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IoT-Technological Maturity Model Development and Maturity Assessment of Norwegian Manufacturing Companies

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Preface

This master degree thesis represents the final part of the education program Master of Science in Logistics, at Molde University College (MUC), and has been written during the Winter and Spring, 2016. The master thesis has been a part of the research project "Manufacturing Network 4.0", consisting of actors from both academia and the industry, initiated in Molde in 2015.

We are sincerely thankful for having received the opportunity to take part in the project. It has been a great motivation and a valuable experience.

The master thesis has been completed with the main guidance by our supervisor Bjørn Jæger, Associate professor at MUC. We would like to sincerely thank Bjørn for valuable guidance, support, motivation, discussion, comments and advices, during this research. In addition, we would like to thank Lise Lillebrygfjeld Halse, Associate professor at MUC and leader of the "Manufacturing Network 4.0" project, for valuable guidance and advices, regarding our master thesis. Finally, we would also like to thank representatives at Møreforskning, who have been a part of the "Manufacturing Network 4.0" project for valuable advices.

Furthermore, we would like to give a sincerely thanks to the representatives from the four case companies, Ekornes ASA, Pipelife Surnadal, Brunvoll AS and Kleven Verft, which have provided us with the information needed for the case study. We appreciate the possibility to visit all the case companies, and their willingness for us to conduct interviews and providing us with additional information during the project.

Lastly, we would like to thank our family and friends for their support during the work with the master thesis this semester.

Molde 24.05.2016

Agnethe Bø and Heidi Wiig

Summary

At this present time, a trend that is increasingly finding its way into our daily lives, as well as into industrial production, is that of “Internet of Things (IoT)”, an emerging global Internet based information platform, which has gained popular attention in the last few years (Weyer et al., 2015). The emerging technology surrounding the concept of IoT is increasingly being considered to provide new problem solutions in manufacturing, logistics and Supply Chain Management (SCM), and furthermore commonly envisioned to become the fourth industrial revolution (Porter and Heppelmann, 2015). Consequently, with the rapid development of new technologies, manufacturing companies needs to keep up with the technological developments in order to avoid lagging behind.

The aim of this master thesis has been to develop an IoT-Technological Maturity Model (IoTTMM) that can be utilized for assessment of companies` current technology status tied to the concept of “Internet of Things (IoT)”, and which further could serve as a foundation for providing companies in the manufacturing industry with recommendations for future technology adoption and development. This master thesis has been a part of the project “Manufacturing Network 4.0”, and an in-depth case study of four Norwegian manufacturing companies was carried out to develop and refine the IoTTMM in the development phase. The final model was then used for an assessment of each of the companies` current technology status with regard to the concept of IoT. The exploratory research method was applied in this master thesis, as the purpose was to investigate a research area that is under-researched.

The concluding remarks of this master thesis is that the developed IoTTMM reflects a presumed evolution path of the use of IoT-technologies through eight maturity levels, for manufacturing companies. The model may serve as a tool for management supporting the adoption and development of technologies tied to the concept of IoT. In addition, the model can be a reference frame for assessing companies` technological maturity level tied to the concept of IoT as well as being a benchmarked against other manufacturing companies, and for implementing an approach for technology improvements. Specifically for this research, the technological maturity level of the Norwegian manufacturing companies gives knowledge of the current technology level of these companies, as well as providing a direction path for technology adoption towards the concept of IoT and the envisioned fourth industrial revolution.

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ATO	Assemble-to-Order
CMM	Capability Maturity Model
CNC	Computer Numerical Control
CRM	Customer Relationship Management
CODP	Customer Order Decupling Point
ETO	Engineer-to-Order
ERP	Enterprise Resource Planning
FMS	Flexible Manufacturing System
ICT	Information and Communication Technology
IoT	Internet of Things
IoTTMAT	IoT-Technological Maturity Assessment Test
IoTTMM	IoT-Technological Maturity Model
IP	Internet Protocol
IS	Information Sharing
IT	Information Technology
M2M	Machine-to-Machine
MES	Manufacturing Execution System
MTO	Make-to-Order
MTS	Make-to-Stock
MRP	Material Requirements Planning
MUC	Molde University College
PDA	Personal Digital Assistant
PLC	Programmable Logical Controller
RFID	Radio Frequency Identification
SC	Supply Chain
SCM	Supply Chain Management
SCMAT	Supply Chain Maturity Assessment Test
TRL	Technology Readiness Level
QR	Quick Response

1.0 Introduction

In this chapter, the background, the research problem and the motivation, as well as the structure and limitations surrounding our master thesis, will be outlined.

In the present business environment, characterized by globalization and increasing market competition, companies worldwide have realized that it is not sufficient to improve efficiencies within their companies, in order to survive. Instead, companies have realized that their supply chains have to become competitive. Because of the complex nature of supply chains, where various activities, encompassing multiple functions and organizations, are performed, substantial efforts needs to be taken to enhance the performance of the supply chain. In this context, efficient cooperation among supply chain partners is considered to be an essentially issue to both create and maintain companies competitive advantages. Furthermore, the companies which are able to achieve efficient cooperation with their supply chain partners, are considered to attain improvements with regard to increased product quality and flexibility, reduced lead times and overall costs (Marinagi et al., 2014; Patterson et al., 2003).

The traditional way of managing supply chains has changed dramatically over the last decades, prospering from paper-dominated order processing systems, and Face-to-Face management, to a paperless order processing with the use of Enterprise Resource Planning (ERP) systems and other information technologies for managing supply chains. According to Ketikidis et al. (2008), the currently most used information systems, and intended to be implemented in the future, are Enterprise Resource Planning (ERP), Warehouse Management System (WMS), Material Requirements Planning (MRP), and Barcoding. In addition, more advanced technologies as Radio Frequency Identification (RFID), global positioning satellite and wireless and mobile technology have more recently been applied in manufacturing, service, logistics and distributions, and retail (Ketikidis et al., 2008).

1.1 Background

Information Technology (IT) is considered being a key enabler for building competitive advantages throughout the supply chain. The current diversity of IT, offers supply chain actors a vast amount of tools and techniques, that can be utilized to enable efficient information flow management, which in turn can improve the overall supply chain performance (Marinagi et al., 2014). Information and Communication Technologies (ICT)

is a combination of electronics, telecommunications, software, networks and the integration of information media, all of which plays an increasing role in businesses, industry and the economy as a whole. (Apulu and Latham, 2011; Farhadi et al., 2012). The use of ICT is considered as a prerequisite for the effective control of today`s complex supply chains (Fasanghari et al., 2008). Furthermore, the use of ICT has provided a digital platform for integration, cooperation, new ways of storing, sharing, processing, and exchanging information, both within companies, and with customers, suppliers and other partners. ICT further enables a company to manage information and knowledge databases, for making effective managerial decisions and strengthen the competitive advantage (Luo and Bu, 2015). In the last decade, the world has experienced a fundamental transformation through the emergence of ICT. The size of computers has continuously become smaller, leading them to vanish inside virtually all of the technical devices we are surrounded with. Beyond this, things and objects (e.g. technical devices, cars, cameras, etc.) communicates via the worldwide network: the Internet. This trend is increasingly finding its way into our daily lives, as well as into industrial production. Furthermore, this trend has resulted in the introduction of the concept of “Internet of Things” (Weyer et al., 2015).
“Internet of things (IoT)”, also referred to as the “Internet of Everything” or the “Industrial Internet”, is an emerging global Internet based information platform, which has gained popular attention in the last few years. According to Zhang et al. (2016), the widespread deployment of Wireless Sensor Networks (WSN), embedded computing and sensors has fostered the rise of an “Industrial Internet of Things”. Furthermore, mentioned by Lee and Lee (2015), “IoT is a new technology paradigm envisioned as a global network of machines and devices capable of interacting with each other”. The concept came into the spotlight in the year 2005, when the International Telecommunications Union published their first report, and has further become a key concept since the year 2009 (Porter and Heppelmann, 2015; Sehgal, 2014).

Gartner (2014) forecasts that the IoT will reach 26 billion units by the year of 2020, an increase from 0.9 billion in 2009, and it is considered that this will affect and increase the information available to supply chain partners, and how the supply chain operates. McKinsey Global Institute has developed a research to calculate potential value from IoT technology. Since the concept of IoT is quite new, their assessment is only potential estimations of economic value. A bottom-up approach was used in order to measure the impact of IoT from the perspective of the whole value chain (businesses, customers, suppliers and governments). Their results indicates that the estimated economic impact of IoT-applications could range from $3.9 trillion to $11 trillion per year in 2025, where the declining costs of technology will have an impact. From their estimations, factories are likely to have the greatest potential impact from IoT, with as much as $3.7 trillion per year.

Currently, the concept of IoT is recognized as one of the most important areas of future technology, which is gaining vast attention from a wide range of industries. IoT is commonly being envisioned to becoming the 4th industrial revolution, based on technology innovations, smart materials and enhanced manufacturing operations. According to Haddara and Elragal (2015), the connection of smart devices through the Internet are envisioned to transform how factories operate, buildings are managed, and vehicles are maintained and operated, and potentially result in an almost limitless number of new industrial processes, functions and services. The emerging technology is increasingly being considered to provide new problem solutions in manufacturing, logistics and Supply Chain Management (SCM) (Porter and Heppelmann, 2015).

The envisioned 4th revolution currently comprises different initiatives, entitled “Industry 4.0” (Germany), “Smart Manufacturing” (USA), the “Industrial Internet”, “Factories of the Future” and “Cyber-Physical Systems”, where machines and systems are networked together to completely automate and optimize production (Porter and Heppelmann, 2015). In Norway, the attention around the vision of the 4th revolution and the concept of IoT led to the initiation of the project “Manufacturing Network 4.0” in Molde in 2015.
The vision of the four-year long “Manufacturing Network 4.0” project is to create a knowledge platform between research and industry that enables Norwegian manufacturers to expand the concept of Industry 4.0 from the factory level and towards the integration of global manufacturing networks. A central part of the project is the idea of an increased, long-term competitiveness for the Norwegian manufacturing industry.
The research project will be carried out in a co-operation between Molde University College and the Norwegian University of Science and Technology (NTNU Trondheim), with partners as Møre Research Centre (Møreforskning) and SINTEF[1], and other interests

[1] A broadly based, multidisciplinary research institute with international expertise in technology, medicine and social sciences

as IKuben[2], and the manufacturing companies Ekornes ASA, Pipelife Norway AS, Kleven Maritime AS and Brunvoll AS. The project was introduced to us by our supervisor, and we found it to be very interesting to perform a research and write our master thesis as a part of the "Manufacturing Network 4.0" project.

1.2 Research problem

Manufacturers worldwide are facing increasingly complex and competitive environments when performing their businesses. As trade barriers crumbles and less developed countries are entering the competitive marketplace, organizations are more than ever before confronting a greater amount of competitors, which are able to introduce new products and services faster and cheaper (Patterson et al. 2003). The international competition and global sourcing of production are considered to be two of the major forces, which in these days creates demand for a new excellence level in manufacturing.

According to Patterson et al. (2003), organizations must be able to innovate at the global frontier and commercialize a stream of new products and processes which leads to a shift in the technology frontier, progressing as fast as their rivals' catches up. Consequently, a challenge for manufacturers is the escalating technological change, as exemplified by 73% of Fortune 500 leaders, saying that keeping up with technological change is their biggest challenge (Jæger et al., 2016). Furthermore, innovation is becoming increasingly important for organizations and regarded as a competitive necessary for future success. New technologies, and the emergence of the IoT, may have a significant impact on the direction of innovation efforts (PwC, 2013).

The technology developments manufacturers are currently facing creates challenges that needs to be addressed. Meaning that the manufacturers for instance need to decide on what technologies to invest in, when to invest, and how to implement them while maintaining production. Much of the existing research surrounding the concept of IoT and its related technologies has focused on the expected gains, and problem solutions for supply chains. In order to be able to keep up with technological changes, manufacturing companies need a tool in order to assess their current technological level with regard to the concept of IoT. Which further can contribute to give an understandable overview of the path towards the envisioned optimal level with regard to IoT in the future, and serve as a guidance for future

[2] A cluster of 27 innovative and internationally-oriented companies in Møre and Romsdal in the field of propulsion, lifting and petroleum, operations, on an ETO-basis

technological developments. Searching through the existing literature, a suitable tool that was identified for this purpose was the maturity model. A maturity model describes the development of an entity over time, through different development stages (Wendler, 2012). Several maturity models have been developed within different domains through time. However, to our knowledge, there are currently no models that can serve the purpose of assessing the technological maturity level tied to the concept of IoT for manufacturing companies.

Maturity models have through time been an important instrument, and commonly been applied, to assess organizations current stage within specific areas, in order to come up with improvements and provide guidelines in order to reach higher maturity levels (Poeppelbuss et al., 2011; Wendler, 2012).

Pressures to gain and remain competitive advantage, finding ways of reducing costs, improving quality, reducing time-to-market, etc. are surrounding manufacturing companies. Maturity models have been developed in this setting, in order to assist companies to overcome such pressures and to achieve goals and strategies. Therefore, with the rapid development of new technologies, there is a need for a research on how to develop a model for assessing manufacturing companies` current technological level with regard to the concept of IoT.

Based on the background previously outlined and the properties surrounding maturity models, the first aim of our master thesis is to develop an IoT-Technological Maturity Model (IoTTMM) with the foundation of the existing research and literature surrounding maturity models and the concept of IoT. In compliance with this, and to guide our research, the research question related to the master thesis first aim is:

RQ1: How can an IoT-Technological Maturity Model for assessment of Norwegian Manufacturing Companies be developed?

After having developed the IoTTMM, the model should be tested in a real-life setting. Since the model will be developed based on the existing literature, there is no assurance that the model can be used directly into a practical situation, and therefore testing the model is considered to be required to confirm its validity and applicability. Furthermore, since this master thesis is one of the first deliveries in the project "Manufacturing Network 4.0", the participating manufacturing companies and other project participants proposed two initial needs. The first need was an assessment of the companies` current technology status with regard to the concept of IoT, and the second need was to receive recommendations on how to develop their current technology status. In compliance with this, and to guide our research, the research questions related to the master thesis next aim is:

RQ 2: What is the current IoT-Technological Maturity Model level for the four selected case companies?
RQ 2.1: How can the case companies develop in order to reach a higher level on the IoT-Technological Maturity Model?

1.2.1 Limitations

Since the research field surrounding the concept of IoT is a vast research area, we will delimitate us in this research to focus on the technology surrounding the concept of IoT and the technology adoption in manufacturing companies. Meaning that potential consequences on for instance business processes, smart materials, and smart manufacturing, etc., are out of scope for the development of the IoTTMM, as well as this master thesis.

1.3 Motivation

With regard to the industry and business environment, the impact of IoT are seen to become most visible in fields such as automation and industrial manufacturing, logistics, business process management, and intelligent transportation of goods and people (Atzori et al., 2010).
Furthermore, many manufacturers have started to realize that their conventional automation systems are standing in the way for the ability to respond rapidly to the changing market conditions and demands, and to be able to compete effectively in the global economy. Therefore, there are currently an increasing focus on technology development, with for instance use of robots and 3D printing to enhance productivity in manufacturing.
The concept of IoT further encompasses the connection of industrial equipment and systems, to communicate with each other, and share data with IT-systems and people. The availability of data and information is considered being a crucial factor for enabling an efficient value chain. Whereas the sharing of this information regarded to be the heart of

supply chain collaboration, and an important advantage for supply chain partners in order to survive in the current global competition characterized by uncertainty.
In this context, technology is identified as an important and enabling factor for the concept of IoT and the envisioned next revolution, which correspondingly contributed to catch our attention and interest. Furthermore, our motivation originated from the impression that the concept can currently be seen to be new for many companies and industries, in addition to be of a diffuse character, since it is still only a future vision. This impression was strengthened after participating on a workshop in the project “Manufacturing Network 4.0”. Furthermore, searching through the literature it was found to be lacking a model for assessing what technology level the companies currently are on with regard to IoT. Therefore, we found it motivating to develop an IoTTMM for assessing manufacturing companies technology level tied to the concept of IoT. We believe that developing an IoTTMM is needed for both the industry and the academia, due to a two-folded reason. The need occurs because of a business problem, since the companies in the project needed to address their currently technology level and achieve recommendations for further technology development, as well as acquiring a more thorough understanding of the concept of IoT. In addition, the need occurs because of a literature gap, since there was found to be lacking a maturity model tied to the concept of IoT.

We hope that our master thesis can give valuable insights to different parties:

- For the project “Manufacturing Network 4.0”, the participating companies can get knowledge on where they are in the path towards the concept of IoT, In addition, the model can provide them with recommendations for future directions of technological development. Further, other stakeholders in the project can get an insight of the companies` current technology adoption and status.
- For manufacturing companies in Norway, as well as other countries, the model can contribute in the similar way as described for the project above, namely contribute to provide knowledge of their technology level regarding the concept of IoT, and recommendations for future directions of technological developments.
- For Molde University College, the model can serve as a basic overview for the path towards the concept of IoT, and be an initial point for further development and research.
- For the authors, to broaden our knowledge around maturity models and the concept of IoT, as well as contribute to an understanding of the importance of technology for

manufacturing and SCM. In addition, the case study and company visits will increase our learning and understanding of business environments by blending theory and practice, which we will bring with us into our future jobs.

Lastly, from the point of view of our personal motivation to explore this topic in our master thesis, we truly believe that the concept of IoT will influence industries and SCM in the future, and that companies needs to keep up with technology developments in order to avoid lagging behind. We also find it motivating to get an insight of the importance and impact of technology on manufacturing, which for instance can contribute to enable less costly production. This can further lead to reduce the trend of outsourcing, and contribute to backsourcing and increased work employment for countries.

1.4 Structure

In the next chapter, chapter 2, characteristics around the manufacturing industry will be presented, before the literature review is outlined in chapter 3. In chapter 4, the methodology surrounding this master thesis will be presented. In chapter 5, the essential literature background supporting the development of the IoTTMM will be briefly outlined, before the development of the IoTTMM is presented. In chapter 6, the empirical study, which mainly entails the presentation of the case study findings and companies‘ assessment, will be presented. The chapter ends with the recommendations for further technology development for the companies. In chapter 7, the discussion of the findings in the master thesis is presented, before the conclusion of the master thesis is presented in chapter 8.

2.0 Manufacturing Industry

In this chapter, a brief history of former industrial revolutions, the Norwegian Manufacturing Industry, and different production strategies for manufacturing companies, will be outlined.

2.1 Brief history introduction – the industrial revolutions

Throughout the history, the world has experienced multiple industrial revolutions, which commonly has been divided into three separate industrial revolutions. In the 18th century, the steam engine represented the technological breakthrough, which led to the 1st industrial revolution. By the utilization of the steam energy, machines were introduced into production, which led to the general mechanization of the economy. Starting in the late 19th century, the 2nd revolution emerged with the utilization of electric power which led to the introduction of mass production. The beginning of the 3rd industrial revolution, can be dated to the mid-1990s, centering around the change from analogue- to digital-technology, using electronics and information technology to further automate production. The industrial revolutions brought with them several different effects and influenced in areas as economic growth and income, working conditions, urbanization, child labor, public health, the role of women, the emerging middle class, etc.

A contemporary view is that one are facing the next industrial revolution, which is driven by extreme automation and connectivity. Extreme automation is initially expected to expand the range of jobs it is possible to automate from the highly repetitive low-skill jobs to routine medium-skill jobs. Extreme connectivity is expected to enable a more universal, global and close-to-instant communication, giving rise to for instance new business models. A combination of extreme automation and connectivity is envisioned to allow computing systems to control and manage physical processes and respond in “human” ways. Furthermore, a special feature of the envisioned next revolution is the wider implementation of artificial intelligence, e.g. that robots can analyze results and take complex decisions, and adapt conclusions to environmental factors (World Economic Forum, 2016).

2.2 Norwegian Manufacturing Industry

The Norwegian manufacturing industry is standing in front of what is distinguished to become major changes in the years to come, as the manufacturing industry will be further affected by digitization and automation. Furthermore, it is seen that highly advanced processes and operations will characterize the future Norwegian manufacturing industry where technology is seen to have a vital role, which are regarded to be in accordance with the concept of IoT and the envisioned 4th revolution. Consequently, the trend with regard to outsourcing of production to low-cost countries, is about to change, as the foreseen development towards advanced manufacturing will require the capabilities of high-cost countries, as economic strength and high competence. The technological development one are standing above thus reduces the demand for low-cost production. The business challenges will still be based on achieving competitiveness through efficient and responsive manufacturing of high quality products, and it can thus be seen to be important for the Norwegian manufacturing industry to explore and develop in accordance with the future technological developments to be able to stay competitive (Norsk Industri, 2016).
In order to get an impression of the current level of digitalization in the Norwegian manufacturing industry, the organization “Norsk Industri”, conducted a survey in order to map todays production characteristics, e.g. how advanced the produced products are, how advanced the production systems are and how the companies are organized. Their survey revealed that the Norwegian manufacturing companies has started the digital journey, however, the level of digitalization among the surveyed companies are highly varying. Some companies are still mostly dependent on manual work, and others have automated part or all of their production. Robots are mostly applied in production, and less in logistics operations. There is shown to be a large proportion of companies having a Make-to-Order (MTO) or Engineer-to-Order (ETO) production strategy in the survey, which entails that companies are supplying customized products, and therefore an explanation for the low robot density, as these operations are often harder and more complex to automate.

2.3 Production strategies

The literature in operations management and production classifies companies on the basis of four different production strategies: Make-to-Stock (MTS), Assemble-to-Order (ATO), Make-to-Order (MTO) and Engineer-to-Order (ETO) (Soman et al., 2004). A central element in the different production strategies is the Customer Order Decoupling Point

(CODP), which is the point of time where the production changes from being forecast-driven to order-driven (Sjøbakk et al., 2014). In other words, the customer order decoupling point is the point in the material flow where the product is tied to a specific customer order (Olhager, 2010).The four different production strategies entails different characteristics and features for the companies.

Make-to-Stock is characterized by the manufacturing of standard products that are stocked, where customers correspondingly are served from the stock. This production strategy offers a low variety of products, and typically, less expensive products. The companies focus is mainly on forecasting demand, and planning to meet the demand. The main operations are inventory-planning, determination of lot-size[3] and demand forecasting. Assemble-to-Order is characterized by that standard parts and components for a product are finished manufactured, but not assembled. The final assembly is based on a specified customer order, and therefore this production strategy offers a degree of customization for the customers, which can select a products composition from a predefined group of product parts and components. The companies focus is on forecasting demand and planning for the inventory of components, enabling a quick final assembly for the customer order. Make-to-Order is characterized by the manufacturing of products from raw materials or components based on customer orders that has been received and accepted. This production strategy offers a higher variety of customer specific products, and correspondingly, more expensive products. The companies focus is on order execution that entails an attention towards a fast response time, avoidance of order delays, and achieving the shortest lead-time as possible. The main operations are capacity planning, order acceptance or rejection and attaining a high due-date adherence. Engineer-to-Order is characterized by that all production activities, from design to assembly, and in addition the purchasing of required raw materials, are related to a specific customer order. Thus, this production strategy offers a significant degree of customization by unique engineering, which further entails very expensive products. The companies focus is on production planning and control, high product quality, meeting the specific customer demands with flexible design and production in order to handle order changes and adjustments (Hovind, 2012; Sjøbakk et al., 2014; Soman et al., 2004). As mentioned above, Customer Order Decoupling Point is a central issue in the different production strategies, and the figure

[3] The quantity of a product manufactured in a single production run.

below illustrates how the different positions of the Customer Order Decoupling Point contributes to give rise to the different production strategies.

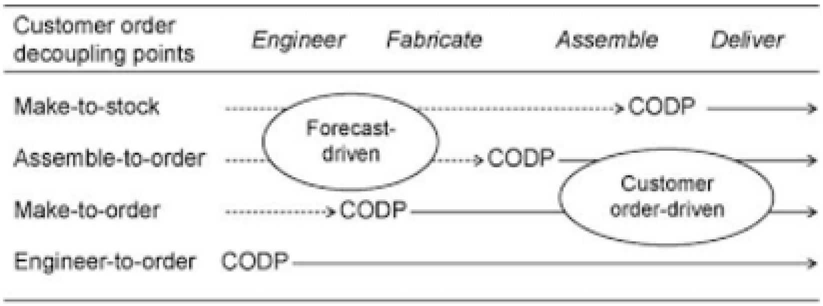

Figure 1: Different production situations and the CODP

(From Olhager, 2010)

As one can see from the figure, the decoupling point for the Make-to-Stock production strategy is located between the assemble and the deliver stage. For the Assemble-to-Order production strategy, the decoupling point is located after the fabricate stage. The decoupling point for the Make-to-Order production strategy is located between the engineering and fabricate stage. Lastly, for the Engineer-to-Order production strategy, the decoupling point is located at the very beginning at the engineering or design stage.

3.0 Literature review

In this chapter, the relevant literature surrounding this research will be presented.

Based on the stated research problems, the main research fields to be combined in this master thesis have been distinguished to be Maturity Models and Internet of Things (IoT).

3.1 Maturity Models

Organizations stands above pressures to gain competitive advantage, retaining their market positions, identifying ways of cutting costs, and improving their product quality. Maturity models have been designed to assess the maturity (i.e. competency, capability, level of sophistication) of a set of selected domain, based on a specific area within an organization, in order to assist in this matter. The domain can for instance be IT-management, project management, or business management (de Bruin et al., 2005). In short, maturity models allow an organization to get its processes and methods evaluated according to management best practices against a set of external benchmarks (Braun, 2015).

Maturity models have their early roots in multistage models, as Maslow`s hierarchy of human needs, and maturity within quality management, introduced by Crosby.
Crosby was the first to introduce the concept of maturity stages and maturity level in his quality management process maturity grid, which categorized best practice with five maturity stages and six measurement categories. This have inspired the later development of maturity models, such as the well known Capability Maturity Model (CMM). Ever since that, the publications on this topic have been increasing, frequently used the structure of the CMM as a template (Poeppelbuss et al., 2011). The Capability Maturity Model (CMM) has been widely adopted in the software industry. However, other issues, as for instance, Enterprise Resource Systems (ERP), technology and knowledge management are becoming increasingly important (Wendler, 2012).

3.1.1 Definition and structure

In general, the term "maturity" can be defined as "the state of being complete, perfect or ready" (Braun, 2015). Wendler (2012), has used the following definition of maturity models, "Maturity models describes the development of an entity over time". The entity can be anything of interest: a human being, an organizational function etc.

Maturity models are conceptual multistage models that outlines a path to maturity, involving a sequence of stages that together form a desired path until maturity is reached. The number of levels varies depending on the maturity model (Wendler, 2012). As there is no "rule" on how many levels a maturity model should have, four criteria`s are proposed for identifying and classifying the required levels; (1) the levels should be theoretically defined, and significantly different from each other, (2) the levels should not be overlapping, in terms of content, (3) no level should be a subcategory of another level and (4) each level should be transferable to an empirical setting (Junttila, 2014). Different degrees of maturity are described as stages or levels, with each level being superior to the previous one (Neff et al., 2013). The bottom level representing the initial stage and the uppermost level, representing the highest possible stage (maturity). The levels represent an anticipated, or desired path towards maturity (Becker et al., 2009). The progress from one level to the other should occur hierarchically (Wendler, 2012). Due to the models nature, maturity models is frequently referred to as stages-of-growth or stage models (Poeppelbuss et al., 2011).

It is observed, that in general, all maturity models share the same way of defining specific elements. These basic elements of maturity models are a number of levels, a descriptor for each level and a summary of the characteristics of each level. However, some variations can be made between maturity models. Further, maturity models can either be developed in a top-down or bottom-up approach. When developing a model using the bottom-up approach, the criteria are developed first and then the definitions are written in compliance with the items. With a top-down approach, the definitions are written first and then the assessment items or criteria are developed to match the definitions (de Bruin et al., 2005).

Maturity models serve as a tool for measuring an entities current position on its path towards maturity. Therefore, it must contain characteristics and criteria`s that needs to be fulfilled in order to reach a particular maturity level (Becker et al., 2009). The criteria`s for assessing the capabilities, can be conditions, processes or applications (Wendler 2012).

3.1.2 Purpose of use of Maturity Models

The purpose of maturity models are considered as being flexible, and they are often distinguished between the maturity of processes, the maturity of objects or technology, but the purpose of its use, can typically be divided into three groups: (1) descriptive, (2) prescriptive and (3) comparative. A purely descriptive maturity model describe changes observed in reality, and the as-is situation, without suggesting improvements. This type of model would be suitable for assessing the current situation without the need for improving the current or as-is situation. A prescriptive model give a guidance on how to improve the maturity. A comparative model serves as a means of benchmarking. Enables the assessed entity to compare itself to other entities, in and across regions. Benchmarking is considered as a way of compare an actual situation with industry specific practices (Braun, 2015; de Bruin et al., 2005; Wendler, 2012).

In addition, maturity models has been provided to be an important instrument and are commonly applied to evaluate an organizations current stage, to come up with improvements, to control the progress, and guidelines in order to reach higher maturity levels (Poeppelbuss et al., 2011; Wendler, 2012).

3.1.3 Criticism

Maturity models have gained a lot of attention from researchers and practitioners. However, the models have also been subject to criticism. As outlined in the previous section, the increasing attention towards maturity models has resulted in a vast amount of new developed models, leading to multiple similar models being published in the same application domain. In addition, the design of the new models are increasingly influenced by existing models (Becker et al., 2009). Literature scholars have counted numerous models in the last years. In contrast to the large number of maturity models developed, the research and documentation on how to develop these models that is theoretically sound, rigorously tested and widely accepted is lacking (de Bruin et al., 2005). Moreover, maturity models have been subject to fundamental criticism, being regarded as models that are oversimplifying reality and lacking an empirical foundation (de Bruin et al., 2005; Neff et al., 2013). According to a literature review conducted by Neff et al. (2013), only a few development procedure models methodologies were encountered. The results suggested that there are two popular methodologies most commonly used among scholar, namely one by de Bruin et al. 2005 and one by Becker et al. 2009.

3.1.4 Previous Maturity Model research

As previously mentioned, maturity models have been widely adopted in the software industry. However, other issues, as for instance, Enterprise Resource Planning (ERP) systems, technology and knowledge management are becoming increasingly important. Poeppelbuss et al. (2011) reviewed 76 articles concerning maturity models in the broad field of information systems (IS). The authors study the maturity models from the perspectives of research, publications and practitioner. The study reveals that the Capability Maturity Model (CMM) is the most dominant foundation of past information system research on maturity models. In addition, their study revealed that theories on the design and adoption of maturity models are rare. Wendler (2012), provided a systematic mapping study of a total of 237 articles, published between 1999 and 2010. The study reveals that maturity model research is dominated by studies in the software engineering field, and most of the studies dealt with development of maturity models, where the issue of validation and evaluation of maturity models are scarce. In addition the research proposed a research cycle that should be completed by every newly adopted maturity model. Most of the articles reviewed had carried out all the three “steps” for maturity models research, however, there was still newly developed maturity models which didn’t complete the third stage, “maturity model validation”. The suitability and usefulness of a model without any application and validation is doubtful. The research cycle is shown in Figure 2 below.

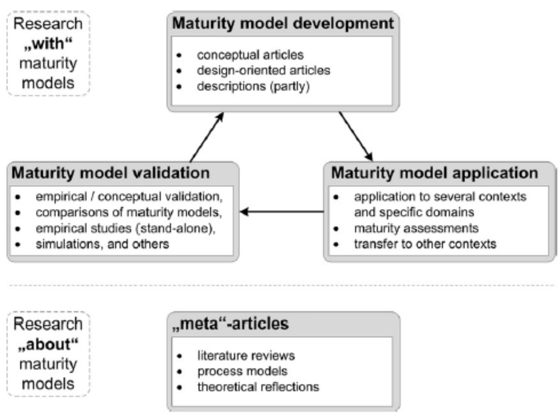

Figure 2: Research cycle

(From Wendler, 2012)

In a research by Becker et al. (2009) it was revealed that hundreds of maturity models for supporting IT-management have been developed. However, the procedures and methods used, have only been documented very sketchily. By using a scientific approach the author has developed a criteria for the development of maturity models. Tarhan et al. (2016) performed a systematic literature review on developed Business Process Management (BPM) maturity models, in order to better understand the state of the research. The authors searched studies between the years 1990 and 2014, and ended up with selecting 61 studies to further research. The study revealed that despite many business process management maturity models were proposed in the last decade, the level of empirical evidence that reveals the validity and usefulness of these models is scarce.
de Bruin et al. (2005) proposed a generic methodology for development of maturity models in various domains, consisting of six phases, (scope, design, populate, test, deploy and maintain) which need to be followed in order. In each phase, a decision need to be addressed. The value of having a generic methodology lies in the ability to develop a model that is generalizable and enables standardization.

3.2 Technology Readiness Level (TRL)

Another well known means of assessing the technology level, is that of "Technology Readiness Level tool". Technology Readiness Levels (TRLs) are a systematic measurement system that supports assessment of the maturity of a particular technology and the consistent comparison of maturity between different types of technology. TRLs have been proved to be effective in communicating the status of new technologies among diverse organizations. TRL was originally developed by NASA[4] to allow more effective assessment of, and communication regarding the maturity of new technologies. The TRL tool is widely used, but is often adapted to the specific needs of an organization (Mankins, 1995). The first developed TRL scale contained only seven levels, today, the scale runs from TRL 1 through TRL 9, where level 1 is the lowest and level 9 is the highest. However, it has been through a lot of modification in previous years. Each technology is evaluated against the parameters or definitions for each level, and is then assigned a TRL rating based on the progress (NASA.gov, 2010). An overview of the TRL scale is shown in Figure 3 below.

[4] The National Aeronautics and Space Administration

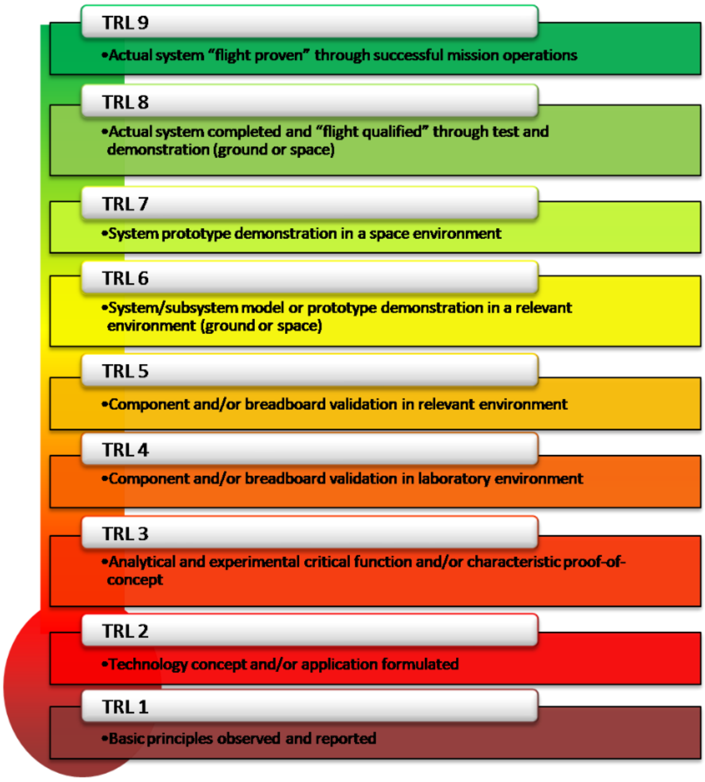

Figure 3: Overview of the TRL scale

(From NASA.gov)

According to Azizian et al. (2009) the TRL scale is only sufficient at a very basic level in evaluating technology readiness, and is considered as inadequate in other areas. Sauser et al. (2006) argues in their research that the TRL scale does not take integration of two technologies into account, when assessing the maturity level. Thus, this can have an impact on implementation of the system, and whether or not it will fail at the integration point. Further, the problem associated with the use of TRL is that is lacking the "how to" guideline when implementing the scale (Nolte et al., 2004). Mahafza (2005), claims that the TRL is not sufficient, because it does not measure how well the technology is performing against a set of criteria. The author further argues that the TRL methodology does not give any indications on whether or not a technology is highly or lowly mature, it only rates the technology against a subjective scale.

3.3 Internet of Things (IoT)

In the next decade, its foreseen that the development of the IoT-concept will dramatically affect and alter manufacturing, energy, agriculture, transportation as well as other industrial sectors of the economy, which collectively account for approximately two-thirds of the global gross domestic product (GDP) (World Economic Forum, 2015). Based on this, there is a strong interest surrounding the concept of IoT from governments, academia, and industries, and there is an increasingly amount of vivacity debates around IoT in the media. Furthermore, since the concept of IoT is still a future vision, and the fact that IoT is expected to have implications in various areas, the research field of IoT is currently characterized by being vast and deficient. A manifold of definitions of IoT is currently traceable within research, which can be seen to testify the strong interest of IoT. However, when browsing through the literature, understanding what the concept of IoT means and the basic ideas behind it is considered being somewhat difficult since the concept has no clear and unison definition. Consequently, the concept of IoT can currently be regarded being characterized by being somewhat fuzzy.

3.3.1 Definitions of Internet of Things (IoT)

IoT is defined by McKinsey Global Institute (2015) "as sensors and actuators connected by networks to computing systems. These systems are able to monitor and/or manage the actions of connected objects and machines". This definition can be seen to be somewhat simple and easily understandable, however, several definitions that can be seen to be more comprehensive have been developed. For instance, Sundmaeker et al. (2010) defines IoT as "a dynamic global network infrastructure, that integrates the physical and the virtual “things” (physical or digital devices capable of being identified by identification numbers, location addresses, etc.) which have identities and virtual personalities and use intelligent interfaces, into an information network". Sehgal et al. (2014) defines IoT as, “Things that have identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environment and user contents”. Mentioned by Vermesan and Friess (2014) “The Internet of Things (IoT) is defined by ITU[5] and IERC[6] as “a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical

[5] International Telecommunications Union
[6] European Research Cluster on the Internet of Things

and virtual "things" have identities, physical attributes and virtual personalities, use intelligent interfaces and are seamlessly integrated into the information network”. Several other definitions are available, but for the purpose of our master thesis, we find this last definition mentioned by Vermesan and Friess (2014) to be the most explaining, and suitable.

We understand the concept of IoT as being a future vision of a global information network infrastructure, where the basic idea is the pervasive presence of various “things” or “objects” surrounding us, such as Radio Frequency Identification (RFID) tags, sensors, actuators, tablets, smart phones, etc. Through specific and unique capabilities, these “things” or “objects” can interact, communicate and cooperate with their surroundings to achieve common benefits and goals. According to Sehgal et al. (2014), IoT is a concept that aims at connecting all the things around us to each other and to the Internet. The term “thing” can range from a washing machine to mobile phone, laptops and computers, which must be able to identify themselves and to communicate with each other. In IoT, “things” are expected to participate in businesses, information and social processes, being able to interact and communicate among themselves and with the environment, by exchanging information. In order to be able to exchange information, all the “things” need standardized formats of electronic labels (Sehgal et al., 2014). Based on this, one can understand that the IoT-infrastructure includes different essential IoT-technologies.

3.3.2 Essential IoT-technologies

According to Atzori et al. (2010), “Actualization of the IoT-concept into the real world is possible through the integration of several technologies”. In their research, Atzori et al. (2010) addresses the integration of several technologies and communication solutions. The research states in similarity with other researches that among the various technologies, some technologies can be designated as being the most essential and relevant technologies with regard to IoT (Atzori et al., 2010; Botta et al., 2016; IEC, 2015; Li et al., 2016; Minerva et al., 2015). According to a research by Lee and Lee (2015), for the deployment of successful IoT-based products and services, five technologies are considered as being central, namely; Radio Frequency Identification (RFID), Wireless sensor networks (WSN), Middleware, Cloud computing and IoT-applications. IoT-infrastructures encompassing some, or all of these five essential technologies, allows for communication between combinations of smart objects (e.g. products, robots), sensor networks and human beings, using different but interoperable communication protocols.

Currently, there are approximately 1.5 billion PCs and over 1 billion cell phones connected to the Internet. According to Vermesan and Friess (2014), IoT has through the last years changed from being a vision of the future, to becoming an increasing market reality. Moreover, major ICT-actors as Google, Apple and Cisco have taken significant and comprehensive business decisions in order to position themselves in the IoT-landscape. The adoption of new technology is increasingly gaining momentum as technological, societal, and competitive forces are pressuring companies across industries to innovate their businesses (Lee and Lee, 2015; Vermesan and Friess, 2014). In their research, Miorandi et al. (2012) presents a survey of technologies, applications and research challenges for IoT. The contribution of the research is to increase the understanding of the potential of IoT for various areas, among them inventory and product management, major issues to be handled, and devising innovative technical solutions in order to enable IoT from a research vision, into reality.

3.3.3 Potential impacts on manufacturing

The concept of IoT in the future is considered being transforming business processes by providing more accurate and-real time visibility into the flow of materials, products and services, across a wide range of industries and application areas (Lee and Lee, 2015). In manufacturing, it`s seen that smart, connected products will create new production requirements and opportunities. For instance, the final assembly might be switched to the customer site, where the last step will be to download and configure software. Moreover, the future vision are so-called “Smart Factories”, where new capabilities of smart, connected machines are reshaping the operations of manufacturing plants themselves, by being increasingly linked together in systems. In the new initiatives as “Industry 4.0” and “Smart Manufacturing” (USA), machines are networked together to completely automate and optimize the production (Porter and Heppelmann, 2015).

According to a research by Sundmaeker et al. (2010), IoT is believed to bring benefits into manufacturing, such as, high-resolution of assets and products, better collaboration between companies and an improved life-cycle management. In a research by Bughin et al. (2015), some similar benefits are also proposed. The research states that by equipping physical assets with sensors, information systems have the ability to capture, communicate and collaborate, and will create benefits as, production efficiency, improving the performance of machines, and extending the machines lives.

According to a research by Velandia et al. (2016), manufacturers have already begun to invest in hardware, software, and networking systems across the world and networking strategies to build the IoT and services architecture in order to capitalize upon its benefits. The research further states that to become smart manufacturing companies, the companies have to employ new intelligent production methods and target a marketplace where real-time information is exchanged between products and machine services. By embedding processors, sensors and transmitters in any type of physical object (e.g. machine, product, material), and developing software systems for structuring data flows, intelligence in production is made possible (Velandia et al., 2016). The contribution of the research by Velandia et al. (2016) is of practicality, as it helps decision makers to address business decisions in adopting RFID in comparison with other technologies, and on objective evaluations in industrial environments.

3.3.4 Risks and challenges

The wave of technological developments and changes that are seen to arise with the concept of IoT, will not only bring unprecedented opportunities, but it will also introduce new risks for both business and society. With regard to the realization of the potential of IoT, businesses and governments will need to overcome a number of important obstacles. Several researches, among them a research by Avram (2014), states that the most crucial important obstacle and is that of security- and data privacy risks that can already be seen to be of rising importance due to increased vulnerabilities for attacks, espionage and data breaches – driven by increased connectivity and data sharing. Another obstacle is the lack of interoperability among existing systems that will lead to the risks of substantial increase of complexity and costs in the deployment of the IoT. In addition, other obstacles that is identified is uncertain return on investment in new technologies, immature or untested technologies, a lack of data governance across geographic boundaries, and a shortage of digital talent (Atzori et al., 2010; Avram, 2014; Miorandi et al., 2012; World Economic Forum, 2015).

4.0 Research Methodology

In this chapter, the methodological approach for the master thesis, will be outlined. Firstly, the research design will be presented, entailing the methodology for developing a maturity model and the case-study research methodology. Lastly, considerations of validity and reliability, will be outlined.

4.1 Research design

A research is carried out to obtain information regarding a specific research question, and the selected design should be linked to the purpose of the research. The purpose of a research can either be, exploratory, explanatory, descriptive or predictive. Exploratory research is conducted when the purpose is to investigate an area that has been under-researched (Ellram, 1996; Yin, 2009). The purpose of this master thesis is considered to have an exploratory nature as the purpose of the research is to develop an IoT-Technological Maturity Model for assessing the technology level tied to the concept of IoT for manufacturing companies, and as there is not to our knowledge developed a similar model currently. The model will be developed by using a methodology presented by de Bruin et al. (2005). The applicability of the developed model will be tested by performing a case study of four Norwegian manufacturing companies, by assessing their technology level, and further placing them on the developed maturity model. The placement will be based on interviews, by following the "order management cycle" perspective, and observations from company visits. The "order management cycle" contains steps, from planning to post-sales services, and are mainly used as a tool for managers by giving them the opportunity to look at their company through a customer`s eyes (Shapiro et al., 1992). In this research, the "order management cycle" will be used as a tool for mapping technology used in the different departments at the case companies.
Based on the above, the research design for this master thesis will consist of the maturity model development methodology proposed by de Bruin et al. (2005) and the case study methodology proposed by Yin (2009), which will be elaborated in the following.

4.1.1 Maturity Model development methodology

As mentioned, even though there exists many different maturity models, there is little documentation on how to develop one that is theoretically sound, rigorously tested and widely excepted (de Bruin et al., 2005). de Bruin et al. (2005) has based on the lack of documentation on how to develop maturity models, proposed a methodology that consists of six phases for development of maturity models. In the following, these phases will be briefly described, followed by comments on how it relates to the development of the IoTTMM in this research.

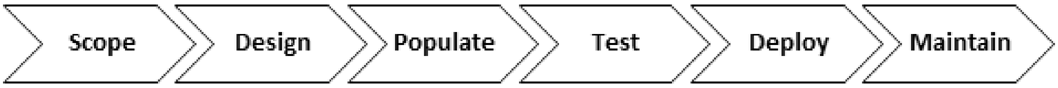

Figure 4: Six phases of developing a maturity model

(From de Bruin et al., 2005)

According to the figure above by de Bruin et al. (2005), the methodology consists of six distinctive phases. However, this research will only utilize the five first phases, because maintaining the model has a long-term perspective, meaning that phase six will suffer from time- and scope restrictions in this master thesis. The first three phases, *scope, design* and *populate*, will be conducted based on existing literature, while the fourth phase, *test*, requires a form of empirical study, in order to examine the relevance and rigor of the model in a real-life setting. The fifth phase, *deploy*, entails that the model should be made available for relevant users.

Phase 1 – Scope

The first phase in developing a maturity model is to determine the *scope* of the desired model, which entails to decide the focus of the model and who the stakeholders are.
The scope of the model in this research is to assess manufacturing companies regarding their current technology status and adoption tied to the concept of IoT. The stakeholders of the model are in general identified to be a combination of companies in the manufacturing industry and academia. Specifically for this research, the stakeholders are identified to be various participants in the project “Manufacturing Network 4.0”, the four selected case companies, and Molde University College (MUC).

Phase 2 – Design

The second phase in developing a maturity model is to determine a *design* for the model, which entails to incorporate the needs of the intended audience and how these needs will be met. An important note in this setting is that in order to meet the audience needs, the model design should strike an appropriate balance between the often complex reality and model simplicity. Therefore, it has been emphasized that the model describes the characteristics that represents each level of the IoTTMM, which can be seen as a summary, or collective terms, of the major requirements tied to the concept of IoT, from a technological perspective, based on the existing literature. Based on the characteristics, correspondingly criteria`s that needs to be fulfilled in order to be assessed to be at the various levels, represents the measures in the model. In addition, specific technology examples have been incorporated in the model with the intention of making the model easy understandable. Specifically for this research, the maturity model are seen to be a tool for the four selected case companies to measure their current technology status, and provide the companies, as well as other participants in the project and the academia, with an understanding of the concept of IoT and expected future technology development in line with the envisioned fourth revolution. In addition, the model can serve as a basis for providing the companies with recommendations for further technology development.

Phase 3 – Populate

The third phase in developing a maturity model is to *populate* the model, meaning that when the two first phases, *scope* and *design*, have been determined, the model content must be decided. This entails deciding *what* needs to be measured in the maturity assessment and *how* this can be measured.

In this research, the model content has been developed, as mentioned, based on the existing literature surrounding the concept of IoT, which has been carefully divided into the maturity levels. The technological company assessment was decided to be conducted from an "order management cycle", meaning that the technology used in the different departments in the four case companies, with an emphasis of the technology adoption in the production- and warehouse environments, has been investigated. The findings in the four case companies was measured based on the level criteria`s representing the characteristics surrounding each maturity level.

Phase 4 – Test

The fourth phase in developing a maturity model is to *test* the model, meaning that when the model has been populated, the model has to be tested for, relevance and rigor. The model should be tested with regard to the construct of the model and the model instruments for validity, reliability and generalizability.

The IoTTMM in this research was tested through the case study of the four selected companies, where the model was first refined, and then the final model was used to assess the case companies current technology level tied to the concept of IoT, and give recommendations for further technology developments. The test was performed in a combination of conducting interviews and direct observations.

Phase 5 – Deploy

The fifth phase in developing a maturity model is to *deploy* the model, meaning that the model should be made available for use and to verify the extent of the model`s generalizability. The IoTTMM was firstly distributed to the various participants in the project "Manufacturing Network 4.0", the four selected case companies, and Molde University College (MUC), and further made available for other users through the publishment the article "IoT technological maturity model and assessment of Norwegian manufacturing companies" by Jæger et al., 2016. In addition, the model will be made available with the publishment of this master thesis.

Phase 6 – Maintain

As mentioned, the sixth phase, *maintain*, was not included in this research, due to time- and scope restrictions. This last phase is seen to be of a more long-term perspective, which entails that the relevance of the model should be maintained with necessary updates over time. Since the IoTTMM is based on what is still seen as a future vision, it is envisaged that the model must evolve in line with future technology developments towards the fourth revolution, and that the project or other stakeholders, or the academia will hopefully perform this last phase.

4.1.2 Case study research

Case study as a research method is defined by Yin (2009) as a method that tries to illuminate a decision or a set of decisions, which investigates a contemporary phenomenon in depth and within real-life context. In order to test and validate the developed maturity model for this research, a case study was carried out, by assessing the technology level of four manufacturing companies, in accordance with the methodology presented by Yin (2009). The case study methodology consist of six stages, which is illustrated in Figure 5.

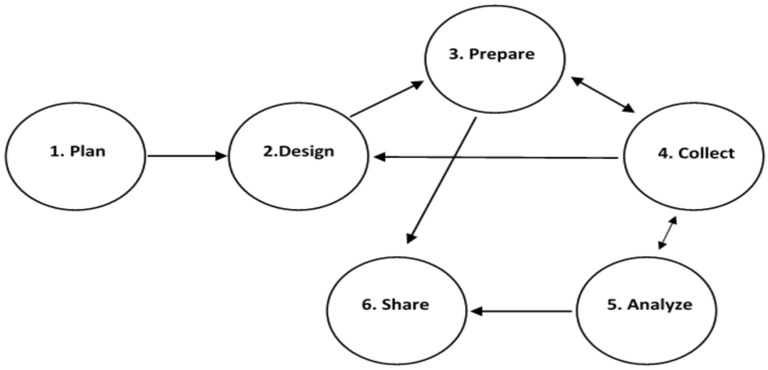

Figure 5: Six stages case study methodology

(From Yin, 2009)

The first stage in this case study methodology is to *plan* the research, and to decide if the case study method is the preferred method compared to other methods. Yin (2003 s.1) pointed out that a case study are appropriate for studies which intent to answer "how" and "why" research questions.

In this research, the first research question aims to develop a maturity model for assessing the technological level of Norwegian manufacturing companies with regard to the concept of IoT. The second research question aims to test the developed maturity model, and then perform an assessment of the companies technological level, leading to recommendations for further technology development. This assessment test could possibly been carried out through other methods, as for instance a survey. However, since these two research questions are interrelated, and a main part of the assessment is through observations, a case study are considered to be an appropriate research method.

The second stage in this case study methodology is *design*, which aims at linking the data to be collected to the research questions of the study. The unit of analysis and the case(s) to be studied need to be defined. Further, theory, propositions and issues underlying the anticipated study must be explained. Based on this the case study design should be selected. There are two types of case study design or characteristics; *holistic* or *embedded*, and *single* or *multiple* case study. Holistic case study is a situation where there is only one unit of analysis, while embedded case study refers to situations where there are multiple units of analysis. Single case and multiple case, refers to the number of cases being studied.

As mentioned, the purpose of this research is to explore how to develop a maturity model for assessing the technological level of Norwegian manufacturing companies. In addition, perform an assessment of each of the case companies and place the companies on the maturity model. Based on this, the unit of analysis is the technology level of each case company, which implies that this case study is holistic since there is only one unit of analysis. Furthermore, as the four different case companies are surrounded by different production strategies, it is distinguished that the companies have various contexts, which implies that there are multiple cases. Based on this, this case study is classified into a multiple-holistic case study.

The third stage in this case study methodology is *prepare*. When performing a case study it is important for the case study investigator to be trained and prepared and to have the right skills for performing a case study. Further, a case study protocol should be developed. The case study protocol contains the procedures and general rules to be followed. Having a case study protocol is desirable under all circumstances, but it is essential when performing a multi-case study. This stage also includes identifying relevant case study participants and the conduction of a pilot case study.
When choosing the case study method, both the investigators prepared themselves by reading about, and familiarize themselves with the method. Further, as the companies in this case study is the same as the participants in the “Manufacturing Network 4.0” project, the screening of the case study candidates was not carried out. Furthermore, a pilot case study was not carried out, because of the time- and scope restrictions of this master thesis. However, the interview questions were developed, discussed and evaluated in collaboration with the supervisor, prior to the interviews. A case study protocol was developed in order to have comparable information among the different manufacturing companies and to ensure the repeatability of the case study. The case study protocol can be found in Appendix 2.

The fourth stage in this case study methodology is *collect.* Data collection refers to the process of collecting data through data collection methods. This is the part where the case study investigator collects the required information or data. The data collected serves as a basis for the analysis. There are six different ways of collecting data, and it is important that the investigator knows which methods to use. The collection of data can be conducted through for example, interviews, questionnaires and observations, and can be categorized as either *qualitative* or *quantitative*. Some overall principals are important to any data collection method, when performing a case study. These includes the use of (a) multiple sources of evidence, (b) a case study database, and (c) a chain of evidence. The use of these different principles will increase the quality of the case study substantially.

In this master thesis, a qualitative method for data collection was used. The data consists of primary data, mainly collected from interviews and observations, and secondary data such as scientific articles, books, and other research papers. The reason for choosing a qualitative methodology was mainly that the data collection method were considered more suitable for the purpose of this study. The main source of primary data was collected through interviews, which is the most common data collection method used in a case study (Yin, 2012). The most common type of case study interviews is the open-ended interviews, which allowing for flexibility. If properly done, it indicates how case study participants think about situations, not only answering to a researcher's specific questions Another source of data collection which also is commonly used in a case study research, is observations (Yin, 2012). Observational evidence is often useful for providing additional information about the topic being studied (Yin, 2003). If a case study is about a new technology, for instance, observations of the technology at work are invaluable aids for understanding the actual uses of the technology or potential problems being encountered. In addition, another important notion which were taken into account was that of using multiple observers. Mentioned by Yin (2003) "To increase the reliability of observational evidence, a common procedure is to have more than a single observer making an observation- whether of the formal or the casual variety. Thus, when resources permit, a case study investigation should allow for the use of multiple observers" (Yin, 2003).

For this research, open-ended interviews were selected as an appropriate data collection method. It allows for flexibility in the interviews, which was important in order to obtain an understanding of the current technology used at each of the case companies, and to support the case study analysis. In addition, observations was also considered as important, in order to get a visual impression of technology used in production and/or warehouse operations. These observations were conducted together with multiple observers, namely the supervisor and two other students investigating related research areas, which thus contributed to increase the reliability of the observational evidence, in accordance with the statements by Yin (2003) above. Through the interviews, the "order management cycle" perspective was used as a basis for mapping technology currently used in the case companies, considered to be a suitable reference frame for the investigation of the current technology used by the companies in this case study. The aim of the interviews and the observations is to collect enough information to be able to evaluate the case companies' technology level. Even though the details of each activity in the "order management cycle" can be seen to vary between companies, and being different for various products and services, it`s noticed that almost all companies, either it`s a small manufacturing company or a global manufacturing enterprise, have the same general activities included in their "order management cycle" (Shapiro et al., 1992). After successfully conducting the interviews, a brief summary was written for each of the case companies, in addition to follow-up questions and distributed to the companies contact person for validation. This was done to avoid misunderstandings and to get the most accurate information from the case companies.

The fifth stage in this case study methodology is *analyze*. This phase consists of examining, categorizing, tabulating and testing evidence, in order to draw empirically based conclusions. A general analytic strategy should be followed, which defines priorities for what to analyze and why. Different techniques for analyzing the collected data can be used for further draw conclusions.

Using the data collected from the interviews, and the observations, it was possible to assess the companies. The analysis was performed by assessing the case companies based on the established criteria from the maturity model. When evaluating the case companies according to the criteria, it became obvious whether or not the case companies fulfilled the different level requirements. Further, it was possible to draw a conclusion based on this, on what level the companies belonged to.

The sixth stage in this case study methodology is *share*, which is considered as one of the most challenging aspects of performing case studies. Sharing and reporting the case study means bringing the result and finings to closure. It is important to identifying the audience for the report. For instance, differences in knowledge level of the topic being researched, will influence the theoretical part of the case study. Another important part of reporting is to develop a compositional structure and having drafts be reviewed by others. It is also important that the report contain enough evidence for the reader to reach its own conclusions.

The reporting of the case study is outlined in chapter 6 in this master thesis. The concept of IoT is briefly explained in the literature review, and the methodology for developing the maturity model is briefly explained in the methodology chapter, which means that the reader should have a basic understanding of the concept, prior to reading our master thesis. The case study findings and the company assessment can be found in chapter 6, where the findings are presented and argued for, in such a way that the reader can easily draw their own conclusions on whether or not the companies have fulfilled the criteria at the level where they have currently been placed.

4.2 Validity and reliability

Validity and reliability are two important aspects in order to test and evaluate the quality of a research. Mentioned in Golafshani (2003), validity determines whether the research truly measures what it was intended to measure. Yin (2009) describes three different tests for testing the validity in research; Construct validity, internal validity and external validity.

According to Yin (2009) there are three tactics for increasing construct validity. (1) use multiple sources of evidence, (2) establish a chain of evidence, (3) have key informants review draft case study report. The two first tactics are relevant in the data collection process. The use of multiple source of evidence, has been handled by having more than one person present when interviewing all four case companies, combined with observational evidence. Also by performing a round of follow-up questions after the interviews. Establishing a chain of evidence, has been handled by using scientific literature in addition to the empirical study. The third and last tactic has been handled by writing a summary from the interviews, which has been distributed to the participants from the case companies present at the interviews, for approval and comments and changes.

Internal validity has not been taken into consideration in this case study, as it is according to Yin (2009) only relevant for explanatory or casual studies, and not for exploratory or descriptive.

External validity, are according to Yin (2009) the problem of knowing whether the case study findings are generalizable beyond this particular case study. To handle this, the developed maturity model has been tested on four manufacturing companies. To further generalize our model we planned to carry out a maturity assessment test for distribution to other companies, but because of time- and scope restrictions, we were not able to go conduct the assessment. An overview of the initial planned assessment test can be found in Appendix 3.

In terms of reliability, this is concerned with the replication of a research, and if the same results would appear if the case study was performed over again. The goal of reliability is therefor to minimize the errors and bias in a study. An important way of securing reliability in a study is to document the procedures which is carried out, thus allowing other researchers to perform the same study (Yin, 2009), which also is the aim of this methodology chapter. Throughout this master thesis, a thorough explanation has been given on data collection method, and interview guidelines and the case study protocol are attached in the Appendixes. In addition, literature references have been made.

5.0 Development of the IoT-Technological Maturity Model

In this chapter, the essential background, the model composition and the descriptions of the various maturity levels of the IoT-Technological Maturity Model (IoTTMM), as well as a model overview and visualization, will be presented.

5.1 Background for developing the Maturity Model

Various literature has created the background for the development of the IoTTMM. The most essential literature background, which has been distinguished to be most central is literature surrounding robotics and automation, Machine-to-Machine communication (M2M), and standardization, and will in the following be elaborated to potentially increase the understanding of the various level characteristics surrounding the developed IoTTMM.

5.1.1 Automation and Robotics

In general, automation can be traced back to the start of the industrial revolution in the 18th century, and are considered being a major force for the rationalization of production processes. With the development of computers, and integrated circuits, it made it possible to automatize with the help of systems integrated by a central computer. Which later resulted in the development of the industrial robot. The first use of industrial robots can be traced back to the 1960s, where they were used for simple tasks as, pick and place. With further technological development, robots started replacing humans in repetitive, heavy and dangerous tasks, as, welding, grinding and assembly (PwC, 2014; Wallén, 2008). Assembly is considered as the task that is most frequently replaced by robots.
Currently, industrial robots and robotic systems are key components of automation. Moreover, industrial robots in manufacturing today, tend to be large, and dangerous to anyone who is too close to the robot arms (Hegerty, 2015). The robots are usually operating in cages to avoid any damages and injuries. However, new innovations in the development of industrial robots, have made it possible for robots and humans to work alongside each other, and help assemble all sort of objects. This new generation of industrial robots is called collaborative robot (or so-called “co-bot”), designed to work next to people in the warehouse, and performing tasks as, sorting packages or operating CNC machines (PwC, 2014). The robots are equipped with sensors, sonar, cameras or other technologies, making the collaborative robots able to sense where people are and slow down or stop to avoid damages and injuries (Hegerty, 2015).

It is considered that industrial robots of the future will be multi-functional, meaning that the same machine can be put to several different uses. As of today, most of the industrial robots are limited to one operation (PwC, 2014; Wallén, 2008).
Furthermore, according to PwC (2014), industrial robots are at the edge of revolutionizing manufacturing. A new generation of robots is on the way—smarter, more mobile, more collaborative, faster and cheaper and more adaptable (Hegerty, 2015). In addition, these new robots are equipped with more "human" capabilities such as sensing, object recognition, memory and trainability. Which has resulted in their ability to perform other type of work operations – such as picking and packing, testing and inspecting, and assembly (PwC, 2014). In general, industrial robots are used to reduce costs, improve product quality, eliminate dangerous tasks and increase productivity. Industrial robots can roughly be divided into three different groups; material handling, assembly and process operations (PwC, 2014; Wallén, 2008).

5.1.2 Machine-to-Machine (M2M) communication

A central part of the IoT is obviously the connection to the Internet. In the years to come, more and more physical objects will be connected to the Internet. This enables physical objects to exchange and share information among themselves. This communication between objects is called Machine-to-Machine (M2M) communication (Lier, 2012). According to (OECD, 2012). M2M-communication is considered as devices that are connected to the Internet, using a variety of fixed and wireless networks and are able communicate with each other and the wider world. Machines with communication capabilities, and machines communicating with machines is far from new. For instance in manufacturing, machines are sending signals or information to control rooms, where control circuits automatically need to react to that information. Todays` technology, inexpensive electronics, the use of the Internet, together with ubiquitous networks and (cloud) computing allows almost any device to be equipped with communication capabilities. Thus, enables devices to communicate information, internally or externally towards others, which further allows for using this data in new and useful ways (OECD, 2012). According to Breeden (2015), M2M-communication has actually been around since the early days of computing, it has recently evolved to where devices can communicate wirelessly without a human or centralized component. The most popular M2M-setup has been to create a central hub that accepts signals from all connected devices. Sensors would note an event, as temperature change, the removal of a piece of inventory or a door opening, and send that data to a central location where an operator might turn down the air conditioner, order more bolts or tell security about a door opening (Breeden, 2015). The model for M2M-communication in the future, however, eliminates the central hub and has devices communicating with each other and working out problems on their own. For instance, a M2M-enabled device will be able to automatically turn on the air conditioner in an overheated space, order more bolts when it senses that supplies are low or alert security if a door opens (Breeden, 2015).

5.1.3 Standardization

According to Xu et al. (2014), the success of IoT depends on standardization. Standardization is considered a central element in the IoT, and especially with regard to the Machine-to-Machine (M2M) communication. In addition, it is considered a key enabler for the success of communication technologies, as RFID, and any M2M-communication. The rapid growth of IoT makes the standardization difficult, and is one of the biggest issues, concerning the IoT (Xu et al., 2014). In a research by Weyer et al. (2015), a network of technology providers for automation where a multi-vendor and highly flexible production line had been implemented jointly, was examined. It was found that a crucial element for the successful collaboration among ten companies was the definition of mechanical, electrical and communication standards between all vendor-specific subsystems. Furthermore, it was stated that standardization is fundamental in order to guarantee interoperability between various modules of the production line (Weyer et al., 2015). Consequently, one can understand that standardization are needed to ensure that devices from different companies and countries to be able to exchange information. Without global standards, the development of M2M-solutions are not seen to be able to reach a global scale (Vermesan et al., 2011).

A number of standardization activities with focus on tag-based technologies have been active in recent years. These standardization activities have mainly been limited to the RFID-domain (Miorandi et al., 2012). In the RFID-field, the most commonly adopted solution is the Electronic Product Code (EPC), a unique identifier for each RFID-tag provided by EPCglobal, which is a subsidiary of the global standards non-profit organization GS1 (Atzori et al., 2010; Miorandi et al., 2012).

Standardization solutions in IoT are seen to lower the entry barriers for new service providers and users, to improve the interoperability of different systems and to allow products or services to connect with each other, on a global scale (Xu et al., 2014; Vermesan et al., 2011).

5.2 Composition of the IoT-Technological Maturity Model

As earlier discussed, a number of different maturity models have been developed within various domains. However, there is a lack of documentation about how to develop a maturity model that is theoretically sound, rigorously tested and widely accepted (de Bruin et al., 2005). Therefore, the IoT-Technological Maturity Model has been developed in close compliance with the model development framework proposed by de Bruin et al. (2005) which is suggested to be applicable for various domains.

The developed IoTTMM consists of eight different maturity levels in an ascending succession, ranking from level 1 (3.0 Maturity) to level 8 (4.0 Maturity). The creation and descriptions of the different levels in the model has mainly been created based on existing literature surrounding the maturity of the third industrial revolution and the concept of IoT. In addition, the creation of the maturity model levels have been supported by observations in the case companies in this study. The combination of the data sources has been carefully divided into the eight maturity levels, suggesting a direction path of technology developments, from the current technology status tied to the maturity of the third revolution and towards the envisioned optimal level of IoT-technology and the envisioned maturity of the fourth revolution. The maturity model levels can be seen to be of a general character, and can thus be utilized across organizations in the manufacturing industry. The model can assist and contribute with assessment of organizations current technology level tied to the concept of IoT. In addition, the model can serve as a comparative basis for improvements and as an informed approach for further technology developments for organizations in the manufacturing industry.

The IoTTMM is composed upon four main parameters, *level*, *range*, *characteristics* and *criteria*. As mentioned, the model consists of eight *levels* that in an ascending succession guides the path towards the highest level of the model. The *range* represents whether it`s internal or external for the organization. The *characteristics* describes the capabilities and properties organizations needs to have in order to be evaluated to be at a particular level. Based on the characteristics, a set of *criteria's* that represents the main objectives which needs to be fulfilled for each level, are presented. The criteria`s are regarded to contribute

to provide a compressed and practical understanding of the organizations characteristics at the different levels. As a main guideline, an organization needs to fulfill all the criteria`s to be ranked at a particular level. However, an exemption can be made in a particular case. More specific, for instance if the case is that an organization fulfills all of the criteria`s at level four, but fails to fulfill one criteria at level three, the organization can be ranked at level four. We believe that organizations in the manufacturing industry will not have the exact same technology, and thus find it appropriate to open up for this exemption.
In the following, the characteristics and the criteria`s for each of the different levels are described and presented. Lastly, Table 1 provides a summary of the level descriptions and an easy understandable overview of the developed IoT-Technological Maturity Model. In addition, a visualized overview of the maturity model is presented in Figure 6. Lastly, thoughts around and a suggestion for a simplified IoT-maturity assessment test, is presented.

5.3 Description of the IoT-Technological Maturity Model levels

5.3.1 Level 1: 3.0 Maturity

Level 1 exists of three main characteristics, and three corresponding level criteria`s.
The model originates with the perception that organizations are currently at the brink of embracing the concept of "Internet of Things". Organizations at level 1 are regarded to be at the 3.0 maturity level of the third revolution, which can be considered being reached around year 2015. The *first* main characteristic of this maturity level, is that organizations have implemented some use of "Track and Trace" technology, as RFID and/or barcodes in the production and/or warehouse environment, but with limited functionality. The *second* main characteristic of this maturity level, is that the organizations have implemented an Enterprise Resource Planning (ERP) system, or individual ERP-modules, that the organization can use to collect, store, manage and interpret data from different business activities, as product planning, manufacturing, inventory, marketing/sales, shipping and payment, etc. The *third* main characteristic of this maturity level can be identified by an initial automatization of the production and/or warehouse environment with the use of at least one robot, performing a specific activity independently in the production and/or warehouse. At this level, the ERP-system (or modules) and the machine control are technically regarded to be two different non-integrated worlds. The organizations are considered to be characterized by being unconnected in the meaning that there`s no

requirements for any features of vertical or horizontal communication between robots, machines and IT-systems. However, organizations at this level are searching for solution for improving the effectiveness of existing business processes moving towards higher levels of intelligence related to the evolving connected world of robots, machines, IT-systems, products and humans. In addition to these three main level characteristics, we should mention some additional potential characteristics, which can be considered being essential elements of the maturity of the third revolution. Since organizations have various need for technologies, the characteristics will not be included in the model. 3D printing is an example of an initial technology that is regarded to be a central part of the maturity of the third industrial revolution. 3D printing can enable the printing of various products by simply using a computer and a 3D model of an object. According to LEF[7], 3D printing is a classic disruptive technology that is simpler, smaller, inexpensive and more convenient to use than traditional manufacturing technology. However, the technology is not expected to prosper into the traditional manufacturing markets for a number of years. Moreover, some organizations have less need for 3D printing (Report LEF, 2012). Thus, 3D printing will only be seen as a potential characteristic at this level, and it will not be a level criteria. Furthermore, sensor technology, which enables the connection of the physical and digital worlds and allows real-time information to be collected, shared and processed, is considered as being a key technology enabler at this level. Sensors are vital for automatization, where every robot is equipped with sensors for enabling the functioning of the robot and for the robot to be familiar with the surrounding environment. However, the same does not necessarily apply products. Nevertheless, the equipping of products with sensors in order for the products themselves to register events and store information about its functioning or surrounding environment, are increasingly being explored by organizations. Moreover, this is an important prerequisite of the envisioned smart products tied to the concept of IoT in the future. However, having sensors on products at this level will in similarity with 3D printing only be considered as a potential characteristic, and it will not be a criteria at this level. This reasoning stems from the outline above that sensors are vital for automatization where the robots are equipped with sensors in order to function, while products in many cases does not need the sensors to function. Therefore, the sensors on products are not vital for the automatization in the same manner as the sensors on the robots are.

[7] Leading Edge Forum – a global community whose programs contributes to help participants realize business benefits from the use of advanced IT more rapidly

5.3.2 Level 2: Initial

Level 2 exists of three main characteristics, and three corresponding level criteria`s. Having at least one IoT-enabled object is determined to be the main entry requirement for the path towards the 4.0 maturity, and thus, the *first* main characteristic for level 2. Currently, the literature surrounding the concept of IoT is lacking a clear definition of what an IoT-enabled object really is. Taken literally, it means "things" connected to the Internet. Therefore, it must be possible to communicate with the object via the Internet, either directly if the object has Internet Protocol (IP) communication capabilities, or indirectly via intermediate software. Different terms are used for core concepts, and an indistinct use of "Smart Object", "Smart Thing", "Intelligent Product" and "Ubiquitous objects", among others. In addition, some authors has proposed their own original terms that seems to refer to the same, or a very similar entity. An "Intelligent Product" has from a manufacturing perspective been defined as a commercial product with five specific characteristics; a unique identity, communication abilities, storage or self-data, a deployed language and decision-making capabilities. Similarly, smart devices (as PDA`s and mobile phones), have been defined as physical objects with computing resources that are able to communicate with each other and with other users (Hernândez and Reiff-Marganiec, 2014). Thus, in order to avoid confusion and for the purposes of this research context, an IoT-enabled object needs to be defined. This is also important in order to state the difference between IoT-technologies, and earlier technologies (mechanical-, electrical-, computer-technologies) (Jæger et al., 2016).

In the third revolution, a major progress was the introduction of the "Programmable Logical Controller (PLC)", which was designed for controlling manufacturing machinery and equipment. The PLC contained all three elements of a computer in one unit, namely the computer memory, processing capability and Input/Output (I/0) communication facilities. As one can understand, the PLC is thus the core component of the IoT-technologies. However, as one can understand from the outline above, some additional requirements needs to be included. According to Porter and Heppelmann (2014, 2015), all smart, connected products from home appliances to industrial equipment's shares three core elements. These three core elements are; physical components (comprising the product`s mechanical and electrical parts), "smart" components (comprising the sensors, microprocessors, data storage, controls, software, embedded operating systems, etc.) and connectivity components (comprising the ports, antennas, protocols enabling wired or wireless connections with the product). While the smart components enhances the capabilities and the value of the physical components, the connectivity components enhances the capabilities and value of the smart components. In addition, the connectivity components enables some of the capabilities to exist beyond the physical product itself (Porter and Heppelmann, 2014, 2015). Based on this, and as stated by Jæger et al. (2016), the definition of an IoT-enabled object in this research context exists of three different requirements:

1) The object needs to have the core elements of a "Programmable Logic Controller (PLC)", namely that the object is an electronic component with computer memory, processing capabilities and Input/Output communication facilities.

2) The object needs to have a globally unique identifier, or an IP-address that can be used if the object has IP-communication capabilities. Otherwise a globally unique identifier must be assigned, e.g. by GS1 following the AutoID standards which is typically used for RFID-tags.

3) The object have to be enabled to be reached globally. Wherever the object is in the world, a two-way communication with the object must be possible, meaning that the object has to have the ability to send and receive messages. In practice, this means that the object needs to be connected directly to the Internet or via a middleware software (e.g. a control system). If it is a non-IP object, it needs to be given IP-communication capabilities by adding a reader/writer unit with IP-functionality. A typical example can be an RFID-tag that needs to be within the range of an RFID Reader (and Writer) antenna to be considered an IoT-enabled object (Jæger et al. 2016).

According to the requirements outlined above, an organization fulfills the first main requirement at level 2 if it has one IoT-enabled object, within the assets (manufacturing machines, robot, transportation units, etc.) or the products (component/semi-finished product, etc.). The *second* main characteristic at this level, is that the technology in the organizations is under development, meaning that the organizations are searching and exploring for further automation in the production and/or warehouse environment. This entails that robots, machines and IT-systems are increasingly being connected, and set up with the ability to communicate vertically through a control system or the Internet. Thus, at this level, it is regarded that organizations have adopted, or are exploring an initial use of the M2M-communication, e.g. the most common M2M-setup according to Breeden (2015), with a central hub that can accept signals from all connected assets (vertical communication).

The *third* main characteristic at this level, which can be seen to be related to the ability of vertical communication in the previous characteristic, imply that assets (machines, robots) and/or products can be remotely programmed, accessed, and managed by for instance the use of a PC, tablet, or a smart phone, from a remote location.

5.3.3 Level 3: Connected

Level 3 exists of two main characteristics, and two corresponding level criteria`s. At level 3, the *first* main characteristic is that an organization needs to have an internal supply chain control with at least two IoT- enabled objects, within the assets and/or the products, with the ability to communicate vertically through a control system or the Internet. Cloud computing can be regarded as another way of supporting vertical communication, and are correspondingly regarded as one of the enabling platforms to support the connection of devices and sensors in IoT. Cloud computing, also commonly referred to as just Cloud, has become a popular key IT-word in the last decade. The simplest working definition of cloud computing is provided by Kim (2009), who defines cloud computing as being that organizations are "able to access files, data, programs and 3rd part services from a Web browser via the Internet, hosted by a 3rd party provider". Building on the second characteristic in level 2, organizations at this maturity level have further implemented the most common M2M-setup according to Breeden (2015), with one kind of a central hub that can accept signals from all connected assets (vertical communication).

The *second* main characteristic at this level, is that at least one specific operation within the production and/or warehouse environment has been automated.

5.3.4 Level 4: Enhanced

Level 4 exists of two main characteristics, and two corresponding level criteria`s. At level 4, the *first* main characteristic is that an organization needs to have an internal supply chain control with <u>more</u> than two IoT-enabled objects, within the assets and/or the products. In addition, the assets or products needs to have the ability to communicate vertically through the use of a control system, the Internet or a Cloud. Further, the assets and/or products needs to be able to communicate horizontally. Thus, at this level, assets and/or products are seen to become internally connected and the Machine-to-Machine (M2M) communication are regarded to initial include the model for the future M2M-communication, where the machines and robots have the ability to directly communicating with each other (horizontal communication).

The *second* main characteristic at this level is that a specific part of operations in the production and/or warehouse environment have been automated.

5.3.5 Level 5: Innovating

Level 5 exists of four main characteristics, and four corresponding level criteria`s. At level 5, the *first* main characteristic is that organizations needs to have an internal supply chain control with an increasingly number of IoT-objects (at least ten) within the assets and/or the products. In addition, these IoT-objects needs to have been enabled with the ability of horizontal communication (e.g. robot-to-robot) and vertical communication (e.g. robot-to-Internet) between the assets and/or products. Thus at this level, building on the first characteristic at level 4, the Machine-to-Machine (M2M) communication including the model for the future M2M-communication, where the machines and robots have the ability to directly communicating with each other (horizontal communication) are becoming more extensive, in accordance with the third characteristic at this maturity level.

The *second* main characteristic at this level is that the IoT-objects are further developed and equipped with advanced features. More specifically, that the objects at this level have self-awareness capabilities, which means that the objects have the ability to know its own status and structure, as well as any changes to it, and its history (Hernández and Reiff-Marganiec, 2014).

The *third* main characteristic at this level is that the production and/or warehouse environment is extensively automated, e.g. the production and/or warehouse environment is characterized by an increasingly use of robots replacing the manual workforce. The *fourth* main characteristic involves organizational understanding of the importance of, as well as interacting to achieve standardization (data standards, wireless protocols, technologies). Without standardization, the communication between asset-to-asset and product-to-product becomes difficult, especially communication beyond organizational boundaries. Thus, standardization and interoperability both can be regarded as two especially central elements organizations should be engaged in at this level, since standards are needed for interoperability both within, and between various domains.

According to IEC (2015), interoperability can be defined as the ability of a system to interact with other systems, without application of special effort for integration, e.g. customization of interfaces, etc. Moreover, interoperability has to be established on various levels, namely the physical level; when assembling and connecting manufacturing equipment, the IT-level; when exchanging information or sharing services, and on the business level; where operations and objectives have to be aligned (IEC, 2015).

5.3.6 Level 6: Integrated

Level 6 exists of four main characteristics, which is divided into six level criteria`s. The *first* main characteristic at this level is that there are an increasingly number of IoT-objects among the assets and products. Moreover, the organizations have further implemented the IoT-technology, and the IoT-objects have the ability directly to communicate with humans and other stakeholders internally in their organization, in addition to horizontal (e.g. robot-to-robot) *and* vertical (e.g. robot-to-Internet) communication. Thus at this level, building on the first characteristic at level 5, the Machine-to-Machine (M2M) communication including the model for the future M2M-communication, where the machines and robots have the ability to directly communicating with each other (horizontal communication) is becoming more advanced due to the ability to communicate with humans and stakeholders. In addition, the M2M-communication are considered to become even more extensive, in accordance with the third characteristic at this maturity level.

The *second* main characteristic at this level is that the IoT-objects have the ability to be self-managed. This feature passes beyond self-awareness (in the previous level), and includes the IoT-objects ability to use the information gathered - in order to manage its own life cycle, including services, self-repair and resources. It also includes the ability to learn from experiences and the ability to improve operations (Hernández and Reiff-Marganiec, 2014). The *third* main characteristic at this level is that the production and/or warehouse environment is highly automated involving robots that performs a high degree of the production and/or warehouse operations, further replacing the manual workforce. The *fourth* main characteristic at this level is that the connected robots, machines and products constantly and increasingly are exchanging various types of information. Consequently, the volume of the generated data and the processes which is involved in the handling of the data, becomes critical and important to manage. Data management is a crucial aspect within IoT, and organizations at this level should have a deep focus on all the exchanged data and initially develop a plan and strategy for further data management.

The organizations needs to understand what information they need in order to create as much value as possible (Tan et al., 2015).

5.3.7 Level 7: Extensive

Level 7 exists of four main characteristics, which is divided into seven level criteria`s. The *first* main characteristic at this level is that, in similarity with the previous level, there are an increasingly number of IoT-objects among the assets and products. Moreover, the organizations have further implemented the technology and evolved to external communication between products and assets, and supplier and customers. In addition, as from the previous level, the communication can occur horizontally and vertically, between assets and products. Thus, at this level the range of the organizations are extended from being merely internal, to embracing the organizations external network. Building on the first characteristic at level 6, the Machine-to-Machine (M2M) communication including the model for the future M2M-communication, where the machines and robots have the ability to directly communicating with each other (horizontal communication) are regarded to become even more advanced due to the ability of both internal and external communication. In addition, the M2M-communication are becoming highly extensive in accordance with the second characteristic at this level.

The *second* main characteristic at this level is that the production and warehouse environment are highly automated, meaning that robots and machines performs a high degree of the production and warehouse operations, replacing a high degree of the manual work operations.

The *third* main characteristic at this level is that organizations moves from Data Management, and towards Big Data Management and extensive Data Analysis. Big Data is the result of an extensive implementation of new technology, and the enormous amount of data that arises from the internal and external communication, and the monitoring and measuring of objects (e.g. a robots and/or a products performance), in the business environment. Consequently, Big Data Management, which is the organizations administration and governance of great volumes, of both structured and unstructured data, becomes crucial important at this level. The aim of Big Data Management is to extract big data to gain helpful business insights, which further means to ensure a high level of data quality and accessibility for business intelligence and Big Data analytics applications. The *fourth* main characteristic progresses from the third characteristic at this level, namely that organizations at this level are actively engaged in Data Analysis, with the inspection, cleaning, transforming and modeling of data from sensors, M2M-communications, and networks, in order to discover useful information and support business conclusions and decision-making (Tan et al., 2015).

5.3.8 Level 8: 4.0 Maturity

Level 8 exists of three main characteristics, and three corresponding level criteria`s.
Level 8, 4.0 Maturity, is the final and optimal level on the maturity model, which represents the envisioned fourth industrial revolution organizations are predicted to reach in the future. The *first* main characteristic at this level is the vision of optimal IoT-technology use, in which all objects in the organization (assets and products) are connected to the Internet and seamlessly integrated, and that the objects can communicate with other objects, using common architectures, interoperability and open standards, enabling limited human intervention. Building on the first characteristic on level 7, organizations at this level have completely embraced into the future model of M2M-communications, and are considered to be highly advanced utilizing a variety of fixed and wireless networks for global communications (OECD, 2012).
The *second* main characteristic at this level is that the production and warehouse environments are optimally automated, having manual work operations only because it is considered most appropriate. The *third* characteristic at this level is that Business Intelligence and Continuous improvement characterizes the organizations. Moreover, the business environment at this level will be characterized by continuous improvement, enabled by continuous monitoring of real-time performance data, which allows organizations to discover and figure out design problems that testing failed to reveal. Further, at this level, it is anticipated that one will see "smart factories", where the new capabilities of smart, connected machines are reshaping operations at manufacturing plants on their own, and where machines increasingly are linked together in systems. In these "smart factories", networked machines fully automates and optimizes production. For instance, it`s believed that a production machine can discover and detect a potentially malfunction, close down the machine and IT-system, and other equipment that could be damaged, and further direct maintenance workers to the problem. The key enabler for such a smart environment are seen to be Business Intelligence, which can be described as a set of techniques and tools for transformation of raw data - into meaningful and useful information for the purposes of analysis of business (Porter and Heppelmann, 2015). Thus, at this level, organizations have become predictive, meaning that organizations can

forecast what can happen in the future, from the basis of Big Data management. For instance, can predictive analytics identify consumers buying behavior, which organizations can use for marketing trends, as well as production and capacity planning. Furthermore, it is believed that new business processes and models might arise, since the smart, connected machines and products creates new production requirements and opportunities. For instance, might the final product assembly be switched to the customer site, where the final step will be loading and configuring software or the product itself might be delivered as a service (Porter and Heppelmann, 2015).

5.4 Overview and visualization of the IoT-Technological Maturity Model

Table 1: Overview of the IoT-Technological Maturity Model

Level	Range	Characteristics	Criteria	Specific descriptions and technology examples
1 3.0 Maturity	Internal	Initial use of RFID *and/or* barcodes in the production *and/or* warehouse environment, but limited function and connection	Use of RFID *and/or* barcodes in the production *and/or* warehouse environment	Use of "Track and Trace" technology as RFID *and/or* barcodes in the production *and/or* warehouse environment. For instance, labeling products with barcodes that can be scanned with the use of barcode readers. The barcode readers can be connected to the ERP-system, which thus enables an automated tracking and tracing of the products location in the warehouse.
		An ERP-system (or individual modules) has been implemented	ERP-system (or individual modules) implemented	ERP-system, or individual ERP-modules, that supports the collection, storage, management and interpretation of data from various business activities, as for instance production- and inventory planning. Common ERP-modules that are integrated with each other are sales, procurement, accounting, production and human resources.
		Initially automated production *and/or* warehouse environment	Robot(s) used in the production *and/or* warehouse environment (at least one robot)	Robot(s) has replaced some of the manual work, either in the production *and/or* in the warehouse. In the production, for instance, (a) welding robot(s) has replaced a part of the manual welding operation. *And/or* (an) automated transport carrier(s) has replaced some, or all, of the manual goods movement between working stations. In the warehouse, for instance, (a) robot(s) can receive the finished goods and perform the packaging of the products. *And/or* (an) automated transport carrier(s) has replaced the manual placement of goods at given locations in the warehouse.

2 Initial	Internal	One single IoT-object among the assets *or* the products	One single IoT-object (an asset *or* a product)	A robot (asset) is able to send and receive messages. More specifically, the robot can send signals to the control system, and notify about errors, the need for raw materials, finished goods etc. The robot can also receive messages on the basis of programming codes, which gives the robot information and direction on what tasks to be performed.
		Technology development – Robots, machines and IT-systems are initially connected for automation in the production *and/or* warehouse with the ability to communicate vertically	Robots, machines and IT-systems have been initially connected for automation in the production *and/or* warehouse ,with the ability of vertical communication	
		Remotely programming, access and management of asset(s) *and/or* product(s) (by PC, tablet, smart phone)	Remotely control of asset(s) *and/or* product(s) are possible	For instance for (an) asset(s), the robot(s) or the machine(s) can be remotely accessed from a location outside the production- *and/or* warehouse facility. For instance, if a robot in the production stops functioning because of some error, the robot sends an error notification through the IT-system that a responsible person (e.g. operator) receives. This person can then access the system from a remote location, remove the error and initiate the functioning of the robot again. For instance for (a) product(s), service agents at the supplier of the product can access the product remotely, identify and solve errors, without making use of resources on-site at the customers location.
3 Connected	Internal	At least two IoT-objects among the assets *and/or* products, with the ability to communicate vertically	At least two IoT-objects (assets *and/or* products) with the ability of vertical communication	For products for instance, an example can be that a supplier of thruster engines has equipped their thrusters with sensors that can sense temperature and vibration. If the thruster engine in a ship starts to get heated, the thruster can send a notification about the high temperature through the IT-system, and a responsible person can look into the data transmitted from the thruster, and see what actions that needs to be taken. For instance, can the data reveal that there is a part that needs maintenance or has to be replaced.
		A specific operation (at least one) within the production *and/or* warehouse environment has been automated	At least one specific operation has been automated within the production *and/or* warehouse environment	In the production environment for instance, the welding-, assembly-, or cutting operation, etc. has been automated by the use of (a) robot(s). In the warehouse environment for instance, the packaging operation, or the placement of products in the storage racks in the warehouse operation has been automated by the use of (a) robot(s).

4 Enhanced	Internal	More than two IoT-objects among the assets *and/or* products, with the ability to communicate horizontally (between asset to asset, product to product) *and* vertically, between assets *and/or* products	More than two IoT-objects among the assets *and/or* products, with the ability of horizontal communication *and* vertical communication, between assets *and/or* products	For instance, Robot A, assembles cardboard boxes, and supplies Robot B with the finished boxes. Robot B, produces standard parts, and places the standard parts directly into the cardboard boxes, supplied from robot A. When the level of cardboard boxes reaches a minimum level, a signal is sent directly from Robot B to Robot A, to send more boxes (horizontal communication). In addition, in the same manner as the example on level 2, the robots can send signals through the control system and notify about errors (vertical communication). The robots are internally integrated.
		A specific part of the production *and/or* warehouse environment is automated	A specific part of operations in the production *and/or* warehouse environment have been automated	In the production for instance, can the production of standard parts and components for a company`s various products have been fully automated, where robots and machines performs all of the production operations leading to a finished part or component, in a production network monitored by an operator. In the warehouse for instance, can a specific part of the outbound warehouse operations, as the picking and packing of products on the basis of a customer order have been fully automated, where robots and machines performs all of the operations leading to a complete packaged customer order for shipment. In similarity as for the production example, an operator monitors this product-packaging network.

5 Innovating	Internal	Increasingly number of IoT-objects (at least ten) among the assets *and/or* products, with the ability to communicate horizontally (between asset to asset, product to product) *and* vertically, between assets *and/or* products	At least ten IoT-objects among the assets *and/or* products with the ability of horizontal communication *and* vertical communication, between assets *and/or* products	For assets for instance, based on the example outlined at level 4, there are ten (or more) robots that have the ability to notify the control system about errors and need for raw materials, as well as notifying a collaborating robot(s) to slow down if the capacity is nearly full, or to speed up if it has excess capacity.
		IoT-objects (assets *and/or* products) are equipped with self-awareness capabilities	IoT-objects has self-awareness capabilities	For assets for instance, robots *and/or* machines are equipped with sensor data that makes them able to sense and compare e.g., the humidity data of a product. If the robots *and/or* machines defines the conditions as unfavorable, the robots can route the product to another area of the manufacturing process, reducing duplicate work and maximizing plant uptime.
		Extended automated production *and/or* warehouse environment	There`s an extended use of robots in the production *and/or* warehouse environment	The production *and/or* warehouse environment is characterized by an increasingly use of robots and machines replacing manual work operations.
		Standardization (data standards, wireless protocols, technologies)	Standardization	Standardization of data, wireless protocols, technologies, e.g., in order to enable horizontal *and* vertical communication - between assets *and* products, asset/product-to-human/stakeholder, asset/product-to-supplier/customer communications, and interoperability both within, and between various domains. Thus, standardization is a prerequisite to enable communication between robots, machines, products and IT-systems.

6 Integrated	Internal	Increasingly number of IoT-objects, among both assets *and* products, with the ability to communicate with humans and other stakeholders, in addition to the ability to communicate horizontally and vertically, between assets *and* products	Increasingly number of IoT-objects, among both the assets *and* products Asset/product-to-human/stakeholder communication internally Horizontal communication *and* vertical communication, between assets *and* products	For products, for instance, based on the example outlined at level 3, if a thruster engine in a ship starts to get heated, the thruster can send a notification about the high temperature to the ship who can look into the data transmitted from the thruster, and see what actions that needs to be taken. In addition to the ship owner, other stakeholders, e.g. a person responsible for the maintenance of the ship, can assist the owner with error diagnosis. The thrusters can also communicate with the ships engine-system, for instance, can the engine-system be automatically turned off, or the speed can be lowered, in case of errors. If the ship has several thrusters, the engine power can automatically be adjusted and switched to the other thrusters, to avoid crucial damage on the overheated thruster.
		IoT-objects with self-management capabilities	IoT-objects have self-management capabilities	For products for instance, it can mean that the products are able to sense position, light conditions, weather and geographic conditions, e.g. a smart motorcycle helmet that includes a light that can be automatically activated when the light conditions are poor, and a GPS-navigation system that can reroute the planned route in case of accidents, closed roads, etc.
		Highly automated production *and/or* warehouse environment	Use of robots in the production *and/or* warehouse environment replaces a high degree of manual work operations	The production *and/or* warehouse are highly automated, where robots performs a high degree of the production *and/or* warehouse operations. For instance in the production, based on the example outlined in level 4, robots and machines have been further connected for automated production, and the movement of products between the working stations are performed by automated transport carriers, creating an automated production network monitored by an operator.
		Data Management	There exists a plan and strategy for Data Management	The connected robots, machines, products and IT-systems are constantly and increasingly exchanging various types of information and data, and the volume of the generated data and the processes which is involved in the handling of the data can be seen to become critical and important to manage.

7 Extensive	Internal and External	Increasingly number of IoT-objects, among both assets *and* products, with the ability to communicate external with a supplier *and/or* customer, in addition to the ability to communicate with humans and other stakeholders and to communicate horizontally *and* vertically, between assets *and* products	Increasingly number of IoT-objects among both assets *and* products Asset/product-to-supplier/customer communication externally Asset/product-to-human/stakeholder communication internally Horizontal communication *and* vertical communication	For assets for instance, based on the example outlined at level 5, there are an increasingly number of robots that have the ability to notify the control system about errors and need for raw materials, as well as notifying (a) collaborating robot(s) to slow down if the capacity is nearly full, or to speed up if it has excess capacity. In addition, the products are capable of communicating with the robots and machines, e.g. in the production of various juices the empty bottle can notify the robots about what juice to be filled in, and what labeling the robots should put on the bottle. The production network is characterized by being extensive; meaning that the robots have the ability to allocate some of the production capacity externally to other manufacturers in the network, and the customers can monitor the real-time status of the placed juice order, and when to expect the order delivery.
		Highly automated production *and* warehouse environments	Use of robots in the production *and* warehouse environments replaces a high degree of manual work operations	The production *and* warehouse environment are highly automated, where robots performs a high degree of the production *and* warehouse operations. Based on, and in addition to the production example outlined at level 6, the use of robots have also been implemented in the warehouse. E.g., picking and palletizing robots have been installed for shipping preparation, and automated transport carriers perform the goods movement in the warehouse, replacing manual work operations.
		Big Data Management - organization, administration and governance of great volumes, of both structured and unstructured data, ensuring good quality and useful data	Big Data Management	Based on Big Data Management and Data Analysis, one can be able to have predictive maintenance. Meaning that equipment *and/or* finished products equipped with sensors can notify operators *and/or* customers when machines, components *and/or* products are indicating malfunctions. The equipment *and/or* products can receive attention and repairs at the time when it is actually needed, rather than on a prescribed schedule when the repair may not be needed.
		Data Analysis - inspection, cleaning, transforming and modeling of data from sensors, machine-to-machine, and networks, in order to discover useful information and support business decision-making and conclusions	Actively engaged in Data Analysis	

8 4.0 Maturity	Internal and external	Optimal IoT-technology use, through seamless integration and communication between humans, robots, machines and products, and products *and* assets are equipped with communication capabilities to act independently, without direct human intervention	There`s an optimal IoT-technology use, meaning that there`s a seamless integration and communication between humans, robots, machines and products, with limited direct human intervention	Based on the example outlined at level 7, a specific example of optimal IoT-technology use can be that an empty automated product carrier equipped with a RFID-tag arrives at a workstation, and "asks" for work. The workstation identifies the carrier with use of the RFID-tag. The workstation automatically connects with the MES-system *and/or* the ERP-system and selects the next order to be produced, and further releases the production execution for the order. A unique number (production order number) tracks the production order. The manufacturing execution system can transfer this unique number, the material number and the next routing step to the workstation. The workstation can update the RFID-tag on the product carrier with this information, and the product carrier can then be sent to the next station. The product carrier will arrive at the next station, and the same process will repeat itself. If the capacity at a workstation has reached the upper level, it has the ability to allocate some of the work to other workstations internally, or to manufacturers with spare capacity externally in the network. The workstation can independently contact (a*)* robot(s) *and/or* workstations at the external manufacturers' site, and allocate some part of the production, meaning that human intervention is not needed. Further, meaning that the production and warehouse environment are completely automated, where high-skilled technological operators monitors the internal and external production network.
		Completely automated production *and* warehouse environment	The production *and* warehouse environments have been completely automated	
		Business Intelligence (BI) Continuous Improvement	Business Intelligence and Continuous Improvement	BI is a set of techniques and tools for the transformation of raw data, into meaningful and useful information for the purposes of analysis of business, which is further seen to enable continuous monitoring of real-time performance data, and correspondingly continuous improvement of business operations.

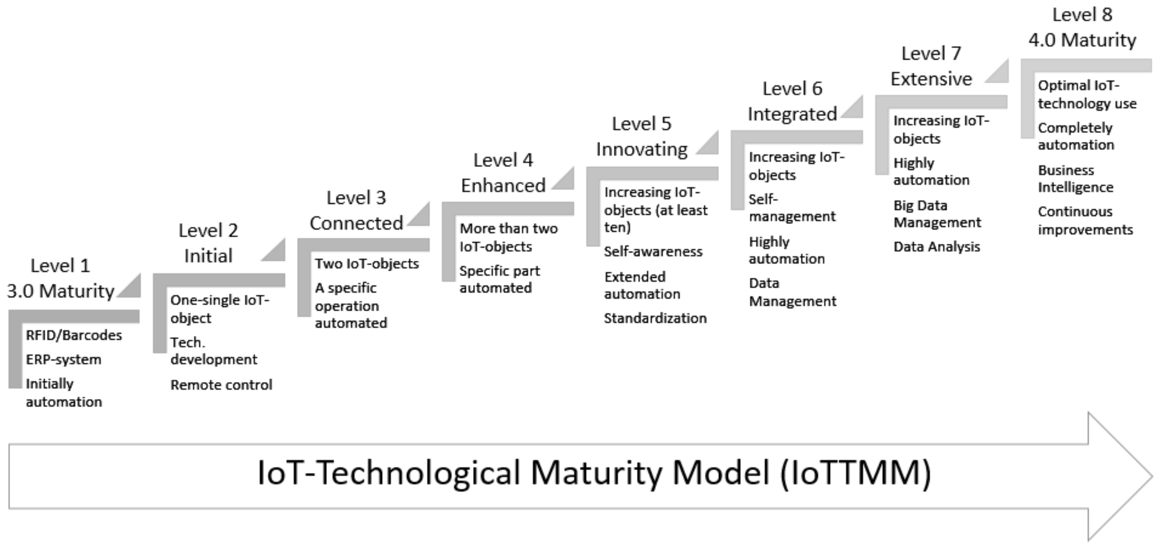

Figure 6: Visualization IoTTMM

6.0 Empirical study

In this chapter, the case companies will be introduced and the case study findings will be presented. Lastly, the assessment of the case companies will be outlined, and a potential quick tool for maturity level assessment, will be presented.

According to de Bruin et al. (2005) and Wendler (2012), many maturity models have been developed conceptually, not been rigorously tested and are thus seen to be missing validation. On the basis of this, the aim of the case study have been to test the validity of the developed IoT-Technological Maturity Model (IoTTMM), in addition to assessing the current technology level tied to the concept of IoT in the four selected case companies.

As described previously in the methodology chapter, interviews being the most common data collection method used in a case study, open-ended interviews were conducted in the different case companies for gathering the needed information for the assessment, further representing the main source of primary data in this research. Further, visual observations in the case companies' production and warehouse environments contributed to increase the impression of the technology adoption in the production and warehouse operations. In order to obtain comparable information among the four selected case companies, the structured interview guideline formed on the basis of the "order management cycle" perspective and the literature surrounding IoT, were followed as closely as possible for the interview prosecution, and the observations, of the case companies current technology adoption and status. The interview structure, which was maintained in the different companies, can be seen to have been two-folded. Meaning that the first part of the interview were focused around general information about the companies, i.e. company history and structure, number of employees, production environment (i.e. MTS, MTO, ATO, ETO), the degree of technology competence, etc. The second part of the interview was focused around the technology adoption in the different departments in the companies, i.e. sales, purchasing, production, warehouse, and accounting, with an emphasis on the technology adoption in the production and warehouse environment. Thus, the second part of the interview was conducted with the basis of the "order management cycle" perspective and the questions in this part of the interview were related to the criteria`s in the developed IoTTMM, in order to assess the company's current technology status. The use of the two-folded interview structure in combination with observations were seen to be very useful and important. This since the knowledge about the case companies and their business environments was considered to contribute for the authors to gain a deeper understanding of the companies surrounding contexts and technology adoption.

In all of the interviews and the further data collection, representatives from the companies different departments participated, which contributed to give us a thorough understanding of the companies "order management cycle" and technology adoption and status. After having obtained the needed information for the assessment, an information summary was sent to the different case companies for validation. In the following, the four different case companies will be introduced, and the case study findings and company evaluations will be presented.

6.1 Introduction of the case companies

As mentioned earlier, the four companies in this case study is Ekornes ASA, Pipelife Norge AS (Pipelife Surnadal), Brunvoll AS and Kleven Maritime AS (Kleven Verft).

6.1.1 Ekornes ASA

Ekornes is the largest furniture producer in Norway, and has the ownership over the brand names Ekornes®, Stressless® and Svane®. Ekornes ASA is the parent company in the Ekornes Group. Ekornes ASAs head quarter is co-located with the Groups plant on Ikornnes in Sykkylven municipality, Norway. Ekornes history originates from the year of 1934, when the founder Jens E. Ekornes started the production of furniture feathers on J. E Ekornes feather plant in Sykkylven municipality, Norway. The production takes place in the Ekornes Groups ten plants. The group has six plants in Norway, one in the USA, one in Thailand and two in Vietnam. The products of Ekornes are sold over large parts of the world, through own sales companies, or through importers. The Ekornes Group achieved a total sales/turnover of 2 757, 5 million NOK in 2014, and had a total number of around 2400 employees worldwide. (Annual Report 2014, Homepage, Ekornes ASA).

6.1.2 Pipelife Norge AS (Pipelife Surnadal)

Pipelife Norge AS is currently the largest producer and vendor of plastic pipe systems. The company is a part of the Pipelife Group, which is among Europe's leading producers of plastic pipes, and related parts. The Pipelife Group is present in 26 countries with a total number of approximately 2700 employees, and achieved a total sales of 872 million EUR in 2014. Pipelife produces and markets a wide range of quality pipe systems for different application areas. A typical market place for the company is road and rail construction, and a substantial part of their production volume is exported. Pipelife Norway AS has two plants, one in Stathelle (Telemark) and one in Surnadal, which serves as the case company. In addition, Pipelife Norway AS has sales offices in Oslo, Bergen and Trondheim. Pipelife Surnadal has approximately 100 employees, and this is where the main office is located. Pipelife Norway AS has experienced a tremendous growth from 442 million NOK (1996) to 905 million NOK (2013), with the foundation of their success criteria's of product innovation, and high presence in the marketplace where they focus on co-operation with their customers (Pipelife, 2015 a, Homepage, Pipelife Norway AS).

6.1.3 Brunvoll AS

Brunvoll Holding AS, fully owned by the Brunvoll family, is the holding company of the Brunvoll group of companies, consisting of seven subsidiaries, all located in Molde. Brunvoll AS is responsible for conducting the company`s business operations. The roots of the company goes back to 1912, when "Brødr. Brunvoll Motorfabrikk" was founded, by the two Brunvoll brothers, Andreas and Anders Brunvoll. The company has been present in Molde since the year 1918, and manufactured originally low-pressure diesel engines and controllable pitch propellers for fishing vessels. In the 1960s, when lightweight and high-speed diesel engines overtook the market, Brunvoll was faced with a business challenge. However, Brunvoll responded by the introduction of tunnel thrusters for purse seiners, which contributed to improve safety and efficiency in fishing operations. Since then, the company has grown into a world-leading supplier of Thruster Systems, and Brunvoll AS has delivered about 8000 thrusters to more than 5000 vessels. The company is currently present through agents in 28 different countries and has approximately 330 employees. The total revenue in (NOK 1000) in 2014 was 827 471, divided between a revenue of 546 330 from new sales and 281 141 from after-sales service (Annual Report, 2014, Homepage Brunvoll AS).

6.1.4 Kleven Maritime AS (Kleven Verft)

The Group Kleven Maritime AS was established in January 2000, and is the holding company of the Kleven group of companies. Kleven Maritime AS is a family-owned company with deep roots in the local communities, consisting of two yards, Kleven Verft and Myklebust Verft, both located at Sunnmøre. In December 2014, the total number of employees within the Kleven group, was 768. Kleven has through decades been a strong brand name within the shipping industry, delivering newbuildings, rebuilding, service and modifications. The two ship yards have a history that stretches almost hundred years back in time. Kleven Verft, which serves as the case company in this study, is located in Ulsteinvik. The ship yard mainly builds advanced offshore vessels. The yard has a module-based ship construction that enables Kleven to have increased control, better quality and shorter delivery lead times. In 2014, Kleven built and delivered 8 new buildings. The total contract value of the delivered vessels were approximately NOK 3.8 billion. In addition, Kleven completed several repairs and modifications (Annual Report, 2014, Homepage Kleven).

6.2 Case study findings

As mentioned previously, the details of each activity in the "order management cycle" varies between companies, being different for various products and services. Furthermore, the nature of companies operations can be quite different, which has led to a classification of different production strategies into Make-to-Stock (MTS), Assemble-to-Order (ATO), Make-to-Order (MTO) and Engineer-to-Order (ETO). The four selected case companies in this study are characterized by having different production strategies that entails some different characteristics and features for the companies. Ekornes ASA is characterized by production of products from raw materials or components inventory based on a received and accepted customer order. Therefore, the company`s operations are classified to be a Make-to-Order (MTO) production strategy.

Pipelife Surnadal is characterized by production of mainly standard products that are stocked, and where customers correspondingly are served from a finished goods inventory. Thus, this company`s operations are classified to be a Make-to-Stock (MTS) production strategy. Kleven Verft and Brunvoll are both characterized by that all, or a high degree, of the production activities, from design and to assembly, and in addition the purchasing of required raw materials, are related to a specific customer order. Therefore, these two companies operations are classified be Engineer-to-Order (ETO) production strategies. Moreover, these two companies can be regarded being characterized by some special features with regard to the "order management cycle". Meaning that Kleven Verft and Brunvoll typically doesn`t receive a customer order that can be reacted upon in the same manner as Ekornes and Pipelife Surnadal. Instead of the customer order, Kleven Verft and Brunvoll receives a detailed specification from a customer that creates the foundation for design and planning, leading to a quotation that is sent to the customer for approval and acceptance.

Since automation mainly occurs currently in the production and warehouse environment, the majority of information gathering and observations were associated with these departments, and somewhat less emphasis were placed on information gathering in sales, purchasing and accounting - but the most important elements according to the model criteria`s in these departments were studied.

6.2.1 Case study findings, company 1: Ekornes ASA

When it comes to the degree of technological competence in Ekornes ASA, there is in general a high level of technology competence in the company, comprising approximately 25 engineers in automation and production. Historically, the company has had somewhat low academic knowledge, where most of the employees has a more practical background. However, the level of academic knowledge has increased in recent years, since Ekornes has recognized the importance of automatization, and future technology adoption, in order to increase productivity and maintain a competitive position in the market. The company has their own IT-department with approximately 15 employees, which are responsible for application management for ensuring efficient use of their most important software. Other IT-applications as server operation, hardware operation, and internal network are currently outsourced, meaning that the company has an external supplier of these services.

In the sales department, the different sales activities is mainly performed by the support of the ERP-system, “SAP”. The sales process is initiated with a sales orders that is created on the basis of a purchase order received at one of Ekornes`s sales offices.

In the purchasing department, the purchasing practices varies for different products. When it comes to purchase orders to suppliers that the company has a frame agreement with, typically low cost products as packaging, the purchase orders are generated automatically through the ERP-system, but the purchase orders needs to be confirmed by a purchaser. When it comes to other, more complex products, purchase orders are manually entered into the ERP-system and sent to the suppliers.

In the production, the different production operations are mainly supported by the ERP-system, and the company`s Flexible Manufacturing System (FMS), which serves as their Manufacturing Execution System (MES)[8]. The FMS-system is a manufacturing system that provides some amount of flexibility to the production, meaning the possibility to react and adjust production plans in case of both predicted or unpredicted changes. Thus, the system provides Ekornes with the advantage of being able to quickly change and adapt the production due to for instance changes in market demand.

With regard to automation in the production environment, Ekornes has had robots assisting in the production since the 1990s. The company developed their own sewing robot, in corporation with NTNU Trondheim, and the world's first seam sewed by a robot, was sewed at Ekornes`s production facility. At the present time, the sewing robot are only used for less complex seams on inside materials for the products. Currently, the company`s production environment consists of approximately 130 robots that assists the manual workforce with activities in the production. The robots are programmed by the use of a standard programme, which was supplied together with the robots. The robots are not connected with the company`s ERP-system or FMS-system. At this present time the robots used in production are only able to communicate vertically to a control system. There are no communication between the robots; hence, horizontal communication is not possible. The robots can be remotely accessed, meaning that the robots can send a signal and notify a responsible operator about an error and the operator can initiate the robots from another location. In order to further develop and improve production, Ekornes has a focus on supplying information about what to produce, when to produce, and in some cases in what shape, down to operator level. Ekornes sees this as desirable, since it enables the possibility for updating information in only one system. In addition, this contributes to that every operator receives the same information, further enabling the possibility for the operator to individually plan the production in any given workday.

With regard to the movements between the different workstations in the production, in addition to the manual workforce, different modes of transport as conveyor belt, automated truck and automated trolley is utilized. When it comes to registering the level of product completion, this is performed in two different ways; either manually in the ERP-system

[8] A manufacturing execution system (MES) is a real-time system used in manufacturing, for the tracking and documentation of the transformation of raw materials into finished goods. MES can provide the right information at the right time and show manufacturing decision maker "how the current condition on the plant floor can be optimized in order to improve the production output (Wikipedia.org)

where an operator updates the production order before the trolley are sent to the next workstation, or automatically using barcodes. The barcode reader is connected to the FMS-system, which is also connected to ERP-system.

In the warehouse, a manual workforce currently carries out the different warehouse operations. When it comes to inbound logistics, a warehouse worker, based on the packing slip, purchase order and the physical goods received, manually registers goods receipt into the ERP-system. For the outbound logistics, a warehouse worker manually places the finished goods in the warehouse based on the region and/or country. This enables the company to obtain an overview, as well as to sort the goods, to be shipped to a particular region or country. The finished products are labelled with an internal barcode displaying product details as item number and region code for the shipment, enabling internal tracking of the products in the warehouse. The transport carriers usually uses their own consignment notes for the transportation. The company has considered implementation of robots for automation and RFID-technology for increased product visibility, but because of the different sizes on the products (sofa, chairs, etc.), Ekornes has found this to be difficult and expensive, at this present time.

In the accounting department, the different accounting activities is mainly supported by the ERP-system. When it comes to the handling of invoices, this is manually performed in the ERP-system based on the "Three-way match"[9] principle, but it needs to be verified by an accountant.

6.2.2 Case study findings, company 2: Pipelife Surnadal

When it comes to the degree of technological competence in Pipelife Surnadal, there is in general a high level of technology competence in the company. However, the knowledge can be seen to be somewhat unevenly distributed. For instance, the technology competence among the workers in the production is identified to be of a lower level than the rest of the company. Moreover, Pipelife envisions that this can create a challenge with regard to rapidly developments in technology, etc., in the future, and the need for higher skilled

[9] Three-way match entails that the purchase order, and the goods receipt are compared to the invoice. If the data in the three documents match, the payment is sent (Magal and Word, 2009).

workers. Further, the company currently sees it challenging to attract and get hold of production operators with technology knowledge. The company has an own Research and Development department, consisting of three engineers and civil engineers with a high expertise and knowledge, focusing on product innovation and development. In addition, the company has an own small IT- department consisting of two persons, one person as an IT-responsible and the other person as ERP-responsible. The company has currently outsourced the operation of IT-services, including servers. Based on the increasing IT-complexity and the need for more advanced IT-expertise in the production, Pipelife are considering to employ an IT-responsible resource for the automated production environment.

At Pipelife, there`s a coordination meeting every morning to inform about the current production, where persons from the different departments (i.e. sales, purchasing, production, warehouse) participates to coordinate their plans and plan their work activities. In the case of unforeseen events, adjustments to original planning schedules are jointly made. Therefore, the coordination meeting are important for the company in order to achieve an optimized production. Pipelife has implemented the ERP-system, “M3”. In addition, there are some use of other systems within the different company departments. To our knowledge, some but not all of these additional systems, have been integrated with the ERP-system.

In the sales department, the sales activities are mainly supported by the ERP-system, but some other different systems are also used. For instance, there is a different system for creating quotations for customers, named “Cordell”. In addition, when performing their sales activities they actively use the material planner program in the ERP-system in order to see what there is currently a large stock of, and correspondingly what products the sales representatives should emphasize to sell.
As mentioned, Pipelife is considered to be characterized by having a Make-to-Stock (MTS) production strategy. However, approximately 10 percent of the company`s production is related to customized orders, meaning that the company also has some characteristics in compliance with the Make-to-Order (MTO) production strategy. Therefore, the company receives both standard orders and customized orders, and the practice of receiving orders varies between standard orders and customized orders. A standard order proceeds automatically in the ERP-system if the order data from the

supplier is entered correctly. If there are some errors, as for instance unusual large amounts or wrong item numbers, the orders are stopped in the system, and must be manually changed by the sales department. Customized orders are generally received through e-mail, where the sales person needs to manually enter the order data into the ERP-system.

In the purchasing department, the purchasing activities are mainly supported by the ERP-system, but some other different systems are also used. These other systems is for instance, “Barco”, which shows an overview of the production plan, “Merit Intelligence”, which is integrated with the ERP-system and used for statistics, and “House of Control”, which is a platform for supplier agreements. The company`s purchasing practices varies with the different kinds of purchase orders, e.g. the purchase of packaging material is quite simple, but pipe materials is more comprehensive. Currently, every purchase needs an approval from a purchaser. The company has tried various practices for the purchases. For instance, a supplier previously controlled the purchasing of packaging material, but because of some dissatisfaction with the suppliers’ performance, the company decided to reclaim the control of this purchase. In addition, Pipelife emphasize on having strategic suppliers in close proximity. The company`s ERP-system, generates purchase proposals based on monthly forecasts, but because the forecasts are not sufficient and accurate enough, the purchase proposals are only used for guidance. Meaning that in general, purchase orders are mainly created manually in the company.

With the use of the Make-to-Stock (MTS) production strategy, the company manages to keep a delivery promise that standard orders that is received before 11am the present day, are picked, packed and shipped within the next day. Pipelife`s production is planned on the basis of three criteria’s, namely product stock level, expected sales and production productivity. The company has a strong focus on production efficiency and the utilization of production capacity, with a desired efficiency increase of 3.5 percent per year.

In the production, the different production operations are mainly supported by the ERP-system and “Barco”, which shows a visualized overview of the production plan and serves as the company`s MES-system. The “Barco”-system is actively used by the production operators, meaning that the operators initiates the production and manually enters the different production statuses, as product type and quantity produced, time completed, machine uptime and dividend etc. Thus, “Barco” is also used as a reporting tool, holding

the ERP-system updated with delivery dates from the production. The ERP-system is merely used as a source of information for the production operators. “Barco” and the ERP-system are integrated and the “Barco”-system communicates back and forth with the ERP-system through data files.
The production environment in Pipelife is characterized by a mix of automated- and manually production. With regard to the specific orders for customization and design, the production is carried out by the use of a manual workforce. The same applies for the production of standard products as pipes for electric installation, however, specific activities, as for instance the packaging of these standard pipes, has been automated. With regard to the production of pipe related parts, this production area has been almost fully automated by the use of robots and machines. In this production area, a manual workforce performs the switching of the casting molds that needs to be changed according to the production of the various pipe parts for the different pipes dimension. The robots and machines are able to communicate vertically through a control system and the Internet, and in addition, the robots and machines are able to communicate horizontally. For instance, at the parts packaging station, when the level of cardboard boxes are reduced, a signal is sent to the robot who puts together the boxes, to deliver more boxes. The robots are programmed by the use of a standard program, and currently there is only one operator who monitor that the production flows smoothly. The responsible operator needs to be physical present at the production site meaning that the robots and machines are not able to be remotely controlled. However, in case of errors, etc. external assistance can connect to the robots and machines through the Internet and provide help without being on-site. The production area were automated in the year 2007, prior to this there were a workforce consisting of approximately 15 persons performing the manual production of these pipe related parts. Overall, the company envisions to increase the automation in the production and recognizes the importance of adopting more advanced technology in the future.

In the warehouse, a manual workforce currently carries out the different warehouse operations with the support of the ERP-system. The company mainly uses barcodes and Quick Response-codes (QR)[10] for the labeling of the various products. Personal digital

[10] QR-codes is capable of handling several dozen to several hundred times more information than the conventional barcode (www.qrcode.com)

assistants (PDA`s) [11] have been installed in the forklifts, with the intention to scan barcodes for the goods placement and goods picking, but are currently not in use due to an anticipated upgrading of the company`s ERP-system. When it comes to inbound logistics, and when a delivery of goods are received at Pipelife, the goods are controlled on the basis of the delivery note and the packing list. If there are no deviations, the registration of the goods reception is manually entered into the ERP-system, before the goods are located at the right location in the warehouse. Finished products are labeled with barcodes and placed on a temporary location in the warehouse, before a warehouse worker places the products by the use of forklifts, on the right location in the warehouse. The finished pipes are, in addition to being marked with printed writing of the production date and time, production line, pipe type, etc., labeled with a QR-code, and placed at the company`s outside storage area by the use of forklifts and wheel loaders. When it comes to outbound logistics, a picking list based on a customer order is generated in the ERP-system that comprises the products that should be picked from the warehouse. After the goods have been picked and loaded for shipment, this is registered into the ERP-system, and a packing slip and delivery note is generated.

In the accounting department, the different accounting activities is mainly supported by the ERP-system. There are some different practices when it comes to the approval of invoices. Meaning that all the invoices, which are originated from a purchase order in the ERP-system, is automatically controlled and matched, in accordance with the “Three-way match” principle. With regard to purchase orders that has not been generated through the ERP-system, invoices needs to be manually controlled and approved through the company`s invoice system. The company is currently striving towards developing the manual routines in the accounting department, to become more automatically.

6.2.3 Case study findings, company 3: Brunvoll AS

When it comes to the degree of technological competence in Brunvoll AS, there is in general a high degree of technology competence in the company, comprising a department working with the business system (BBS) and a separate Information and Communications Technologies department (ICT- department). More specifically, the BBS-department

[11] Personal digital assistant (PDA) is a term for a small mobile hand-held device that provides computing and information storage and retrieval capabilities for personal or business use (www.techtarget.com)

consists of 4 people, mainly working with their business systems, where their goal is to be the interface between the system and users. The ICT-department consists of 5 people, mainly operating and maintaining the company`s software system and network. In addition, the company also have a software developer, which mainly works with the company`s sales support system, “Lotus Notes”, and the integration of this system, as well as the “Customer Relationship Management (CRM)” system and the “Product Data Management (PDM) ” system, into the ERP-system, “M3”.
Currently, there is an overall high focus of investments in automation in the company. Moreover, in addition to a high focus of increased automation with the use of robots and machines in the production, there is also a focus surrounding becoming a paperless organization and the automation of administrative work. Brunvoll has currently two ongoing projects; one project which comprises integrated document handling, where the intention is to achieve having all documents belonging to a specific project in one place, and one project which comprises the reduction and elimination of the use of paper documents for service engineers in the company. For instance, the company are currently developing an app for smart devices that the company`s service engineers can utilize to register the working hours spent on each project. Instead of writing the time spent on a paper slip and deliver it to an administrative consultant, the app will enable an automatically registration of the working hours into the in the ERP-system, where the consultant thus approves the recordings, before it is further processed by an accountant.

When it comes to their products, the thrusters are equipped with sensors that can measure temperature and vibration. Brunvoll provides the technology needed being able to communicate vertically via internet with their thrusters, but this requires approval from their customers. At this present time, there is no extensive use of this technology, but Brunvoll sees this to be a future area the company desires to commercialize.

In the sales department, the different sales activities is mainly performed by the support of “Lotus Notes” and the ERP-system. In accordance with the characteristics of being an Engineer-to-Order (ETO) organization, Brunvoll typically receives a request from a customer, by the means of a detailed technical specification. A quotation is made in “Lotus Notes” with the support of the ERP-system, where the price is calculated with the basis of a standard cost estimate. Since the customers’ typical requests thrusters with different features, this step contains a high degree of configuration of technical specifications that is made by a seller in the “Customer Relationship Management (CRM)” system, in order to make a quotation that matches the details requested by the customer.

In the purchasing department, the different purchasing activities is mainly supported by the ERP-system. The purchase orders in the company are mainly demand-controlled on the basis of customer orders and “Materials Requirement Planning (MRP)”[12]. Meaning that, the thruster that is ordered by the customer releases the purchase of the different parts and components that is needed for the production of the thruster. This is enabled with the support of the products MRP and the ERP-system, which contains data and information about all of the different parts and components the thruster consists of. A purchase order with the technical specification are manually created in their ERP-system and sent to the vendors, by e-mail. When it comes to the purchase of less complex parts and components, as for instance nuts and bolts, there is automatically generated a purchase order, with the use of 2-box kanban system[13]. In this case, the responsible purchaser typically generates a yearly purchase order that the workers at the goods reception occasionally makes call-offs against.

In the production, the different production operations are mainly supported by the ERP-system, and the production environment consists of both automated and manually operations. Currently, Brunvoll has one welding robot, and 20 CNC machines, which performs operations as, milling, drilling and turning independently. In addition, the company are currently also installing a grinding robot, where the only manual assistance will be when loading and unloading materials. Currently, the welding performed by the welding robot needs to be assisted by manual welding of for instance corners that requires a high accuracy. All of the machines and robots are programmed by using a standard programming system. The robots and machines are not able to be remotely accessed and controlled. If an error occurs, in either of the machines or robots, a signal is sent through a control system to the operator who`s responsible. However, the operator needs to be on-site to take care of the error. The robots and machines are not set up with the ability to

[12] Material requirements planning (MRP), which is a computer-based inventory management system designed to assist production managers in the scheduling and order placement for items of dependent demand (www.inc.com)

[13] Kanban system is a way of managing the inventory. Factory workers have two containers or boxes of inventory from which they can pull for builds. Working through one, and then the other. The quantity in the container or boxes is determined by the lead time to replenish and the consistency of usage. An empty container or box is the trigger to reorder (falconfastening.com).

communicate horizontally.
The operators in the production facility has the responsibility to start production. An overview of all projects are shown in an execution schedule in the ERP-system, with related comments whether the components needed for that particular project are available on stock or not. If all the components are available, the order is ready to be produced. When the operator presses the "produce botton" a production order is automatically printed, and a picking list is sent to the warehouse. This generates the picking and packing at the warehouse, and it further becomes the warehouse operators' responsibility to deliver the right parts and components to the right machine for production.

In the warehouse, a manual workforce currently carries out the different warehouse operations with the support of the ERP-system. For instance, the warehouse operator register physically into the ERP-system or a web-portal integrated with the ERP-system, that the different parts and components have been picked and delivered for the production. In the past, Personal digital assistants (PDA`s) were used to support the picking and delivery of parts and components to the production, but because of an outdated PDA-system, meaning that the user interface and functionality were limited, the company found it easier to manually register this activity into the ERP-system. The use of barcodes are partially implemented in the warehouse, meaning that barcodes are currently used to support the location of different parts and components in the racks in the warehouse.

In the accounting department, the different accounting activities is mainly supported by the ERP-system. The company receives many e-invoices by e-mail that automatically are scanned into the ERP-system. Moreover, these invoices are automatically processed further, and there is no need to manually type any information into the system. In addition, the company also receives some invoices on paper, and these invoices are directly scanned into the system with the support of a "recognition program", meaning that there is no manually information typing here either. The "Three-way match" is performed by the ERP-system controlling that the purchase order, goods receipt and invoice match with each other.

6.2.4 Case study findings, company 4: Kleven Verft

When it comes to the degree of technological competence in Kleven Verft, there is somewhat difficult to provide an exact answer of this, since the company has a high degree of experience-based competence. Meaning that the company has a relatively large mixture of employees with low- and high formal education. However, the company is currently in a process of enhancing the technology competence, over a broad range of knowledges. This since the company recognizes the importance of enhancing the technology competence to keep up the pace with future developments.

The shipbuilding process can be seen to be a quite complex process that entails some special features with regard to the order management cycle in Kleven. In general, the ship design process can be divided into four main stages. The first stage is the "Concept Design", where the ship type, deadweight, type of propulsion, and service speed are defined. The second stage is the "Preliminary Design" where more details, as the main hull dimensions and the elements necessary and sufficient to allow the estimation of the shipbuilding and exploitation costs, are determined. The third stage is the "Contract Design", where the elements that define the general characteristics of the ship and its main equipment, are determined. This stage further creates the foundation for the Shipbuilding that is established between the owner and the builder. In the fourth stage, "Detail Design", design details at all levels are determined in order to supply all the information necessary to its manufacture and assembly (Ship Design, Ventura). On the basis of this, and as mentioned previously in this section, one can more carefully understand that Kleven typically doesn`t just receive a sales order in the same manner as Ekornes and Pipelife Surnadal. Instead, a detailed specification and request from a customer are received at Kleven, at approximately 100 pages, which becomes their foundation for further design and planning in accordance with the general shipbuilding process outlined above. The specification includes a description of the components of the ship according to the SFI-standard, which is an international standard providing technical and financial ship information. SFI`s can be used as a basic standard for all systems in the shipping industry, which consists of a technical account structure covering all aspects of ship specifications. Based on the customer request, Kleven develops a quotation that is sent to the customer. The ship design and planning for customer quotation is mainly performed by the support of “Microsoft Excel” and “Katia”, which is a program for designing 3D-models.

Overall, Kleven makes use of many different systems in their business processes and activities. The company currently has a somewhat fragmented ERP-system, which communicates with their planning system, and the time registration system, “Tempus”. In addition, the company has a system for accounting and project information management, “Triark”, and a quality system, “ResOp”. Further, Kleven has a wide use of “Microsoft Excel”, which is not linked with the ERP-system. However, Kleven is currently implementing a new ERP-system, “Microsoft Dynamic NAV”, planning to achieve a more holistic system that can replace some, or all, use of “Microsoft Excel” spreadsheets.

In the purchasing department, the different purchasing activities is mainly supported by the use of “Microsoft Excel”. The purchasing routines varies, but typically, there are one project purchaser per project, which is responsible for the different purchasing’s. The procurement cost ratio is approximately 60% of the total ship cost, the wage cost is approximately 10 - 15% of the total ship cost, while the rest 25 - 30% is design, overhead, and additional costs. As mentioned above, the different parts for the ship is divided into SFI`s, which is the most used classification system for the maritime and offshore industry worldwide. As one can imagine, there`s a myriad of products and parts that has to be purchased for the building of a ship. Moreover, Kleven has no knowledge of all these different parts, before they are received at the warehouse.

In the production, the two main systems used are the production planning system “PrimaVera” and time registration system “Tempus”. The workers uses their access cards to stamp their working presence in the production. The workers stamps into a specific work activity, which enables the registering into the company`s time registering system “Tempus”, which is linked with the project accounting programme. Kleven has automated a high degree of the welding operations in the production. This automation is enabled by the use of fourteen robots. In addition, there are one robot that is assisting with the assembly of steel plates. Except from this, the production operations are performed by the use of a manual labor force. According to Kleven, a welding robot uses approximately 80% less input factors than that of a manual welder. In addition, comparing the quality of the welding performed by the robots to that of a manual worker, the quality is increased and the time spent on welding is significantly lower. To our knowledge, Kleven does not use a Manufacturing Execution System (MES) system to support their production. The welding robots can be programmed in two different ways, through “Delmia”, which is a part of the software package “Katia”, which is the most common and most used programming method at Kleven, mainly because it provides the best result. The other method of programming is through use of a camera. The camera takes a picture of what to be welded, and then the robot starts welding, without any manual programming. The robots are linked to a network, and can be remotely controlled, but the operators are usually on-site. The robots can communicate in two different ways; the robots can communicate with each other (horizontal), or the robots can be communicated with through a central control system.

In the warehouse, the different warehouse operations are characterized by being manually, where they use the ERP-system to register the different items and a manual workforce for the goods location. The different items gets a location and the pallets with products are labeled with the project number, and/or Purchase Order number. Most of the products Kleven order from their suppliers consists of many different components, which makes the goods receipt operation challenging. The previous case company Brunvoll is a supplier of thrusters to Kleven, and typically can a thruster from Brunvoll consist of 10 different pallets. In order to keep track of the different products received, a copy of the packing list is attached to the pallets, and when components are picked, it is manually written on the copied packing list. However, Kleven has currently no standardized routine for this. The company receives a great amount of packing lists, and it can be difficult for the warehouse workers to check if all the right items are received, etc. meaning that there`s not easy to go back and control against what has been ordered. A specially challenging area is that the company receive part-deliveries, for instance a pump, etc., and it`s difficult to investigate what delivery this single pump actually belongs to. Intending to obtain improved control of all of the different products and items in the warehouse, Kleven has decided to implement the use of barcodes to label the goods in the nearest future. The implementation are thought to take place in parallel with the implementation of the new ERP-system.

When it comes to accounting, the different accounting activities is supported by the ERP-system, which also facilitates the “Three-way match”. Some invoices are also received through e-mail, and has to be manually entered into the system.

6.3 Assessment of case companies

In the following, the assessment of the companies according to the IoTTMM criteria`s will be outlined.

6.3.1 Level 1: Criteria assessment

There`s an initial use of RFID and/or barcodes in the production and/or warehouse environment

Currently, none of the companies' uses RFID technology, but some use of barcodes are seen to have been initially implemented in all of the case companies. Ekornes mainly uses barcodes in their production as a tool for automatically registering the level of completion between the workstations. In addition, finished products at the warehouse are also labeled with barcodes that for instance enables the tracking of location in the outbound warehouse. Pipelife Surnadal mainly uses barcodes and QR-codes for the labeling of the various products. Brunvoll mainly uses barcodes to support the location of different parts and components in the warehouse. Kleven hasn`t implemented the use of barcodes currently, but the use of barcodes to label products in the warehouse will be implemented in the near future and in parallel with the implementation of the new ERP-system.

Verdict: The criteria is considered to be fulfilled for Ekornes, Pipelife Surnadal, and Brunvoll since they have an initial use of barcodes, but limited function and connection. Kleven has currently no use of barcodes. However, since the company are planning to implement the use of barcodes for product labeling in the warehouse in the nearest future, the criteria is considered to be fulfilled.

An ERP-system (or individual modules) has been implemented

Enterprise Resource Planning (ERP) is an effective business system approach that most businesses implement to enhance their productivity and performance, which is correspondingly seen to apply for all of the companies in this case study. Ekornes has implemented the integrated ERP-system, "SAP", which is the main system that is used by the different departments to support their daily working tasks, meaning that the system is used for orders, purchasing of raw materials, and the planning of production and warehouse operations, etc. Pipelife Surnadal and Brunvoll have both implemented the integrated ERP-system, "M3", which in similarity with Ekornes, is the main system that is used by the different departments to support their daily working tasks. Kleven has currently a somewhat fragmented ERP-system implemented, and much of their planning tasks is based on the use of “Microsoft Excel”, which is not linked to the ERP-system. However, Kleven has identified the need for a more holistic business system, which has led to, as mentioned, the present implementation of the new ERP-system, “Microsoft Dynamic NAV”.

Verdict: The criteria is considered to be fulfilled since all four case companies has implemented an ERP-system.

Robots are used in production and/or warehouse (at least one robot)

Referring to the case study findings, all the case companies have a mix of manually and automated production, with the use of several robots and machines. With regard to the warehouse operations, all the four case companies` warehouses are currently operated with only a manual workforce, without any automation and correspondingly a low technology use.

Verdict: The criteria is considered to be fulfilled since all four case companies have initially automated their production environment.

6.3.2 Level 2: Criteria assessment

One single IoT-object (an asset or a product)

All the four case companies are seen to fulfill the requirement of one single IoT-object by the use of robots (assets) in the production. The first IoT-object requirement can be seen to be fulfilled since the robot is seen as an electronic component with computer memory to store the information it needs for functioning, and processing capabilities and Input/Output (IO) communication facilities for performing different operations independently. With regard to the second and third IoT-object requirements, the robot does not have a globally unique identifier, but it`s seen that the robot have Internet Protocol (IP) communication capabilities since the robot can receive signals through a control system, and give signals back to the control system.

Verdict: The criteria is considered to be fulfilled since all four case companies are seen to have one IoT-enabled object within the assets.

Robots, machines and IT-systems have been initially connected for automation in the production and/or warehouse, with the ability of vertical communication

Referring to the case study findings, for all of the four case companies, robots, machines and IT-systems are found to be initially connected for automation within the production environment. In addition, vertical communication is possible through the use of a control system.

Verdict: The criteria is considered to be fulfilled since robots, machines and IT-systems are seen to be initially connected for automation within the production environment, with the ability to communicate vertically through a control system, in all four case companies.

Remotely control of assets and/or products are possible

At Ekornes, the operator are able to access and control the robots remotely, meaning that the operator doesn’t need to be physically present in the production or onsite to get notifications and status about the robot(s), and potential errors. The operator is also able to do simple programming modifications, but other more complex errors needs to be solved onsite at the production facility. At Pipelife Surnadal, the operator who is responsible for the automated part of the production has to be physical present at the production site. If errors occur, there is not possible to remotely programme, access and control the robots or machines. In similarity, at Brunvoll, the responsible operator for the robots or the CNC machines has to be physical present at the production site. With regard to the CNC machines, an error that can typically arise is that the machines needs a new tool or equipment that only the operator can change. In similarity with Ekornes, at Kleven, the operator are able to programme, access and control the robots remotely, and obtain notifications and monitor the production status.

Verdict: The criteria is considered to be fulfilled for Ekornes and Kleven, since the robots in these two companies can be remotely programmed, accessed, and controlled, without an operator being physical present at the production facility. The criteria is considered to not be fulfilled for Pipelife Surnadal and Brunvoll since it`s seen that an operator in these two companies needs to be physically present at the production site in order to programme, access and control the robots and machines.

6.3.3 Level 3: Criteria assessment

At least two IoT-objects among the products and/or assets, with the ability of vertical communication

Building on the criteria evaluation of one IoT-object from level two, it can be seen that Ekornes has at least two IoT-objects within their assets, since several robots perform most of the preparation of raw materials, as for instance the bending of steel plates supporting the various furniture`s shape. Moreover, the robots have the ability to communicate vertically with a control system. In similarity as for Ekornes, Pipelife Surnadal has at least two IoT-objects within their assets. More specifically, their automated part of production has several casting machines functioning in the same manner as mentioned above. The operator can control and monitor these casting machines by the use of a control system, and thus, it is seen that these assets have the ability to communicate vertically. Meaning that the machines for instance can communicate to the control system about the processing time, and the operator can programme and control the machines through the control system. In similarity as for Ekornes and Pipelife, it is seen that both Brunvoll and Kleven have at least two IoT-objects within their assets. At Brunvoll, the IoT-objects are seen to be present based on the robot performing the welding operation, and the CNC machines performing various operations in the production. The robot and the machines have the ability to communicate vertically with the control system. At Kleven, the IoT-objects are seen to be present based on the several robots performing the welding operations in the production line, with the ability to communicate vertically with the control system.

Verdict: The criteria is considered to be fulfilled at all four case companies since it`s seen that they have at least two IoT-objects within their assets, with the ability to communicate vertically through a control system.

At least one specific activity have been automated within the production and/or warehouse environment

At Ekornes, the sewing of less complex seams, as for instance the sewing of inner seams, is performed by a sewing robot, which can be seen as a specific operation that has been automated. At Pipelife Surnadal, the packaging of small size standard pipes for electric installation can be seen as a specific operation that has been automated. In addition, there are several robots in the production environment, performing the folding, packaging and labeling of products, as well as placing the products on pallets. At Brunvoll, the welding operation has been automated with the use of one robot. Manual workers have to assist with the more advanced welding, e.g. the welding in splices, but it seen that the robot performs the main part of the welding operation, and the welding operation is thus seen as a specific operation that has been automated. In similarity with Brunvoll, Kleven has automated their welding operation by the use of several robots, and which thus is seen as a specific operation that has been automated. In addition, Kleven has also automated the assembling of steel plates.

Verdict: The criteria is considered to be fulfilled by all four case companies since it is seen that the companies have automated a specific operation within the production.

6.3.4 Level 4: Criteria assessment

More than two IoT-objects among the assets and/or products, with the ability of horizontal communication and vertical communication between assets and/or products

Ekornes has more than two IoT-objects among their assets based on the use of several robots in the production. As mentioned previously, the robots are able to communicate vertically with the control system, however, to our knowledge; the robots are not able to communicate horizontally. Pipelife Surnadal has more than two IoT-objects among their assets based on the use of several robots and machines in the production. With regard to the fully automated production of the pipe related parts, it is seen that the robots and machines have the ability to communicate horizontally and vertically. In this production network, the robots are able to communicate vertically with a control system, and in addition, some of the robots are able to send messages and signals directly to one another. Brunvoll has more than two IoT-objects among their assets based on the use of one robot and the CNC machines in the production. However, the robot and the machines are only able to communicate vertically with the control system, meaning that the robot and the machines cannot communicate horizontally. Kleven has also more than two IoT-objects among their assets based on the use of several robots in the production. In addition, the robots have the ability to communicate both vertically and horizontally.

Verdict: The criteria is considered to be fulfilled by Pipelife Surnadal and Kleven since it`s seen that the companies has more than two IoT-objects within their assets that can communicate both vertically and horizontally. The criteria is considered to not be fulfilled by Ekornes and Brunvoll, since the assets in these companies can`t communicate horizontally.

A specific part of operations in the production and/or warehouse have been automated

Ekornes has approximately 130 robots assisting in the various production operations. However, it is not seen that a specific part of the operations in the production have been automated, since the manual workforce and the robots are both involved in the various operations in the production environment. At Pipelife Surnadal, the production of the pipe related parts is fully automated by the use of robots and machines. In the past, there were about 15 workers performing this production operation, but currently there are only one person that monitors that the production flows smoothly in this production network. Brunvoll has one robot and several CNC machines assisting in the various production operations. However, in similarity with Ekornes, it is not seen that a specific part of the operations in the production have been automated, since the manual workforce and the robot and machines are both involved in the various operations in the production environment. In similarity with Ekornes and Brunvoll, Kleven has several robots assisting in the production, but it is not seen that a specific part of the operations in the production have been automated.

Verdict: The criteria is considered to be fulfilled by Pipelife Surnadal since it`s seen that the company has automated a specific part of their production. The criteria is considered to not be fulfilled by Ekornes, Brunvoll and Kleven since there are only specific operations that are seen to have been automated, and correspondingly evaluated to not represent the criteria of that a specific part of operations in the production have been automated.

6.3.5 Level 5: Criteria assessment

When it comes to level 5, it is not found that the case companies fulfills any of the three level criteria's. This since the companies do not have at least ten IoT-objects. Moreover, the IoT-objects are only found among their assets, and not among the products. Further, IoT objects are not seen to have self-awareness capabilities, and the production and warehouse environment are not found to have an extended use of robots. Thus, since none of the companies fulfills any of the criteria`s at level 5, a further company evaluation is not seen to be necessary.

6.4 Summary and visualization of Maturity Level Assessment

Based on the assessment according to the level criteria`s previously outlined, Pipelife Surnadal is considered to achieve the highest level on the IoTTMM, namely level 4 – *Enhanced*. The three other companies Ekornes, Brunvoll and Kleven are all considered to achieve level 3 – *Connected*, at the IoTTMM. The summary and visualization of the company assessment, are presented in Table 2 and Figure 7 in the following.

Table 2: Summary of Maturity Level Assessment
(1=Ekornes, 2=Pipelife, 3=Brunvoll, 4=Kleven)

Level	Criteria	1	2	3	4
1	There`s an initial use of RFID *and/or* barcodes in the production *and/or* warehouse environment	x	x	x	x
	An ERP-system (or individual modules) has been implemented	x	x	x	x
	Robot(s) are used in the production *and/or* warehouse environment (at least one robot)	x	x	x	x
2	One single IoT-object (an asset *or* a product)	x	x	x	x
	Robots, machines and IT-systems have been initially connected for automation in the production *and/or* warehouse, with the ability of vertical communication	x	x	x	x
	Remotely control of asset(s) *and/or* product(s) are possible	x	-	-	x
3	At least two IoT-objects (assets *and/or* products) with the ability of vertical communication	x	x	x	x
	At least one specific operation has been automated within the production *and/or* warehouse environment	x	x	x	x
4	More than two IoT-objects among the assets *and/or* products, with the ability of horizontal communication *and* vertical communication between assets *and/or* products	-	x	-	x
	A specific part of operations in the production *and/or* warehouse environment have been automated	-	x	-	-
5	At least ten IoT-objects among the assets *and/or* products with the ability of horizontal communication *and* vertical communication, between assets *and/or* products				
	IoT-objects has self-awareness capabilities				
	There`s an extended use of robots in the production *and/or* warehouse environment				
	Standardization				
6	Increasingly number of IoT-objects, among both the assets *and* the products				
	Asset/product-to-human/stakeholder communication internally				
	Horizontal communication *and* vertical communication, between assets *and* products				
	IoT-objects have self-management capabilities				
	Use of robots in the production *and/or* warehouse environment replaces a high degree of manual work operations				
	There exists a plan and strategy for Data Management				
7	Increasingly number of IoT-objects among both assets *and* products				
	Asset/product-to-supplier/customer communication externally				
	Asset/product-to-human/stakeholder communication internally				
	Horizontal communication *and* vertical communication, between assets *and* products				
	Use of robots in the production *and* warehouse environments replaces a high degree of manual work operations.				
	Big Data Management				
	Actively engaged in Data Analysis				
8	There`s an optimal IoT-technology use, meaning that there`s a seamless integration and communication between humans, robots, machines and products, with limited direct human intervention				
	The production *and* warehouse environments have been completely automated				
	Business Intelligence and Continuous improvement				
Maturity level achieved		3	4	3	3

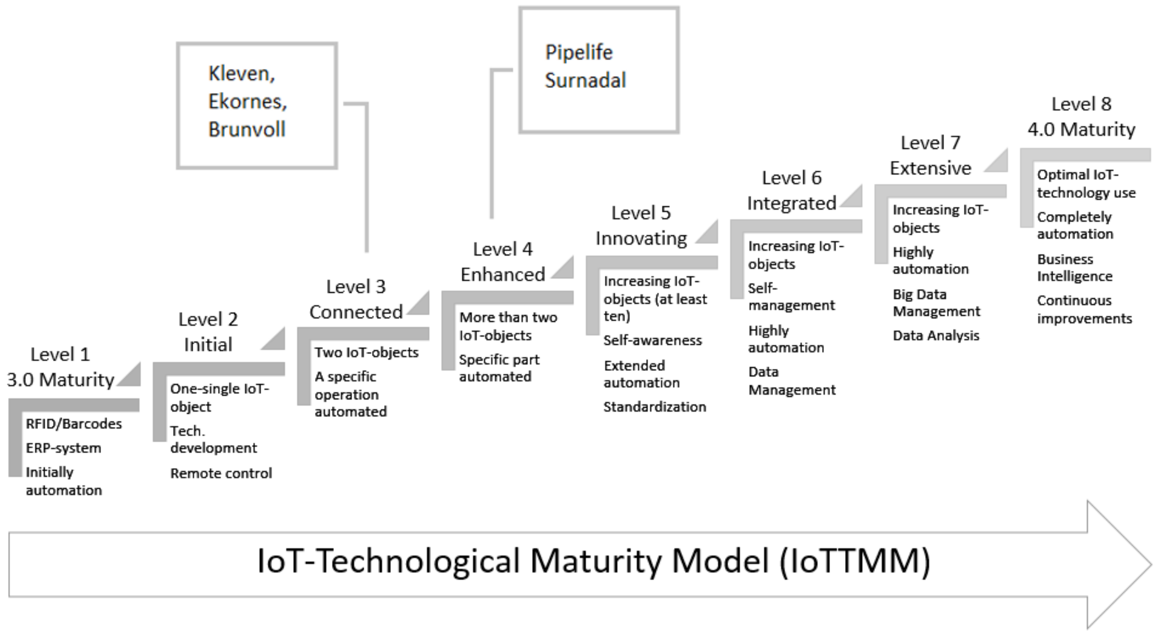

Figure 7: Visualization of Maturity Level Assessment

6.5 IoT-Technological Maturity Assessment Test

According to Netland et al. (2008), the aim of a maturity model is to aid companies with the possibility to benchmark the maturity of their operations relative to the industry best practice, assuming that companies passes through a number of maturity levels in an ascending order, before reaching best practice. With the increasingly focus around the concept of IoT, and the currently rapid technology developments, it can be seen that it can be useful for organizations to have access to a somewhat more simplified IoT-Technological Maturity Assessment Test (IoTTMAT). This maturity assessment test can be seen as a simplified test prospering from the developed IoTTMM, presented in this research. The idea behind the development of such a technological maturity assessment test is approached based on Netland et al. (2008), who developed a Supply Chain Maturity Assessment Test (SCMAT). The SCMAT is meant as a quick tool with three objectives, namely mapping the degree of a companies` supply chain activities at the strategic and operational level, communicate the degree of maturity in a logical and understandable style, and identify improvement areas in a company`s development ground. Furthermore, the idea behind the SCMAT is that it can easily be performed as a self-assessment test by companies (Netland et al., 2008). Based on this, and as an impression from the case study conducted in this research, some essential questions from the original interview guide surrounding the assessment of the IoT-Technological maturity level, could be compressed

into an IoTTMAT. The maturity assessment test could then be tested in several companies, and when validated, potentially serve as a quick tool for self-assessment and comparison against IoT-technologies current best practices.
However, due to scope- and time limitations for this research, the authors were not able to put this idea further forward. An initial planning for the IoTTMAT can be found in Appendix 4.

6.6 Recommendations on how to reach a higher level on the IoT-Technological Maturity Model

In the following, recommendations for the nearest possible actions the companies can take for further development towards the 4.0 maturity level, will be presented.

Based on the case study findings, the companies are as mentioned, placed respectively at level 3 and level 4 at the IoTTMM, which thus provides the ability to suggest some general recommendations to the case companies with regard to further development and actions to undertake, in order to reach a higher level on the IoTTMM. As the concept of IoT is still a phenomenon its further development are uncertain, and since the literature surrounding the concept of IoT is vast it has been difficult to find a particular case that could be used as a foundation to recommend further developments.

According to Kuhnle and Bitsch (2015) "an essential successful innovation path towards IoT, may be postulated by smartening up of existing items that are already involved in the manufacturing process". Based on that, a starting point would be to analyze the companies' processes, as production, warehouse, purchasing, sales etc. and identifying those areas where simplification and automation can improve the processes, and further develop clear and specific objectives and strategies for the implementation. In the following, some general recommendations for further developments, which is based on existing literature, and the criteria`s on the developed maturity model, will be presented.

<u>*Developing technological skills*</u>

According to an article in The Washington Post (2014), there will be more and more need for people who are a combination of data scientists and operation managers, also people who have both an understanding of how to use data, how to use analytics, and also an understanding of their own business lines. An important aspect to take into consideration, when it comes to the development of IoT-technologies is the need for developing the technological competence in the organization. Meaning that there might be need for other technological competence, especially as the flow of incoming data and information is increasing. It may be a need for training employees in new skills, so the organization can become more analytically rigorous and data driven, for instance in Business Intelligence and information security, to mention some (Radziwon et al., 2014). It became apparent from the case study that in general, the technological knowledge was at a high level at all the case companies, but it might be, as mentioned above, need for other types of technological competence to handle the increased incoming data and information flow. In addition, as the technology is developing and getting more advanced, the technological competence in an organization also need to be developed

Identification

IoT and “Future Factories” are still only a future vision, and how it will develop are still somewhat vague and unclear, and it would further need some efforts to become true. One thing about this vison that is certain, is that more and more objects are being connected to the internet, which gives them ability to be reached and communicated with, all over the world. According to Borgia (2014), the first step towards IoT, is the collection of information about the physical environment (e.g., temperature, humidity, brightness) or about objects (e.g., identity, state, energy level). Based on this, a starting point on the journey towards IoT, is to give products, components, machines, robots, trucks, trolleys etc. a unique name, or an identification number, as for instance an Internet Protocol (IP) address or through use of RFID technologies. RFID provides the opportunity to identify objects, and people, store the information and transfer the information via wireless communication to other electronic devices (Borgia, 2014). Identifying objects and assets gives the user efficient ways to access information about objects in the supply chain, and easily share the information with other actors. Currently, none of the case companies has made use of RFID-technology. However, all the case companies has implemented some use of barcodes, for assisting in warehouse operations, which also is a way of identifying “things” and objects. RFID-technology is considered as a more advanced technology, and a vital part of the IoT concept. The case companies should start looking into the possibilities for developing these technologies and enabling identification of object and “things”, with the use of RFID. RFID can be attached to the objects and be used for identification of materials and goods. This will among other things, help to manage the warehouse, and the production efficiently. Further, the RFID technology will provide accurate knowledge of current inventory level, thus reducing inventory inaccuracy.

Sensor technology

Sensor technology is a vital part of the development of IoT. In modern factories, sensors not only help to guide machines, but also provide the information necessary to manage the operation of the factory as a whole. Use of sensor technology integrated in products or production systems are becoming extremely important to the future industrial production. With sensors you have the ability to extract information about the product and usage history, which again can be used for resource optimizing, predictive maintenance, product development and process optimizing. The implementation of sensors will make the processes more efficient, providing constant flow of data to optimize workflow and staffing (Bughin et al., 2015). Most of the case study companies have implemented the sensor technology, embedded in their assets (e.g. robots and machines) but not fully exploited its possibilities. A step further for the case companies would be to further implement and develop their sensor technology, and more importantly, use the data which is extracted. Data extracted from the sensors are transformed into context that can be used to help people and machines make more relevant and valuable decisions. With the increased level of data, which is extracted from the sensors, a strategy and plan for data management will also be necessary.

Cloud computing

Cloud computing has long been recognized as a paradigm for big data storage and analytics, and a building block of IoT. Cloud platforms allow the sensing data to be stored and used intelligently for smart monitoring. Meaning that the service is available when you need it, by being a web-based service that can be accessed by the user, though Internet. It can also be accessed from all devices that have access to the Internet or have an Internet connection, such as tablets, mobile devices and laptops. When other “things” and objects are equipped with IP-addresses, the “things” and objects are also able to connect to the cloud. Using cloud computing enables to share data and information with other resources that have the accessing code or address, which thus makes it possible to access the cloud anytime, anywhere as they want (Vermesan and Freiss, 2014). To our knowledge, the case companies has not developed this technology. Cloud computing is as mentioned, a building block of the IoT, and should further be something that the case companies consider developing. It will increase the availability of data gathered from assets and products, and easily be distributed to other stakeholders.

Developing Machine-to-Machine (M2M) communication

Machine-to-Machine communication (M2M) is regarded to be a central technology tied to the concept of IoT. M2M-communication has been around since the early days of computing, but it has recently developed to where devices can communicate wirelessly without human intervention. M2M-communication is referred to as a form of data communication that involves one or more objects that don't need direct human interaction in the process of communication. As previously mentioned, the most popular M2M-setup has been to create a central hub that accepts signals from connected devices. Also referred to as vertical communication. The model for M2M-communication in the future, however, eliminates the central hub and has devices communicating with each other and working out problems on their own, referred to as horizontal communication (Breeden, 2015). All of the case companies have made use of the M2M-technology, however at different levels. From the case study it became apparent that Brunvoll, and Ekornes have the most popular M2M-communication, with the use of a central hub that accepts signals from connected devices. A further development would be to develop their M2M-communication technology, by eliminating the central hub, and give the devices ability to communicate with each other, without human intervention. Pipelife and Kleven on the other hand, has started to further developing the M2M-communication technology, and eliminated the central hub system on a part of their production facility. A further development will be to expand this technology to other production operations, enabling an increased M2M-environment.

With the further development of the M2M-technologies, standardization is an important aspect to take into consideration. It is seen as a key enabler for success of the communication technologies (Xu et al., 2014). The rapid growth of IoT-technologies, makes the standardization difficult (Vermesan et al., 2011; Xu et al., 2014). However, we would like to mention this as a further development, as it is important to be aware of when developing the communication technologies. This recommendation would be primarily to Pipelife and Kleven, as they have implemented the M2M-technology furthest. Furthermore, it is also something the other companies need to consider as they start developing their M2M- technologies further.

Develop the automation in the production and/or warehouse

Automation and implementation of robotics to make production and warehouse operations more efficient are an important part of the development of IoT, and to stay competitive in a global market. Automation can be traced back to the start of the first industrial revolution. As one can understand, automation has been, and still are an important part of manufacturing. Today, industrial robots are seen to be the key component of automation. Industrial robots have gone through some changes, from being large and dangerous, operating in cages, to operating alongside humans. This new generation of industrial robots enables them to perform other type of work, such as, assembling, sorting packages, and operating CNC machines (Hegerty, 2015; PwC, 2014; Wallén, 2008). The case companies have already started the replacement of manual work with automation, more precisely use of robots and machines. The degree of automation at the companies, are considered to be at different levels, and are only involved in the production or at specific operations in the production (welding, assembling, packaging). A step for further technology development, is to exploit the opportunities for automating a higher degree of the companies` production operations, and in addition, exploit automating of the warehouse activities, with the use of for instance picking and packing robots. With the new generation of industrial robots, allowing for cooperation between robots and humans, another further development of automation, would be to automate the facilitation and supplies of raw materials to the robots or other machines (e.g. the CNC machines), enabling for corporation between robots and to further develop the M2M- communication. Another operation, which seemed to be manual at all case companies, and would be a possibility for further automation, is the transportation of products and components between workstations in the production, as well as the transportation of finished goods to the warehouse. Moreover, according to Hegerty (2015); PwC (2014); Zawienska and Duffy (2014); Wallén (2008); a new generation of industrial robots are on their way. They are smarter, more mobile, collaborative, and more adaptable. In addition, they are equipped with more humanlike capabilities, as sensing, memory, self-awareness and trainability. Self-awareness capabilities are a characteristic at level 5 in the IoTTMM. As Pipelife are evaluated at level 4, a further development towards a higher level, would be to look into the possibilities for further develop their existing robots with self-awareness capabilities, or investing in new and smarter robots.

As this is a general recommendation to all the case companies, on how to further develop one need to take the companies different production environment, product complexity and the need for these particular technologies into consideration when evaluating further development of IoT-technologies. Furthermore, in order to give more detailed and specific recommendations for technology development, one need to look more closely into all of the case companies. However, this is distinguished to be out of time and scope for this master thesis.

7.0 Discussion

In this chapter, the discussion surrounding the research questions will be outlined. The discussion has been divided into sub-discussions, following the research structure. Meaning that the discussion surrounding the development of the IoT-Technological Maturity Model (IoTTMM), will firstly be outlined. Then the discussion of the case study findings and the discussion around the proposed recommendations for further development, will be outlined.

7.1 Discussion of the development of the IoT-Technological Maturity Model

In the literature, maturity models have been considered as an important instrument supporting the evaluation of organizations processes and methods according to management best practices against a set of external benchmarks (Braun, 2015; Neff et al. 2013; Wendler, 2012). In recent years, maturity models have been developed in different areas, mostly within the software industry. However, when searching through the existing literature surrounding the concept of IoT, it became evident that a maturity model for the purpose of assessing the level of technology tied to the concept of IoT in an organization, had not yet been developed. Furthermore, the literature made us familiar with the important notion that maturity models can be to offer organizations a simple, and at the same time effective opportunity to measure the quality of their business processes. Further, in addition to serve as an assessment tool that is easy to use and understand, the tool can also provide users with clear and proper guidelines for further developments and improvements related to the maturity models specific target area. Therefore, it was considered that maturity models could serve as a suitable framework for developing an IoT-Technological Maturity Model, and for the purpose of this research of assessing the current technology level of the four selected case companies. As well as providing the companies with directions for further developments in order to achieve a higher maturity level.

Another well known means of assessing the technology level that could have been appropriate in this setting, is that of "Technology Readiness Level Tool (TRL)", originally developed and used by NASA for assessing technology level. However, searching through the literature surrounding the TRL, it became obvious that the model has been through some criticism (Mahafza, 2005; Nolte et al., 2004; Sauser et al., 2006). According to Mahafza (2005), the tool is considered to not be sufficient, because it does not measure how well the technology is performing against a set of criteria, and it does not give an indication of whether or not the technology is highly or lowly mature. Further, it is lacking the “how to” guideline when implementing and using the tool. Based on that, the TRL tool was decided to not be sufficient for the purpose of use of our model. The maturity model was thus considered as being the best for developing a model for assessing the technology level of manufacturing companies with regard to the IoT. Mainly because there exists development methodologies to follow, and it is the most widely used tool for assessing organizations through a variety of domains, in addition to serve as a guideline for improvements.

Through the literature search, it also became evident that maturity models have a poor theoretical foundation and lack of documentation (Mettler, 2009). Further, de Bruin et al. (2005), argues that there is little documentation on how to develop maturity models that are theoretically sound and rigorously tested. Thus, it can be stated that the lack of theoretical foundation and documentation of maturity models is due to few available development methodologies, and another explanation could be that new developed maturity models are using earlier maturity models as a template. However, de Bruin et al. 2005, has proposed a methodology for the development of maturity models, which is further considered as the methodology mainly used by scholars for the development of maturity models. Based on this in particular, and in order to overcome the criticism of earlier developed maturity models, it was decided to apply the methodology proposed by de Bruin et al. 2005 when developing the IoTTMM. Other development methodologies, as for instance the Design science research guideline methodology mentioned by Wendler (2012), would also have been appropriate. However, it was decided to apply the methodology proposed by de Bruin et al. (2005) due to the fact of being the most commonly used methodology, as well as being considered as the most suitable and applicable methodology for our research. However, in order to evaluate the design and research rigor, the research cycle mentioned by Wendler (2012) was also taken into consideration, in addition to the methodology by de Bruin et al. (2005).

During the development of the IoTTMM, it was emphasized to follow the methodology proposed by de Bruin et al. (2005) in as close compliance as possible, in order to ensure that our model would be theoretically sound, and rigorously tested. The methodology consists of six phases, namely *scope, design, populate, test, deploy, maintain*. However, as mentioned, we only had the ability to perform the five first phases of the methodology, as the sixth and last phase, *maintain*, is characterized by having a more long-term perspective and entailing that the model should be maintained with necessary updates over time, which came to be in conflict with time- and scope restrictions for this research. The three first phases, *scope*, *design* and *populate*, of the development methodology were performed through literature reviews, mainly based on literature surrounding existing maturity models, the technology in previous industrial revolutions – limited to the third industrial revolution, and the new technologies surrounding the envisioned fourth industrial revolution – mainly surrounding the concept of IoT. Further, one could have included technological aspects of earlier industrial revolutions. However, as it became evident that companies currently are distinguished to be at the brink of embracing the fourth industrial revolution, it was decided to focus around and include the technologies from the maturity of the third revolution, as well as the technologies surrounding the envisioned fourth revolution, when developing our maturity model. The fourth phase, *test*, was carried out through a case study of the four selected manufacturing companies, in order to test the applicability of the IoTTMM. The fifth phase, *deploy*, which entails that the model is made available for use, can be seen to be set forth by the submission of this master thesis to Molde University College (MUC), as well as with the publishment of the scientific article "IoT Technological Maturity Model and assessment of Norwegian manufacturing companies”, by Jæger et al., 2016.

As mentioned in chapter 5, the literature review surrounding the research field of IoT and the related technologies to the maturity of the third revolution and the envisioned fourth revolution, made the foundation for the various levels in the developed IoTTMM. According to de Bruin et al. (2005), there are in general two ways of developing a maturity model, using a bottom-up or a top-down approach. With the bottom-up approach, the assessment criteria’s are developed first and then the definitions are written in compliance with the criteria descriptions. With a top-down approach, the definitions are written first and then the assessment criteria’s are developed to match the definitions.
Since the development of the IoTTMM was decided to mainly be based on existing literature, which correspondingly served as the foundation for the level characteristics and the level criteria`s, the bottom-up approach was found to be most appropriate for the model

development, and thereby applied. Meaning that the characteristics and the criteria's were first developed, based on the existing literature as previously described, and then appropriate definitions were formed in compliance and based on the characteristics and criteria's. Further, it was emphasized to present each maturity level through *definitions, characteristics, criteria`s* and *specific technology examples,* collectively in a model summary table in order to create an easy understandable model. In the summary table of the model, the definitions serves as a collective term representing the characteristics and criteria`s. The characteristics represents a general description of the technology that was considered essential to the maturity of the third and the envisioned fourth industrial revolution. The criteria`s further specifies the characteristics, and serves as a minimum for what should be fulfilled for an organization in order to be assessed being at a particular level. The intention of presenting specific technology examples, were to give practical descriptions of the level characteristics and related criteria`s, in order to potentially increase the understanding of the various model levels, and make it easier for users that for instance is not so familiarized with the concept of IoT and the corresponding technology, to use the model.

7.2 Discussion of the case study findings

Since there is, as mentioned earlier, a degree of criticism surrounding the development of maturity models, the applicability of the developed IoTTMM was tested through performing a case study of four selected manufacturing companies, by assessing their current technological level and further placing them on the maturity model. The concept of IoT is still characterized by being a future vision, and it`s argued in the literature that the concept of IoT and the related technology is still a phenomenon, and that the outcome and further development of the technology is somewhat unclear (Haddara and Elragal, 2015). Thus, as one can understand, it`s difficult to test every level of the IoTTMM currently, especially the highest levels, since these levels are characterized by representing precisely the path towards the maturity of the envisioned fourth revolution which will occur in the future. As mentioned, due to time- and scope restrictions for this research, we were not able to perform the sixth phase of the development methodology proposed by de Bruin et al. (2005). Hopefully, this last phase of maintaining the model can be carried out as future research, which thus will contribute to test the highest levels of the IoTTMM, as well as potentially modifying the model in accordance with the future developments. However, regarding the lowest levels of the IoTTMM, these were tested through the interviews and guided observation tours through the production- and warehouse environments in the case companies. Through this phase, it became evident that with the support of the lowest levels of the IoTTMM it was possible for the researchers to approach the companies with a low previous knowledge of the companies` technology adoption and to assess their current technology level with the support of the developed IoTTMM. Even though the highest levels of the IoTTMM could not be tested as described, we believe that the model represents the possible further development of the technology regarding the concept of IoT at this point of time, as the levels have been developed in close compliance with the existing literature surrounding the concept of IoT. Moreover, providing the companies with the an overview of the assessment result and their technology status tied to the concept of IoT, the companies can set a level target and achieve guidelines and inspiration for further developments and improvements based on the characteristics and criteria`s in the IoTTMM.

As it`s noticed that almost all companies, either it`s a small manufacturing company or a global manufacturing enterprise, have the same general activities included in their "order management cycle" (Shapiro et al., 1992), the "order management cycle " perspective were found to be a suitable framework for the assessment of the case companies. Moreover, it`s believed that by following the "order management cycle" perspective, through the combination of interviews and visual observations of the technology adoption in the various departments and operations in the companies, a good overview of the case companies current technology status were obtained. Further, it`s believed that this contributed to a sound evaluation of the technology adoption and status tied to the concept of IoT of the case companies, and the correspondingly company placement on the IoTTMM. Through the literature review, it became evident that the literature concerning IoT-technologies and automation in particular, have mainly been focused around production situations characterized as standardized, high-volume, low variety production strategies, also known as, Make-to-Stock (MTS) (Sjøbakk et al., 2014). Whereas production strategies that have been less considered in the literature, concerning IoT-technologies and automation, is characterized by technical complexity, customization, short product life cycles and variable demand, also known as Engineer-to-order (ETO). Further, automation is defined as the degree to which automation can be used to replace human labor by machines. It is argued in the literature that automation is generally reviewed to be an effective way of reducing production and labor costs, decreasing production cycle times and increasing quality in production strategies which is characterized by standardization, high-volume and low variety, also known as Make-to-Stock (MTS). For such production operations, which is typically standardized and repetitive, robots can perform the operations, cost efficiently and accurate. However, when it comes to production operations dominated by complexity, flexibility and customization, Engineer-to-Order (ETO) production strategy, manual labor has mainly been preferred over automation (Sjøbakk et al., 2014). Comparing this to the case study findings, it seems that the findings are in close compliance with the literature surrounding the different production strategies and automation. Moreover, it was found that Pipelife which is considered operating in Make-to-Stock (MTS) production strategy, and Ekornes, which is operating in a Make-to-Order (MTO) production strategy had the highest level of automation in their production, compared to the two other case companies, Kleven and Brunvoll, which are considered to be operating in Engineer-to-Order (ETO) production strategy. One explanation to this can be their generally high focus on technology development, in combination with the fact that Ekornes and Pipelife Surnadal`s products and production processes are considered as less complex and standardized, with a lower variety in the production, as compared to the Engineer-to-Order (ETO) companies. Which according to the literature is production situations that is more suitable for automation, and which thus, can be regarded to be the main explanatory factor for their higher level of automation, as compared to the lower level of automation in the case companies Kleven and Brunvoll.

As this assessment are considering more explicitly the IoT related technologies, other technological factors and characteristics tied to the concept of IoT was also assessed in the case companies, which further resulted in the placement of the companies on the IoTTMM.

Based on the case study findings, it was considered that Pipelife Surnadal achieved the highest maturity level of the case companies, namely level 4 – *Enhanced*, while the three other companies, Ekornes, Kleven and Brunvoll, achieved level 3 – *Connected*. It was revealed through the case study that Brunvoll and Piplife Surnadal did not fulfill a requirement at level 2, namely the criteria of having the ability to remotely control asset(s) and/or product(s). However, since both of the companies fulfilled all the criteria`s at level 1 and 3, this was not taken into consideration when evaluating their final level.

The main reason for the assessment result, where Pipelife was evaluated to achieve a higher level of the IoTTMM than the three other case companies, are regarded to be that Pipelife has achieved to virtually automate completely the production of pipe related parts. Further, the production of the pipe related parts have been transformed into a “self-going” production environment where the robots and machines have the ability to communicate directly to each other (horizontal communication), as well as through a control system (vertical communication). The production environment are currently monitored by only one operator, while there were approximately 15 workers performing the manual operation in this part of the production before it was automated. Based on the existing literature surrounding the concept of IoT, it could be stated that this technology adoption and development at Pipelife is in close compliance with some of the elements of the envisioned fourth industrial revolution. Meaning that for instance the development of this production network can be seen to have dramatically altered a part of Pipelife`s production environment, as it has replaced the workforce earlier performing the manual operations for the parts production. Further, the technology adoption and development of the Machine-to-Machine (M2M) communication, which is distinguished to be an essential IoT-technology, has led to new interactions between robots, machines and humans, at Pipelife.

As mentioned above, in compliance with Pipelife, Ekornes also has a high degree of automation in their production, which has replaced some of the manual work operations. Moreover, Ekornes has been referred to in newspaper articles as a company that can be seen to be leading in Norway with regard to the adoption of robots in the production environment. Thus, before the case study, there was a small expectation connected to that Ekornes could be the company that would achieve the highest level of the IoTTMM. However, an essential part of the IoT-technologies is that of Machine-to-machine (M2M) communication as mentioned above, where the communication between the robots and machines are performed with minimal or without human intervention, which is correspondingly a criteria at level 4 in the IoTTMM. During the case study it was revealed that the robots and machines at Ekornes did not have this technology developed currently, and thus, Ekornes could not fulfill the required criteria at level 4, in the same manner as Pipelife, who has this technology developed in their parts production network. Thus, even though Ekornes has a high degree of automation in their production, the company could not be evaluated to fulfill the criteria`s at level 4 since their automation can be seen to be characterized by being somewhat fragmented. Meaning that their robots and machines are working mainly independently, with the ability of only vertical communication, and not horizontal communication. When it comes to Kleven and Brunvoll, these companies were found to have implemented a lower degree of automation compared to Pipelife and Ekornes, respectively the companies has automated only a minor part of specific operations. With regard to Brunvoll, the robot and machines were only set up with the ability of vertical communication. It was found that Kleven fulfilled the criteria of both horizontal and vertical communications with regard to their robots, and thus fulfilling one of the criteria`s at level 4. However, since it was found that Kleven had a lower degree of automation as compared to Pipelife and Ekornes, it was decided that Kleven respectively should achieve level 3. As both Kleven and Brunvoll are characterized by having an Engineer-to-Order (ETO) production strategy, it can be argued that the lower degree of automation is present most likely due to the complexity of production operations and products, which requires a higher degree of manual work, which is in accordance with the existing literature. For instance, it was revealed that both Kleven and Brunvoll have automated a degree of their welding operations. However, the companies needed to assist with manual welding for especially challenging areas of the materials being welded, as for instance corners and angles of the materials, which can thus be seen to highlighting the nature of their complex products and production situations.

As mentioned, Brunvoll and Kleven are considered to be operating with Engineer-to-Order (ETO) production strategies, characterized by a highly complex production environment with labor intensive operations, customization and variable demand – where manual labor traditionally has been preferred over automation. However, with the rapid development of new technology for flexible manufacturing and robotics, it`s increasingly being seen in the literature that it can become possible to automate manufacturing processes that have traditionally been considered as less appropriate for automation in the future. Thus, it can be likely that Kleven and Brunvoll can be able to automate a higher degree of their production environments in the future, as the technology developments progresses and potentially leads to more appropriate technology features for automation in more complex manufacturing processes.

Furthermore, from the case study findings, we have the impression that technology is an area that is in high focus in all of the four case companies, and there seems to be a common emphasis currently towards investments and adoption of new technology in both production and warehouse operations.

Lastly, it could be interpreted that the focus in this assessment has been on merely technology, and that if other factors were taken into consideration, as for instance product complexity and production strategy (MTS/ATO/MTO/ETO), the company assessment could potentially have provided another result. Meaning that since the companies in this case study operates in different production environments, the companies are faced with different challenges regarding technology adoption and automation. Due to the time-and scope restrictions for this research, it was decided to not take this into closer consideration, but we suggest that this could be a potential factor to take into consideration, and develop the IoTTMM with in further research.

Comparison of the case study findings to "Konjunkturrapporten 2016"

Mentioned in chapter 2, "Norsk Industri" previously this year published the report "Konjunkturrapporten, 2016" which contained a research surrounding Norwegian industrial manufacturers and their current level of digitalization and use of robotics. The largest proportion of the companies being surveyed operated with Make-to-Order (MTO) or Engineer-to-Order (ETO) production strategies. Moreover, the survey revealed a large spread in the current situation in the Norwegian manufacturing industry, spreading from operations mainly based on manual work and paper-based information sharing, to digitalization and production operations based on automation.

The survey revealed that only half of the surveyed companies had one or more robot(s), and that there are still a large proportion of manual work operations. The research also showed that automation is mostly used in production, while technology for supporting other logistics operations seems to be rarely implemented. Further, the research revealed that the surveyed companies have progressed further when it comes to implementation and use of digital information sharing internally and externally towards customers and suppliers, than automation and robotics. However, there are still some companies, which according to "Norsk Industri", are in the "paper age", which is defined from the company's ability to handle production orders and/or other documentations digitally. Overall, the research revealed that Norwegian manufacturers have started their digital journey, towards the concept of IoT and smart manufacturing. However, it is concluded that the generally low level and the large spread of automation in the surveyed companies, is mainly based on the high level of companies operating with Make-to-Order (MTO) or Engineer-to-Order (ETO) production strategies. Which as mentioned, are considered to be more difficult and less favorable to automate, as the products and production processes are more complex than that of the Make-to-Stock (MTS) production strategy.

Interestingly, the research conducted by “Norsk Industri” and the case study findings in this research, seems to display roughly the same results. Even though “Norsk Industri” has studied a bigger sample of manufacturers, as compared to this research, there are similarities in the concluding remarks, where the level of automation within manufacturers seems to be based on their production strategy (e.g. MTS, ATO, MTO and ETO). Further, the research displays that automation is more or less only present in the production, and rarely in logistics or warehouse operations, which is consistent with the case study findings in this research showing that automation is present only in the production in the four manufacturing companies. In addition, the research also reveals that the industry are well on their way on their journey towards IoT and smart manufacturing, which can be regarded to be consistent with the case study findings in this research as well.

7.3 Discussion of the recommendations for further technology development

The concept of IoT, is recognized as one of the most important areas of future technology, which has gained an increased attention from a wide range of industries, as well as researchers. Furthermore, the actualization of the concept of IoT into the real world is considered becoming possible through the integration of several new technologies. Moreover, among these various technologies, some technologies can be designated as being the most essential and relevant technologies (Atzori et al., 2010; Botta et al., 2016; IEC, 2015; Lee and Lee, 2015; Li et al., 2016). The technologies that are most frequently mentioned in the literature, and considered as central IoT-technologies, seems to be; identification and Internet connection technologies, sensor technology, cloud computing, extended automation, and Machine-to-Machine (M2M) communication technology.

Since the concept of IoT is still a future vision, and the IoT-technologies can be seen to be under continuous development, one can almost immediately understand that the case companies haven`t adopted all the IoT-technologies at this present time. Moreover, even though the adoption of the new technology is considered to create value to the supply chain, and to manufacturers as a whole (IEC, 2015; Sundmaeker et al., 2010; Wagenaar 2012), one can understand that the companies can be uncertain and confused regarding the technology adoption since the concept of IoT is characterized by being somewhat fuzzy. Further, a possible explanation regarding this uncertainty can be the lack of research and documentation of actual gains related to the adoption of IoT-technology, as the concept is quite new. Another explanation can be the lack of knowledge and expertise for implementing and using such technology. It became apparent from the case study findings that technology is a high priority in all four case companies, and that some degree of the essential and basic IoT-technologies have been implemented. However, the developed IoTTMM including the designated path from the literature towards the future optimal IoT-Technological Maturity Model level, creates the basis for providing some recommendations to the case companies in order to achieve a higher level on the IoTTMM, based on the companies` current technology level.

IoT is recognized as bringing with it a vast amount of data and information, by the embedded sensors and RFID equipped at machines, objects etc. This available real-time information can thus contribute to add value for supply chains. However, according to Radziwon et al. (2014), and The Washington Post (2014), with the increased level of incoming data and information, there might be need for new technological skills. Which means that the companies needs to become more analytical and data driven, and for instance adopt to business intelligence and information security. Based on that, developing their technological skills is considered as being an important recommendation for further development.

In the literature, it is argued that a central part of IoT is the collection of data and information about the physical environment and about objects. Borgia (2014), states that the first step towards IoT is to equip objects and "things" with identification technology, which enables Internet communication. This is further realized through use of RFID technology, sensors or IP-communication capabilities. In addition to what is argued by Borgia (2014), identification is a widely used term, especially when it comes to the various definitions surrounding IoT (Sehgal et al., 2014; Sundmaeker et al., 2010; Vermesan and Friess 2014). Based on this, one can understand that the identification technology is an essential technology with regard to the concept of IoT, as the core concept of IoT is that "things", objects, assets etc. should be connected to the Internet. Furthermore, as this is considered as an essential IoT-technology, and none of the case companies has implemented this kind of identification technology, this is recommended as a further development towards a higher level on the IoTTMM. It came apparent from the case study findings, that all the case companies has implemented a limited use of barcodes for assisting in warehouse operations. However, barcodes are not considered as an IoT-technology, even though it is a type of identification. Therefore, a recommendation for the case companies is to further develop their identification technology for assets and products.

In addition, sensor technology is a vital part of automatization and the development of IoT (Atzori et al., 2010; Botta et al., 2016; IEC, 2015; Lee and Lee, 2015; Li et al., 2016). Sensors not only assists to guide the machines, but the sensors also provides companies with the information necessary to manage the operation of the factory as a whole. In addition, with products equipped with sensors, one have the ability to extract information about the product and usage history, which again can be used for resource optimizing, predictive maintenance, product development and process optimizing. Brunvoll is currently the only company which has equipped their final product with sensors. By equipping their thrusters with sensors, Brunvoll can be able to take advantage of the predictive maintenance. This is something that is still under development at Brunvoll, and is therefore not fully implemented. Based on that, developing the sensor technology for assets and products is considered as an important part of IoT and is therefore listed as a further technological development for the companies.

In addition, the increased amount of available data and information requires technology that can handle and store the enormous streams of data that IoT-technologies, e.g., the sensors and identification technology, will transmit. Thus, another technology that is considered as essential with regard to the IoT, is that of cloud computing which is considered to be an ideal solution for handling and storing the enormous amount of data (Lee and Lee, 2015), and is therefore considered as an important further development for the companies.

IoT is powered by Machine-to-Machine (M2M) communication, and is seen to be an essential IoT-technology, which allows for communication between objects (e.g. products, robots), sensor network and human beings, using different communication protocols (Lee and Lee, 2015). M2M-communication has been around since the early days of computing, but has with the development in ICT, been further developed, where devices can communicate without human intervention. In addition, an important aspect with M2M-communication, which has got increasingly attention, is that of, global standards. This is considered as a key enabler for success of the communication technologies (Xu et al., 2014). Furthermore, standardization are seen as a prerequisite for ensure devices from different firms and countries to be able to exchange information and communicate with each other. The rapid growth of IoT-technologies, makes the standardization difficult (Vermesan et al., 2011; Xu et al., 2014). M2M-communication is considered as an essential technology in the era of IoT, and is by that listed as a further development for the case companies. All the companies has implemented the technology at different levels, thus there is a need for further development, for reaching a higher level at the IoTTMM scale. For Pipelife, which is considered as being at level 4 on the IoTTMM, need to further develop their M2M- communication. As of today, the most developed M2M-communication was present in only one part of their production. In addition, Pipelife should considering the use of standards when further implementing the M2M-communication. When it comes to the three other companies, in order to reach a higher level on the IoTTMM, further development in M2M-communication is necessary, for developing from vertical towards horizontal communication, with limited or no human intervention. Considering the essential above technologies, it becomes evident that these technologies are interconnected, where implementation of one technology leads to the need for implementation of the other. The case study findings in this research, revealed that none of these technologies are extensively implemented, which thus created the main foundation for recommendations for further developments.

Automation has been around since the start of the first industrial revolution. However, the use of robots and industrial robots in particular can be traced back to the 1960s. As one can understand, automation and robots has been, and still are an important part in manufacturing. It is argued to increasing the efficiency, reducing costs, and improve product quality (PwC, 2014; Wallén, 2008). Robots has most frequently replaced humans in repetitive, heavy and dangerous tasks, as, welding, grinding and assembly. Which also is seen to be the situation at the evaluated case companies. However, with the developments in ICT, the envisioned fourth revolution and the concept of IoT, industrial robots have been further developed, and equipped with more “human” capabilities. Thus, making them able to perform other type of work operations – such as testing and inspection, and assembly. In addition, industrial robots have been developed to cooperate with humans, instead of working separately from each other. With the increasing development of industrial robot, a central “human” characteristic increasingly mentioned, is that of self-awareness (Hernàndez and Reiff-Marganiec, 2014; Zawienska and Duffy

2014*)*. With self-awareness capabilities robots has the ability to sense its own internal state, thus react and monitor its own limitations. In addition, robots are better to adapt to unpredictable environments, and change their behaviors. As the robots become more humanlike, with human capabilities, they are able to increasingly perform other tasks, and assist humans in their work. All the case companies have implemented some automation in their production environment, for replacing human labor. However, the companies are not considered to have fully implemented the newly developed “smart” robots and machines. Thus, makes the exploitation of further technology development and automation considered as an essential recommendation for reaching a higher level on the IoTTMM.

8.0 Conclusion

The aim of this research was to develop an IoT-Technological Maturity Model (IoTTMM) that can be utilized for assessment of organizations current technology adoption tied to the concept of “Internet of Things (IoT)”. Which further could serve as a foundation for providing companies in the manufacturing industry with suggestions for future technology adoption and development, in accordance with the concept of IoT. As this research has been a part of the project “Manufacturing Network 4.0”, this further entailed to perform an assessment of the technology level tied to the concept of IoT for four Norwegian Manufacturing companies, participating in the project. An in-depth study of these manufacturing companies was carried out to develop and refine the IoTTMM in the development phase. The final model was then used for an assessment of each of the companies` current technology status with regard to the concept of IoT, which furthermore resulted in recommendations for further technology adoption and development.

The exploratory research method was applied in this research, as the purpose was to investigate a research area that is under-researched. The exploratory research method allowed the researchers to answer the formulated research questions.

With regard to the first main research question, “How can an IoT-Technological Maturity Model for assessment of Norwegian Manufacturing Companies be developed?” this research has shown that it has been possible to develop an IoTTMM with the basis of the maturity model development methodology proposed by de Bruin et al. 2005, and the existing literature surrounding maturity models, and the concept of IoT. Moreover, this research presents a maturity model comprising eight various levels, ranging from the lowest maturity level, level 1: 3.0 Maturity - which is considered to be the maturity of the third industrial revolution, to the highest maturity level, level 8: 4.0 Maturity – regarded to be the optimal level of the concept of IoT, and the envisioned fourth industrial revolution. Each of the various levels in the IoTTMM are defined to have distinctive characteristics, and correspondingly assessment criteria`s, representing a certain level of the IoTTMM. The composition of the IoTTMM various levels, based on the four parameters, level, range, characteristics and criteria, combined with specific technology examples presented in the model summary, present an easy understandable overview of the IoTTMM. Moreover, based on this composition, and especially the use of the characteristics and criteria`s, various organizations within the manufacturing industry might be able to identify or obtain an impression of their own maturity level with regard to the concept of IoT, based on their current technology status and adoption.

Further, this composition provides organizations with a clear guidance and suggestions for technology development and adoption for achieving a higher level of the IoTTMM.

Based on the methodology proposed by de Bruin et al. (2005), an important part of the development of the IoTTMM was to test the model, in order to ensure model and research relevance and rigor. Moreover, the testing of the model and the need for the selected case companies to achieve an assessment of their current technology status tied to the concept of IoT, served as the main foundation for including the second research question, “What is the current IoT-Technological Maturity Model level for the four selected case companies?”. Therefore, the developed maturity model was tested through interviews and observations in the four selected case companies, Ekornes, Pipelife Surnadal, Kleven Verft and Brunvoll, and it was found that the IoTTMM made it possible to assess the companies` current technology level tied to the concept of IoT. The four case companies were evaluated according to the specific criteria`s developed from the characteristics for the various maturity model levels. It was found that Pipelife Surnadal achieved the highest level on the IoTTMM of the four case companies, namely level 4 – Enhanced, while the three other case companies were evaluated to fulfill level 3 – Connected. The main reason for assessing Pipelife Surnadal to achieve the highest IoTTMM was based on the findings that the company had completely automated a part of their production, and developed a “self-going” production network where the robots and machines had the ability of vertical- and horizontal communication, monitored by only one operator. The main reason for assessing the three other companies to achieve level 3 were based on the findings that the companies had more fragmented production environments, meaning that there were only specific operations that had been automated. In addition, the findings revealed that Ekornes and Brunvoll only had robots and machines with the ability of vertical communication. It was revealed that the welding robots at Kleven Verft fulfilled the criteria of both vertical- and horizontal-communication on level 4. However, it was not found that the company had automated a specific part of their operations, in similarity as for Pipelife, thus it was evaluated that Kleven achieved level 3 on the IoTTMM. It was further found that none of the case companies fulfilled any of the criteria`s on the higher levels on the IoTTMM, which thus resulted in that it was not possible to test the higher levels of the IoTTMM in this research. More importantly, since the concept of IoT is still a phenomenon, it is obviously not possible to test the entire maturity model at this point of time. Based on the existing literature, it is considered that the IoTTMM presents a corresponding path of the necessary technology developments in order to reach the optimal IoT-level, namely level 8, 4.0 Maturity, as foreseen in the future. Furthermore, this provided the foundation for answering the second sub-research question, "How can the case companies develop in order to reach a higher level on the IoT-Technological Maturity Model?". Based on the case study findings and company assessment, and the developed IoTTMM, it was possible to provide general recommendations for the nearest possible actions the companies can undertake in order to reach a higher level on the IoTTMM. There was decided to provide six general recommendations, prospering from the case study findings and the developed IoTTMM. The six general recommendations were suggested to be developing the technological competence and skills among the workers, identification of assets and products, further implement the use of sensor technology and use the extracted sensor data, explore the use of cloud computing, and further developing the Machine-to-Machine (M2M) communications, and increase the degree of automation and robotics in the production and warehouse.

The concluding remarks of this research is that the developed IoTTMM reflects a presumed evolution path of the use of IoT-technologies through eight maturity levels for manufacturing companies. The model may serve as a tool for management supporting the adoption of the technologies tied to the concept of IoT. In addition, the model can be a reference frame for assessing companies` maturity level tied to the concept of IoT as well as being a benchmark against other manufacturing companies, and for implementing an approach for technology improvements. Specifically for this research, the technological maturity level of the Norwegian manufacturing companies gives knowledge of the current technology level of these industries, as well as providing a direction path for technology adoption towards the concept of IoT and the envisioned fourth industrial revolution. The research can be seen to contribute to fill a literature-gap and enrich the literature surrounding maturity models and the concept of IoT.

8.1 Limitations and further research

The purpose of this research was to develop an IoT-Technological Maturity Model (IoTTMM) who could enable the assessment of four Norwegian manufacturing companies and their technology status tied to the concept of IoT, and provide the companies with recommendations for further technology development.

Due to the time- and scope restrictions for this master thesis, the research was delimitated to investigate the technology level of the four case companies. Several interesting findings have been made, and all the case companies had interesting and challenging areas to investigate, but time- and scope restrictions for this master thesis limited the research.

We were inspired to perform a maturity assessment test for assessing the technological level on other manufacturing companies, but we were limited as mentioned by time and scope. Thus, a simple proposal was developed, including essential questions related to the IoT-technologies. Correspondingly, a suggestion for further research is that one could further develop the assessment test, in order for assessing other manufacturing companies, and hopefully be able to test more of the IoTTMM. It was not possible to test the whole model, as expected, because the IoT is still only a vision. In addition, the last phase, *maintain*, in the methodology used for developing the maturity model, are not included in this thesis. The last phase is considered to be of a more long-term perspective, which entails that the relevance of the model should be maintained with necessary updates over time. Thus, makes this reasonable to further research.

Another suggestion is that one could develop a more detailed maturity model for each of the case companies, which are participating in the project, in order to potentially provide them with a more detailed recommendation for individually technology development- and improvement approach. This suggestion prospers from the fact that the companies are surrounded by various production environments entailing a potentially different need for automation and the further implementation of IoT.

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10.0 Appendices

Appendix 1: Interview guide

Introduction:

- Thank the respondent for his/hers participation
- Inform the respondent about the research and what it seeks to find out
- Let the respondent know that we are using the order management cycle perspective

General information about the company:

- Short history about the company
- The degree of technological competence/expertise in the company

The same questions will be asked in every function (sales, purchasing, production, warehouse and accounting, including some additional questions in some functions):

Sales

- How is orders received and further processed?
- Can you elaborate on which IT-systems that are used? How many systems is used in assisting daily work tasks?
- What type of IT-systems or technology is used for communication with suppliers?
- What type of IT-systems or technology is used for communication with customers?
- Is there any integration between the IT-systems used in the company, or against customers and/or vendors?

Additional questions:

Production

- Is there any use of robots in the production, if so, how many?
- How is the robots programmed?
- Does the robot has the ability to be reached remotely?
- Is there any use of track and trace technology in the production? (RFID, barcodes, sensors)
- Is there any type of communication or signals sent between the robots?

Warehouse

- Is there any use of track and trace technology in the production? (RFID, barcodes, PDA)
- Is there any use of robots in the production, if so, how many?
- How is the robots programmed?
- Does the robot has the ability to be reached remotely?
- Is there any type of communication or signals sent between the robots?

Accounting

Is the three-way match performed automatically or manually (purchase order, packing-slip, invoice?

Appendix 2: Case study protocol

It is mentioned in Yin (2009), when performing a multi-case study, a development of a case study protocol in advance of the case study is essential. Having a protocol is a major way of increasing the reliability of the research (Yin, 2009). The guidelines proposed in Yin (2009) is followed for developing the case study protocol.

Overview of the case study research

This research is conducted as a part of the master program at Molde University College (MUC), which aims to develop a maturity model for assessing the technological level regarding the concept of Internet of Things (IoT). A literature review on the concept of IoT will be performed in order to get an overview of essential technologies. In addition, a literature review on maturity models and how to develop a maturity model will be performed. To assure the models applicability, it will be tested by performing a case study on four Norwegian manufacturing companies. Interviews with company representatives are to be conducted in order to obtain rich and detailed information on the topic being investigated, as well as following the order management cycle, in order to map the technology used at each department at the case companies. In addition, visual observations from the production and warehouse environment will be obtained. Based on the assessment of the companies, the companies will be placed on the developed maturity model, and recommendations for further technology development and adoption will be provided.

Field Procedures

The companies being interviewed are all located in the region of Møre and Romsdal. The interviews with the company representatives are planned to be conducted within the period January – March 2016, enabling for the main data collection phase being finished before Easter. Below are some details on the interviews.

Case Companies	Research Representatives	Date of the interview	Place of the interview	Length of the interview
Ekornes ASA	4 students and supervisor	25.01.2016	Sykkylven	2,5 hours
Pipelife Surnadal	4 students and supervisor	16.02.2016	Surnadal	2 hours
Kleven	4 students and supervisor	19.02.2016	Ulsteinvik	1 hour
Brunvoll	4 students and supervisor	04.03.2016	Molde	1,5 hour

Since visual observations are an important part of the data collection method in addition to the interviews, the interviews will be conducted at the case companies' site. The company representatives choose the date and time most convenient for them to perform the interviews and business tours. It is planned for only performing one interview per day, due to the distances between the case companies being interviewed, and to avoid delays and cancelled interviews. Because of the distances, it is preferable to be able to send follow up questions (if any) to the company representatives after the interviews are conducted.

It is planned to distributing the interview questions to the company representative in advance of the interview. Allowing the representatives to get acquainted with the interview questions, and to ensure that all the questions can be answered. It is considered that the interview guide is developed in cooperation and guidance by the supervisor. The same questions will be asked at all the case companies in order to have comparable information.

Case study questions

The following case study questions is planned to be researched in this thesis.

RQ 1: How can an IoT-Technological Maturity Model for assessment of Norwegian Manufacturing Companies be developed?

RQ 2: What is the current IoT-technological maturity level for the four selected case companies?

RQ 2.1: How can the case companies develop in order to reach a higher level on the IoT-Technological Maturity Model?

The interview questions will be developed in order for the researcher to be able to answer the case study questions proposed above. A detailed interview guideline will be developed in order to collect comparable data from the interviewed case companies.

Guide for the case study report

The primary data for this case study are to be collected from the interviews and the observations. The interviews will be transcribed and sent back to the interviewed company representatives for validation. This will be performed in order to secure that the information collected are right. After the validation, the data collected are to be analyzed, and conclusions can been drawn.

Appendix 3: Assessment table

Level	Criteria				
1	There`s an initial use of RFID *and/or* barcodes in the production *and/or* warehouse environment				
	An ERP-system (or individual modules) has been implemented				
	Robot(s) are used in the production *and/or* warehouse environment (at least one robot)				
2	One single IoT-object (an asset *or* a product)				
	Robots, machines and IT-systems have been initially connected for automation in the production *and/or* warehouse, with the ability of vertical communication				
	Remotely control of asset(s) *and/or* product(s) are possible				
3	At least two IoT-objects (assets *and/or* products) with the ability of vertical communication				
	At least one specific operation has been automated within the production *and/or* warehouse environment				
4	More than two IoT-objects among the assets *and/or* products, with the ability of horizontal communication *and* vertical communication between assets *and/or* products				
	A specific part of operations in the production *and/or* warehouse environment have been automated				
5	At least ten IoT-objects among the assets *and/or* products with the ability of horizontal communication *and* vertical communication, between assets *and/or* products				
	IoT-objects has self-awareness capabilities				
	There`s an extended use of robots in the production *and/or* warehouse environment				
	Standardization				
6	Increasingly number of IoT-objects, among both the assets *and* the products				
	Asset/product-to-human/stakeholder communication internally				
	Horizontal communication *and* vertical communication, between assets *and* products				
	IoT-objects have self-management capabilities				
	Use of robots in the production *and/or* warehouse environment replaces a high degree of manual work operations				
	There exists a plan and strategy for Data Management				
7	Increasingly number of IoT-objects among both assets *and* products				
	Asset/product-to-supplier/customer communication externally				
	Asset/product-to-human/stakeholder communication internally				
	Horizontal communication *and* vertical communication, between assets *and* products				
	Use of robots in the production *and* warehouse environments replaces a high degree of manual work operations.				
	Big Data Management				
	Actively engaged in Data Analysis				
8	There`s an optimal IoT-technology use, meaning that there`s a seamless integration and communication between humans, robots, machines and products, with limited direct human intervention				
	The production *and* warehouse environments have been completely automated				
	Business Intelligence and Continuous improvement				
Maturity level achieved					

Appendix 4: IoT-Technological Maturity Assessment Test

Assessment-test Internet of Things (IoT)

1. What type of production environment does your organization operate in?

   ☐ Make-to-Stock ☐Make-to-Order
   ☐Engineer-to-Order ☐Assemble-to-Order?

2. Does your organization have an ERP-system?

   ☐YES ☐NO

3. Does your organization use any type of track and trace technology? RFID, barcodes?

   ☐YES ☐NO
   If yes, what? ______________________

4. Are there any initial use of automation in your production and/or warehouse facilities? If so, how many? (automated robots, machines)

   ☐YES ☐NO
   If yes, how many? ______________________

5. How is the robots/machines programmed? (using a standard control system?)

   ____

6. If there is any use of robots, is it possible to reach them remotely (outside of the production/warehouse facilities)?

   ☐YES ☐NO

7. Is there any specific manually operations/part of operations which has been replaced by automation? If so, what operation(s)?

   ☐YES ☐NO
   If yes, what activity? ______________________

8. Is there any “communication”/signals sent directly between the robots or machines?

   ☐YES ☐NO

9. Is there a part of production which is fully automated (no use of manual workforce)?

   ☐YES ☐NO