be able to see how their company specifically could profit from the new technology.

The conclusion is that there seems to be a mismatch between the belief in positive effects from Industry 4.0 and the efforts that are put into realizing such benefits.

4.7 Most advanced use-cases

The use-cases that are most mature and important vary between the studied companies. To identify the use-cases with the highest maturity and importance for the whole industry, an average maturity-importance level was calculated for each of the use-cases. The average level of each use-case was plotted into a join figure, to enable industry comparison of all use-cases, see Figure 14. The use-cases that have a high maturity and high importance are found in the upper right corner of the figure.

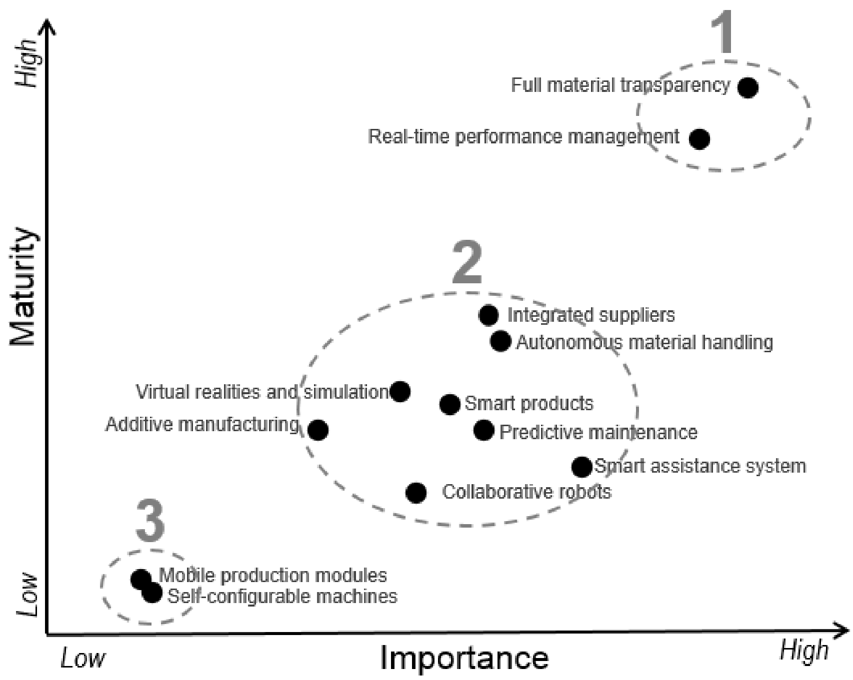

Figure 14, Comparison of maturity and importance of different use-cases

From the graph, it is found that the use-cases can be grouped into three distinct groups. Below, the characteristics of each group are elaborated:

- **Group 1**: Use-cases in this group are considered as being important by all companies. All companies have also to some extent started to work on the use-case.
- **Group 2**: The maturity and importance of the use-cases in this group vary greatly between studied companies.
- **Group 3**: Use-cases in this group are not important, nor mature for any of the companies.

The use-cases in *Group 1* are considered crucial for all companies in order to understand and control processes. This is the reason to why they are the most advanced. Since only large companies have been included in the study, the production processes are so complex that this is a prerequisite for managing and controlling the processes. For full material transparency, legal requirement is also a major driver. For real-time performance management, the main driver is increased operational efficiency by faster reactions and notifications of deviations.

The maturity and importance of the use-cases in *Group 2* differ between the companies. This why the industry average maturity and importance is medium. Based on the findings it is believed that some use-cases are more relevant for some companies to focus on. Companies should hence not necessarily focus on all the use-cases in Group 2, but only those believed most relevant for their business.

The use-cases in *Group 3* have a low maturity and a low importance. The use-cases are believed as not feasible to implement due to immature technology and mobility constraints on machines. Even though many companies are watching the development, primarily in self-optimizing machines, the use-cases are not expected to be implemented in the industry during the next 5-10 years. Only minor applications of mobile-production modules might be implemented, for example of different tools in the production line.

Noteworthy is the linear correlation between perceived importance and maturity. This indicates that the use-cases to some extent are able to implement if the right priority is put to the use-case. Prior to the study it was expected that some of the use-cases would be very important, even though the implementation level is low. However, none of those kinds of blockers have been found.

5 CONCLUSIONS

This chapter aims to conclude the study and answer the research questions. The chapter is outlined after the two research questions.

5.1 Definition of Industry 4.0

This section answer the first research question:

> *What concepts and ideas constitute Industry 4.0 in manufacturing, and how can Industry 4.0 be described in a framework?*

Based on the literature review, it can be concluded that Industry 4.0 is a novel topic and no clear and distinct definition has not yet been provided. A few attempts of definitions exist, for example in the form of design principles or a categorical framework for Industry 4.0 applications. However, these frameworks should rather be considered as first attempts to reach a consensus rather than the final definition. Even though a distinct and clear definition is lacking, numerous visions of the future Industry 4.0 state are available in different forms of publications.

Since no clear definition or framework exist, a joint picture of based on the input from several sources have been compiled. The following description of Industry 4.0 in manufacturing has been used as the basis for this study:

> *Industry 4.0 is a development mainly in two directions: increasing intelligence in manufacturing systems and increasing automation. A successful transformation towards Industry 4.0 requires proper development in both directions. To create a more intelligent and automated production, so called cyber-physical systems will be developed. A cyber physical system is a system where the physical world feeds data to the virtual world that analyzes, monitor and controls the physical units. The integration of new information and communication technologies will play a major role in this development.*

There are a few existing Industry 4.0 maturity models available, but none of these models is applicable for this study. All but one of the models are not trustworthy. The last one requires the interviewee to have knowledge of Industry 4.0, why it is considered as not suitable in this study. Therefore, a new maturity model has been developed. The maturity model consists of two parts. One part with question of more general character. One part consisting of different Industry 4.0 technological applications in manufacturing, so called use-cases.

The general dimensions measured in the study are: priority, strategy, and perceived impact of Industry 4.0 on the industry.

Twelve use-cases have been selected to measure the technological implementation. The use-cases are often appearing in different visions and they are representative for Industry 4.0 in manufacturing. The twelve use-cases measured in the study is: *Smart assistance systems, Predictive maintenance, Smart products, Additive manufacturing, Mobile production modules, Collaborative robots, Autonomous material handling, Full material transparency, Real-time performance management, Virtual manufacturing, Self-optimizing machines* and *Integrated suppliers*. The use-cases have been classified on a scale ranging from *No plans to implement* through *Fully implemented*.

5.2 Industry 4.0 maturity in Swedish manufacturing

This section answer the second research question:

What is the current Industry 4.0 maturity level in the Swedish industry?

To conclude on the Industry 4.0 maturity of the Swedish industry, several findings must be interweaved: the belief of the positive impact of Industry 4.0, the priority given to the topic, the existence of an implementation strategy and the implementation level of use-cases.

From the findings in the study, it can be concluded that the general Industry 4.0 maturity level in Swedish industry is low. This since it has been concluded that the implementation level of Industry 4.0 is low in the Swedish industry as whole. Also, the implementation level differs greatly between companies. No correlation of what companies that are the most advanced has been found. One hypothesis tested is that the size of the company, in terms of revenue, should correlate. However, no such correlation has been found, maybe depending on that only large companies have been included in the study.

Further it has been concluded that there seems to be a mismatch between the belief in positive effects from Industry 4.0 and the efforts that are put into realizing such benefits. This is paradoxical but not surprising given that the finding that almost half of the companies lack a strategy for Industry 4.0 implementation. Without a strategy describing e.g. in what areas to implement Industry 4.0, in what purposes and how, the level of implementation of Industry 4.0 in a company will only gradually increase. It is also paradoxical that more than 60% of the companies do not prioritize the topic more than low to medium (in a scale ranging between low-medium-high-top).

It is not only the Industry 4.0 maturity level on a high level that has been analyzed for the Swedish industry, but also the maturity level of the individual use-cases. The Industry 4.0 maturity does not only vary between the companies, but also for the different use-cases. There are twelve use-cases investigated in this study. For two of these, the maturity level is very high whilst the rest are either medium or very low in maturity. The highly mature use-cases are those that are very important for the companies, used to understand and control the business. The use-cases with a medium maturity are those that are of medium importance for the companies in general, but where importance varies greatly between different firms. The conclusion that can be drawn for the use-cases with medium maturity and importance is that companies need to select which ones of these use-cases to implement, depending on their importance and suitability for their business and goals.

Even though the Industry 4.0 maturity level for the industry as whole is low, there are some companies that are front runners. The company with the highest implementation level has implemented Industry 4.0 to 75% (given 36 out of 48 points), and is hence well underway to implement Industry 4.0, but still has a long way to go to finalize the implementation.

6 DISCUSSION

In this chapter the study and the results are discussed. First, the methodology is discussed. In the second section, the findings and conclusions are discussed.

6.1 Methodology

First, it will be reflected if the chosen methodology is a proper way to measure the Industry 4.0 maturity level in the Swedish industry.

The study uses the implementation level of the different technological applications as one indicator to the Industry 4.0 maturity level. It does not say anything about the efficiency and performance of the applications. This means that a company that have implemented a use-case poorly will get the same maturity level as a company with excellent performance of the same use-case.

One major contribution of the framework to measure the Industry 4.0 maturity is that it allows to examine all companies, not only the companies that have prior knowledge of Industry 4.0. By including all companies in the study, a more accurate result has been achieved and the findings can be generalized for the entire industry.

The result of the study might have been affected by the fact that the interviewees hold different positions in the companies. The interviewees may have answered the questions from their personal perspective rather than from their company's perspective. This is more likely for interviewees with a lower insight in the company's strategical questions, e.g. interviewees that are not part of the group management but only of the management of a specific site. Such a representative may not be aware of the global priorities or strategies, why the findings showing upon that the reasons of the low implementation level may be lack of strategy and low prioritization may be misleading.

The vagueness and uncertainty of the term Industry 4.0 makes it difficult to determine the maturity level. Some researchers stress that Industry 4.0 is rather an evolutionary process than a revolution, due to the evolutionary development of technologies. It becomes very difficult to determine the limit of the use-cases that the companies must exceed to fulfill Industry 4.0 standard, and be considered as implemented in the assessment. The author has tried to clearly describe the limits used in this study to avoid any misunderstandings.

This study measure the maturity within the manufacturing function in the companies. The goal of the Industry 4.0 vision is to achieve integration in three different dimensions: vertical, horizontal and end-to-end engineering. The implication of this is that an implementation of Industry 4.0 is more than just the implementation of different technological solutions. The study has compensated for this by also examine more dimensions than just the technological implementation, such as existence of strategy, priority given to the topic, urgency, etcetera. But Industry 4.0 also serves to integrate different functions in a company. This is something that the study does not consider, since the scope was limited to manufacturing and manufacturing processes so it might have missed a part of the companywide perspective.

6.2 Findings and conclusions

This study has developed a framework for examining the Industry 4.0 maturity in Swedish manufacturing, and the result showed that the current maturity level is low.

One explaining factor to the low maturity is that the topic is very novel, and the knowledge level is very low. 6 out of 11 interviewees stated that they had no or very little knowledge of the topic prior to the interviews. It has also been showed that people believe in the benefits of Industry 4.0 and digitalization. This indicates that even though many people are aware of the benefits of digitalization, perhaps from own experiences in other consumer products, they are still not familiar of how the same technologies can be applied in manufacturing.

The findings also show that the priority given to the topic is low. One reason for this could be that companies are still struggling with everyday issues, firefighting and problems that must be addressed in the short term. In those cases, the companies do not have time to focus on long term improvement strategies, and Industry 4.0 becomes just a utopia. This implies that a company must achieve a certain degree of readiness before it is suitable to start implementing Industry 4.0. Many companies still have other work to do before they can start the implementation.

Another reason why the implementation level is low is that there is a skepticism against new technologies. Even though many companies are aware of the technologies, they do not trust them and think they are immature. It is also difficult to quantify the benefits of the technologies. Several interviewees have mentioned that they know that something is coming and that they must act, but they experience problems in knowing how to quantify the benefits in economic terms.

Many of the companies have also stated that they are working on a selection of the use-cases in this study, but they are lacking a strategy to connect the different initiatives with each other. This could be a problem, since Industry 4.0 will not only affect manufacturing but the entire company’s way of working. An efficient implementation of Industry 4.0 requires cross-functional collaboration in the companies. So at least the manufacturing function must take a holistic approach and integrate different technological initiatives with one another, and preferably also integrate the strategy to the enterprise strategy.

It can also be discussed if the maturity level in Swedish industry is low based on the numbers presented in the findings. The average implementation level score is 17, and the maximum score is 48. The numbers indicate that Industry 4.0 is implemented 1/3. However, this is not the case. To show this, the scales for classification must be considered. The range of the scale is from 0-4 where, 1 is plans to implement and 2 is pilot project/first application in use. Therefore, from 12 use-cases a company can score 17 points from having plans to implement 7 use-cases and have a first application of 5 use-cases. The calculated example show that this is not the same as consider Industry 4.0 as being 1/3 implemented. Hence, the current maturity level is low.

From the literature and visions, it is expected that Industry 4.0 will revolutionized the industry by creating totally different ways of working (urban production, production networks, brokers, environmental aspects) and new business models. However, these seems to still be visionary ideas. Based on the interviews, the major driver for implementing Industry 4.0 is to increase the operational efficiency in the operations. This may be due to the positions of the interviewees, who hold positions related to manufacturing. Just a few of the interviewees have understood the extent of how Industry 4.0 will affect the industry, and have plans to totally innovate the business models. This is closely related to how much knowledge of the concepts.

It is reasonable to expect that the maturity differs between different industries. The sample size in this study is not sufficiently large to draw any conclusions on what industries that are the most advanced.

From the analysis, it is obvious that three clear groups exist. A question appearing is that if the chart could be used as a guideline for smaller companies with lower implementation level, i.e. if companies with very low maturity can learn from more mature companies and implement the use-cases in the same order as they do. The author believes that in general this is the case. The first step should be to gain deeper knowledge and understand the processes before any other technological applications can be applied. This recommendation is based on the statement that only with mature and stable processes, Industry 4.0 concepts can enhance the operational efficiency. If the processes are not stable and mature, the first step must be to control the processes. It is also important to emphasize that the use-cases from the second group should carefully be selected, since this is where the different situations of the companies mostly should be considered, since this is where companies can differentiate among the competitors.

It can be concluded that if a company wants to start implementing Industry 4.0, the first step must be to put priority on the topic and develop a strategy, since the findings in this study indicates that companies with a strategy also have higher implementation level.

The conclusions from this study is important both for practioners and for researchers. For practioners, the study can provide insights of how mature other companies are, and what they consider as important. The framework might also assist some people in making the abstract term Industry 4.0 into something more concrete, and provide a tool that can help starting to think about different applications. The study has also emphasized the importance of having a structured approach and a strategy for the implementation. It has also showed that it is possible to start working today, and that company sized does not matter. For researcher, the maturity in Swedish industry is important to know in order to be able to know where to put the focus and what research questions to prioritize. The literature study has showed the novelty of the topic, and there are many more areas that are interesting to further investigate. This study has given rise to numerous questions to further investigate, these questions are explained in the next chapter.

7 SUGGESTIONS FOR FUTURE RESEARCH

This study has answered the main question "*What is the current Industry 4.0 maturity level in the Swedish industry?"*. The conclusion was that the maturity is low, but that the maturity varies between different companies and for different use-cases. This give rise to multiple wonderings, which are suggested to be investigated in in future research. Below, some of the potential future research areas are listed, each with suggestion of research questions to be investigated:

7.1 Benefits with Industry 4.0

The study has showed that even though the general implementation level is low, companies have started to implement different use-cases and that the implementation in some cases is well underway. This give raise to several questions regarding the benefits of Industry 4.0.

- What benefits have been realized by implemented Industry 4.0 use-cases
- Are there any use-cases that are more beneficial than other?
- Are there specific industries that have a greater potential to benefit from Industry 4.0?
- Are there use-cases that are more/less beneficial for specific industries?

7.2 Prioritization of Industry 4.0 implementation

This study has identified the importance of having strategy for the implementation of Industry 4.0. However, there is much more to learn for a successful implementation.

- Is the implementation of Industry 4.0 to be realized in a specific order?
- How should companies prioritize what Industry 4.0 use-cases to implement?
- How can companies get an increased prioritization of Industry 4.0?
- In what order are the Industry 4.0 use-cases to be implemented to minimize effort and maximize benefits?

7.3 Enablers for an increased Industry 4.0 maturity

Based on the different maturity levels, it is reasonable to believe that some companies are better prepared than other for undertaking an Industry 4.0 implementation. To help practioners in less mature companies, different enablers for an implementation should be investigated.

- Which are the enablers for an increased Industry 4.0 maturity among Swedish companies?
- What needs to be done to release these enablers?

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Appendix A – Interview Guide

General questions

- *How would you describe Industry 4.0?*
- *How do you think Industry 4.0 will affect your industry?*
- *What priority has Industry 4.0 in your company?*
- *Do you have a strategy for implementing Industry 4.0 in your manufacturing?*
- *What is the goal with implementing Industry 4.0?*
- *What are your biggest challenges in the transition towards Industry 4.0?*
- *Based on your experience, how mature would you say that you are in comparison to other large manufacturers?*
- *Do you know how your competitors are acting?*

Questions related to Use-cases

1. Smart assistance systems
    - *Do you have any that automatically provides operators with assembly instructions?*
    - *Do you have any system that provides workers with instructions for service or maintenance?*
2. Predictive maintenance
    - *Can you, based on sensor data from machines predict a machine breakdown?*
3. Smart products
    - *Do the products carry their own process requirements which they communicate directly to the machines?*
    - *Can the products coordinate their own way through the production?*
4. Additive manufacturing
    - *Do you use 3D-printing or other additive manufacturing technologies in production?*
5. Mobile production modules
    - *Do you have any mobile production modules that can easily be rearranged on the shop-floor?*
6. Collaborative robots
    - *Do you have any collaborative robots, i.e. robots that are working side-by-side with humans?*
7. Autonomous material handling
    - *Do you have any systems for autonomous material handling, i.e. AGVs or automatic warehouse systems?*

- *How are the systems controlled?*

8. Transparent material flow
   - *Can all parts, products and material be identified and localized during the entire flow in the factory?*
   - *How do you utilize the collected information?*
9. Real-time performance management
   - *Do you measure any production KPIs in real-time?*
   - *Is the information accessible for different decision makers and operators?*
10. Virtual realities and simulation
    - *Do you use any virtual reality applications?*
    - *Do you use any simulation software? What is the purpose of the simulations?*
11. Self-optimizing machines
    - *Do you have any machines that can self-optimize based on some predefined criteria?*
12. Integrated suppliers
    - *Are inventory levels and demand digital available for the suppliers?*
    - *Do you transfer orders to suppliers automatically?*