For a better understanding of Industry 4.0 – An Industry 4.0 maturity model

Author: Tom Bierhold
University of Twente
P.O. Box 217, 7500AE Enschede
The Netherlands

ABSTRACT

This paper is devoted to the trend of smart technology and the fourth industrial revolution. It concentrates on the creation and identification of items necessary for the maturity in Industry 4.0. Therefore this paper should be also seen as an extension and enlargement of the current literature regarding Industries 4.0 maturity models. To achieve this currently existing Maturity models will be compared with each other. A maturity model is created based on this comparison. The base construct of this model is composed out of an industry identifier and the company and technology domains.
Specifically the importance of the type of industry is highlighted and different concepts out of the academicals field discussed. Further the most important technologies will be elaborated to get a better insight on how to measure each of them. Representative technologies of I4.0 are the IOT, Big Data, cloud computing, 3D printing drones and cyber security. In the end a basic structure how a maturity model for Industry 4.0 is presented and important attributes out of the dimensions are described.

Graduation Committee members:

Dr. R.P.A. Raymond Loohuis
Dr. A.M. Ariane von Raesfeld Meijer

Keywords

Maturity Model, Industry 4.0, I4.0, MM, Industry Modifier, technical regimes

11th IBA Bachelor Thesis Conference, July 10th, 2018, Enschede, The Netherlands.

1. INTRODUCTION

The increasing merge of the virtual and physical world, the growing number of physical objects that possess intelligent sensors that connected create the Internet of things (IOT). Furthermore the availability of in time relevant data throughout all the instances of the networking system provides a base for value creation and to determine the best possible value stream, is triggering the new industrial revolution called Industry 4.0 (Industrie 4.0 Platform, 2016). Industry 4.0 is not only known underneath Industry 4.0 but is also according to Industrie 4.0 Platform (2017) the fourth industrial revolution. Wortmann, Combemale and Barais (2017) describe it as the “vision of manufacturing in which smart, interconnected production systems optimize the complete value – added chain to reduce cost and time-to-market”.

Next to Industry 4.0 as it is proposed by German Industrie 4.0 Platform an association of Bitkom, VDMA, ZVEI and partner companies and the fourth industrial revolution there have been equivalent developments from other countries. In China it is China 2025 (Wübbeke, Meissner, Zenglein, Ives & Conrad, 2016), in Japan Industry 4.1J (Kagermann, Anderl, Gausemeier, Schuh & Wahlster, 2016), in the USA it is Advanced manufacturing Partnership (AMP 2.0) (Executive Office of the President President’s/Council of Advisors on Science and Technology, 2014) and in the Netherlands it is called smart Industry. As the base vision of all these is the same it will further be referred to it in this paper only by the term Industry 4.0.

According to our collaboration - partner the company Future Industries (FI): ”A sufficient amount of companies operate without the right technology and integration of the source.” In this collaboration they want us to create with them a maturity model to analyse companies of different backgrounds. This MM shall include all the dimensions that define the maturity level of Industry 4.0 within a company.

Many countries are involved in creating their plan for industry 4.0. The country contributing the most in terms of scientific literature is Germany where also most of the field research has been done.

The scan is an improvement to the currently existing ones as these are missing out whether on dimensions of maturity, do not clearly separated maturity level and dimension, or do not clearly state on how to measure these. Furthermore most scientific literature is only concentrated on technical part of Industry 4.0 and not on other non-technical dimensions of maturity. Taken the vision of industry 4.0 into account this is not enough to sufficiently measure industry 4.0 maturity.

Based on the collaboration with FI the purpose of the study is to create and validate a maturity tool to analyse the Industry 4.0 maturity of a firm. A goal agreement is that in the end there shall be two operating scans, a quick and detailed. The short scan shall give an overview on how a company is doing in the field of Industry 4.0 and should not take longer than 5 minutes to finish. The long scan then should built up on the short scan. There will be more dimensions included which will ultimately end in a better overview of the maturity of company regarding I 4.0. Also it shows more detailed the maturity level of each dimension of the scan, including the identification of limitations, potential risks and improvement possibilities. This information gathered from this maturity model should then help companies in the future to create a road map for achieve maturity in I4.0.

The research shall combine literature about maturity with literature about maturity in I4.0 and literature about the different technological domains in I4.0. This means that the focus of this thesis will be on the technical components of I4.0 maturity. Further it does not mean that non-technical dimensions will be excluded. Moreover a link between these domains shall be drawn in order to understand the concept of I4.0 and its maturity better.

The research design for this thesis is deductive as existing research is used in order to create the maturity model. The paper “Building a Conceptual Framework: Philosophy, Definitions, and Procedure” by Jabareen (2009) is used as a guideline for creating our own theoretical framework about I4.0 maturity. Jabareen (2009) also suggest that for setting up a new maturity model (MM) mainly existing literature should be used and later validated by professionals. This implies for our study that we will conduct it as a qualitative one.

The outline of the study will look as following. In the beginning there is a general literature review about MM, followed by an elaboration about I4.0. After that a selection of the most popular I4.0 MM models will be presented and compared to each other. The maturity models will then be accessed based on the criteria : 1. fitness for purpose, 2. completeness of aspects, 3. granularity of dimensions, 4. definition of measurement attributes, 5. description of assessment method, 6. objectivity of the assessment method. After the comparison literature about technologies defining I4.0 is reviewed. The methodology used to write this paper will be elaborated as well as the results and the final Maturity Model of Industry 4.0 presented. The last part is about limitations and future possibilities for research in the field of Industry 4.0 .

As we are doing this study as an assignment for Future Industries it will first and foremost benefit them. We discussed to develop a short and a long version of the scan. The short scan is the one that shall be freely accessible for the public whereas the long version is to be used by Future Industries. When either of the scans is used it will provide inside on a maturity level of the company that it is applied to. After gathering data via the tool one gets an overview in which area there is still improvement potential in the domains of Industry 4.0

2. BACKGROUND OF THE STUDY

2.1 Maturity Model

The maturity model is a tool that is used to measure, compare, describe or determine a path or roadmap. It is typically used when measurement tools are not sufficient, contexts of the measurement are complicated and cannot be measured any by merely numbers anymore.

According to Fitterer and Rohner (2010) a maturity model is based on an assessment criterion, “the state of being complete, perfect or ready“.

In order to explain the term maturity model even more precisely I will introduce two general types of maturity models used in the literature. These types are the single-dimension maturity model (SMM) and the multi-dimension maturity (MMM) model.

The base components for both types are the dimension and the maturity level. The dimension is describing what actually is measured and the maturity level is the measurement scale for the dimension and the whole MM.

The SMM is, as the name is suggesting, a MM that concentrates only on one single dimension. This means that it should just be used when influences on this dimension are rather easy to comprehend.

The MMM in contrast can be used to measure, compare and describe paths a roadmaps and an unstable and uncertain environment as every variable can be and should be addressed with its own dimension. One important aspect when having multiple dimensions is on how and if to give an overall score.

There are two common practices. One is to give each dimension a certain weight, multiply it with the sub maturity level score and calculate an overall maturity level score. The other method is to determine the overall score based on the lowest individual score.

Another option is to look upon a MM as scientific function. A function consists out of variables and constants. In terms of the MM the dimensions are the variables, the maturity level the value of variable and some constant that set the frame of what the MM will measure.

2.2 Context of Industry 4.0

To understand Industry 4.0 Maturity, it is essential to understand the development of the industrialisation. The three previous industrial revolutions were based on water/steam, electricity and automation technology. The 4 industrial revolution is based on cyber physical systems according to McKinsey and Company (2015). "The term Industrie 4.0 stands for the fourth industrial revolution" Industrie 4.0 Platform (2017) explains and it is further based on increasing merge of the physical and the virtual world. Sensors within products and production line are forming the IOT which will provide accurate, relevant and in time data that can then be used in optimising industrial core processes like development, production, logistics and service.

Industry 4.0 can be also described by two types of technology changes which are described below. These changes can also be seen as the challenges when implementing Industry 4.0.

There is the technology pull that is driven by the change of the operative framework conditions. In general these are based on social, economic and political triggers. For Industry 4.0 these are particular:

- Short development periods; which means that companies need to be highly innovative in order to be successful on the market. Connected with the innovative capability companies need to reduce their time to market.
- Individualisation on demand or batch size one; means the development that buyers have a greater bargaining power and define the conditions of the trade. Due to this trend it leads to increasing individualisation and in the uttermost cases to individual products.
- Flexibility; meaning that higher flexibility is necessary in product development and especially in the production because of new framework requirements
- Decentralisation; due reduced time to market, batch size one and the increased flexibility companies need to reduce the hierarchy in order to have fast enough decision making procedures
- Resource efficiency; is needed to prevent from resource shortages and the effects from increasing prices. Further the social change to ecological production forces the industry to produce more resource efficient.

Technology push is the other huge influencer of Industry 4.0. In daily life it is already influencing the customer's routine. For example technologies like web 2.0, smartphones, 3D printing, cameras etc.. In the job related, specifically in the industrial context, up to date innovative technology is not widely spread. Therefore these views on technological push can be identified.

- Increasing mechanisation and automation; means that more technical tools will be used in the working progress, which support the physical tasks. Additional automated machines will be able to execute versatile operations based on operational, dispositive and analytical components. These machines could independently control and optimise the manufacturing within the various production steps.
- Digitalisation and networking; Due to the increasing amount of digitalised manufacturing and manufacturing supporting tools, the amount of data created by actor – and sensor data is also increasing. This data can then be used for supporting functions, data analysis and control. The digital processes evolvement combined with the increase of digitised products and digitised services are resulting in a completely digitised environment. These as background are driving forces for new technologies e.g. digital protection, augmented reality, simulation etc..
- Miniaturisation; means that computer require significantly less space than they used to do. Combined with the reduced physical space needed computers are now more versatile and can be used in new fields of application e.g. production and logistics. (Lasi, Fettke, Kemper, Feld & Hoffmann, 2014)

According to Gökalp, Şener & Eren (2017) Cloud Computing, Big Data, Internet of Things (IOT), Cyber-Physical Systems, Augmented Reality [11], Machine Learning [12], and Cyber Security [10] will play an essential role in Industry 4.0 hence in tackling the challenges presented beforehand.

2.3 Industry 4.0 Maturity Models

In this chapter the existing MMs will be explained as well as the general limitations of MMs.

2.3.1 Existing Industry 4.0 Maturity Models

In this study 6 maturity models are presented. These are:

MM1: "A Maturity Model for accessing Industry 4.0 readiness and maturity of manufacturing enterprises" by Schuhmacher et al. is a MM that was published in 2016. It concentrates on the manufacturing industry and has maturity levels as well as maturity dimensions. The dimensions that are presented are Strategy, Leadership, Customers, Products, Operations, Culture, People, Governance and Technology. These dimensions were then further split into sub-dimensions called maturity items. The maturity levels are split up in 5 levels based on a Likert- scale where the first level presents the absence of any Industry 4.0 capability and the fifth the full implementation of Industry 4.0 capabilities. Furthermore they entitled every of their dimensions and their sub-dimensions to a specific weight. These weights are then used in connection with the maturity level of the sub-dimension/ dimension in order to create an overall score of maturity. In Figure 1 the formula for calculating the maturity level can be found.

$$M_D = \frac{\sum_{i=1}^{n} M_{DIi} * g_{DIi}}{\sum_{i=1}^{n} g_{DIi}}$$

M...Maturity
D...Dimension
I...Item
g...Weighting Factor
n...Number of Maturity Item

Figure 1: Maturity Formula according to Schuhmacher et al. (2016)

MM2: "Impuls - Industrie 4.0-Readiness" by K. Lichtblau, V. Stich, R. Bertenrath, M. Blum, M. Bleider, A. Millack, K. Schmitt, E. Schmitz, and M. Schröter (2015) is a study funded by VDMA's IMPULS foundation. Next to the involvement of the industry association VDMA the Cologne Institute for Economic Research and the FIR at RWTH Aachen University participated in this study. Considering the size of VDMA with over 3200

(VDMA About us) the impact of the paper can be considered as rather big. Lichtblau at al. (2015) present 6 dimensions and 18 sub dimension as can be seen in Figure 2.

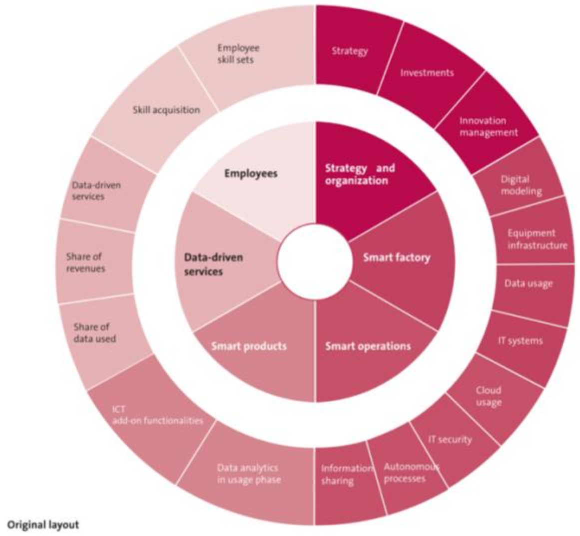


Figure 2: MM Impuls study according to Lichtblau at al. (2015)

Next to their dimensions the paper also shows 6 level of maturity. The first level called level 0 presents the absence of any Industry 4.0 capability while level 5 is set to be a goal for every company. Hence level 5 cannot be achieved and grows with growing Industry 4.0 opportunities. This implies that a company's maturity lie between the levels 0 and 4. In contrast to the paper of Schumacher et al. (2016) this paper evaluates the overall maturity based on an average score of the dimensions and scores the dimensions based on the lowest sub-dimensional score.

MM3: "Industry 4.0 How to navigate digitization of the manufacturing sector" by McKinsey and Company (2015) presents their maturity model as a digital compass. The dimensions, or as they call it the value drivers, are resource/ process, asset utilization, labour, inventories, quality, supply/demand match, time to market, service/ aftersales. Next to these 8 main dimension McKinsey adds another 26 sub dimensions which make the maturity model fairly specific. The model can be found in Appendix 1. One overly interesting point about the study is that McKinsey presented some kind of weights for their dimension based on % of savings, productivity etc.. For more detailed weights per dimension see Appendix 2.

The validity of the study is rather hard to specify. Also they interviewed over 300 industry experts the questions asked in the survey were rather simple and directed on how towards if companies feel prepared for Industry 4.0 or not. Considering it is the base for their study the validity of the outcome is low.

MM4: "Industry 4.0: Building the digital enterprise" by PWC (2016) presents two kinds of maturity tools. The first one is a one being an SMM and the second one an MMM. The SMM is due to its one dimension fitting in all aspects of Maturity 4.0 rather wage. Hence it is too superficial to be used. The MMM on the other side presents 7 dimensions, namely digital business and customer access, digitisation of product and service offerings, digitisation and integration of vertical and horizontal value chains, data and analytics as core capability, agile IT architecture, compliance/security/legal & tax, organisation, employees and digital culture. The maturity dimensions are from bottom to top digital novice, vertical integrator, horizontal collaboration, digital champion. Next to the dimensions the paper also provides an explicit table relating each stage of maturity with each dimension, see Appendix 3. Also presenting both components necessary for a MMM it does not clearly separate some dimensions and the maturity level.

MM5: "SIMMI 4.0 – A Maturity Model for Classifying the Enterprise-wide IT and Software Landscape Focusing on Industry 4.0" by Leyh, Schäffer, Bley and Forstenhäusler (2016) concentrate instead of people, technology etc. on the integration of industry 4.0. Hence the dimensions are called vertical integration, horizontal integration, digital product development and cross-sectional technological criteria including the sub-dimensions service oriented architecture, cloud computing, big data and IT security. The maturity levels from stage 1 to 5 are basic digitization, cross departmental digitization, horizontal and vertical digitization, full digitization and optimized full digitization.

They used the commonly known vertical and horizontal differentiation of organisational structure and applied them on technology. The vertical integration therefore is related to where the data is stored. Meaning if for example enterprise resource planning (ERP) systems, supply chain management (SCM) systems, management information systems (MIS), product life cycle management (PLM) systems are stored in the same place and compatible formats. The horizontal in comparison defines the integration across the value network. A high score therefore would be when all machine are connected and could access the data needed in time. This would not only include one company but the whole company network from supplier to the customer. As limitation for the horizontal integration is the balance between data sharing and data security.

Also making a good point that horizontal and vertical digitization are necessary points to look at, the structure of the MM suggest that horizontal and vertical integration should be both dimensions and maturity level. This easily leads to confusion on who to actually use the MM and therefore makes it not usable to some extent.

MM6: "Development of an Assessment Model for Industry 4.0: Industry 4.0-MM" by Gökalp, Sener, Eren (2017) presents a maturity model that is created based on the comparison of previous MMs. The model can be seen in Appendix 4. The maturity level is called capability dimension and the dimensions are called aspect dimensions. In the maturity level they have 6 levels from 0 incomplete to 5 optimizing. The aspect dimensions are asset management, data governance, application management, process transformation and organisational alignment (Appendix 5). To mention is that they have also used ISO Definitions next to previous MMs to create their MM.

2.3.2 Future Industries MM

MM7: Our Partner Future Industries created an maturity model that consists out of 10 dimensions that can be spitted into general business operations and the utilisation of technology within the production process. The dimensions are namely general, vision/mission/business model, people and organisation, marketing and customer access, product, product development, product automation, performance management, big data analysis. Furthermore they assigned weights in their scan for certain dimensions in collaboration with the HBO Nijmegen and the Smart Industry group.

2.4 Maturity model comparison

The maturity models were compared on different assessment criteria. These are: 1. fitness for purpose, 2. completeness of aspects, 3. granularity of dimensions, 4. definition of measurement attributes, 5. description of assessment method, 6. objectivity of the assessment method. In the first assessment criteria it is checked whether or not the model is suitable in order to measure the maturity of I4.0. The second evaluates if the MM assesses all the aspects I4.0 has to offer. The third determine whether or not the explanation of attributes is detailed enough. The fourth evaluate if the method of dimensional measurement is explained. The fifth criteria diagnoses if the MM provides a complete description of the assessment method. The sixth tells how objective the chosen MM is.

In a comparison every MM could whether achieve, not achieved (NA), partially achieved (PA), largely achieved (LA) or fully achieved (FA). Fully achieved means all aspect of the analysed criteria were fulfilled. Largely achieved means that the criteria is nearby met and is just missing a smaller detail. Partially achieved means that the MM has the criteria fulfilled to some extend but not good enough and not achieved that the MM does not provide none or too little information to be worth recognising.

Table 1: MM Comparison

	fitness for purpose	completeness of aspects	granularity of dimensions	definition of measurement attributes	description of assessment method	objectivity of the assessment method
MM1	PA	PA	NA	PA	PA	LA
MM2	PA	PA	PA	LA	FA	LA
MM3	PA	PA	PA	PA	LA	PA
MM4	PA	PA	LA	LA	PA	PA
MM5	PA	PA	PA	PA	LA	PA
MM6	PA	PA	PA	PA	PA	PA
MM7	PA	PA	PA	PA	PA	PA

Based on the comparison it was clear that none of the MM was offering the complete set of dimension in order to measure I4.0. Especial interesting was that none of the models differentiated for different industries. None of the dimensions was concentrate on the technical part only but rather on their functions. Therefore we concluded that in our model these should be further elaborated and included into the model if evidence is found.

2.5 Industry Identification

The term industry has many of meanings and definitions. The definition we use for this article is "A particular form or branch of economic or commercial activity" ("industry | Definition of industry in English by Oxford Dictionaries", 2018). Previous maturity models of I4.0 did not include a dimension that modifies the results of the MM. We consider this as critical as a necessity as industries vary a lot in their functions.

One of the first ways to describe is by using the Schumpeter Mark I and Schumpeter Mark II (Malerba & Orsenigo, 1997). Schumpeter Mark I is associated with industries where entrepreneurs and new firms play the main role in developing new ideas and innovations as well as launch new enterprises due to the technological ease of entry. This type of innovative industries are also referred to as creative destruction as the newcomers challenge the established firms and built a base of disruptive innovation. This innovation can be in seen in the production process, product, organization and distribution. Schumpeter Mark II in contrast represents the opposite. Meaning that innovation based on creative accumulation. Here large companies and their industrial R&D play the key role for innovation. Furthermore the monopoly of the big firms is the entry barrier for new companies and new innovations.

Based on this description Pavitt (1984) an industry can be differentiated in even more types. According to him there are 4 types of Industries, namely supplier demand industry, production intensive/sale intensive, production intensive/specialized suppliers and science based ones. Attributes on which he identifies industries are typical core sector, sources of technologies, types of users, means of appropriation, technical trajectories, source of process technology, relative balance between products and process innovation, relative size of firm intensity and direction of technological diversification. Another factor in the determining an industry is the velocity of the environment a company is operating in.

Dorado (2005) proposes that the innovation capabilities are based on three factors. These are agency, resource mobilization, and opportunity. Agency is further described as the motivation and creativity that is needed in order to get away from old patterns and create something new. Furthermore this motivation and creativity can be spitted into routine, strategic, and sense making. It is suggested any of these three is taken based on the temporal orientation. Hence with past orientation routine is dominant, in present orientation sense making is dominant and in the future strategic is dominant .The resource mobilization means that cognitive, social, and material support are determents of institutional change. The last factor opportunities which is also the most problematic one of these three. This is because opportunity depends on the objectivity of the actors experience and desires. Contradicting to difficulty to access she proposes a scale in which opportunities are described as hazy (high), transparent (moderate) and opaque (low). While the opportunities is high the institutionalization is low, in moderate moderate and in low high. Hence she is presenting a more scalable approach than Schumpeter. Further Dorado proposes that the hierarchical structure has an impact on the innovative capabilities hence could be a further factor for industry identification.

The assumption that the hierarchical structure of a company has something to do with their innovative activities is further confirmed by Malerba and Orsenigo (1997). They define the concentration and the asymmetries as the main influencer of innovative activities. They include the size, the change over time in the hierarchy of innovators and relevance of new innovators as compared to established once. They found out that there are differences across sectors in the innovative patterns. In 34 out of their 49 sectors the sectorial patterns did not differ across countries. This shows that differences in the industry at first depends on in which sector a company is operating in. The second big influencer is then in which country a company is operating in.

Finally they distinguish different type of conditions for technological regimes. These are opportunity condition, appropriability conditions and cumulativeness conditions.

Marsili and Verspagen (2001) claim that there are a total of 4 different technical regimes hence industry types. The call them " sciencebased regime; fundamental processes regime; complex systems regime; product-engineering regime and continuous processes regime". To decide in which industry a company belongs to the following dimensions have been named. The connection between a company's learning facilities and its problem solving activities, the system for internal and external knowledge sources in order to solve problems and the nature of technical and scientific knowledge base a firm draws on, in order to solve problems.

The science-based regime is defined by innovative activities originating in life science and physics. This regime is defined by a high level of technological opportunities and technological richness, high technological entry barriers and high cumulativeness of innovation. Innovative activities consist out of product innovation and innovation benefits directly from scientific advances in academic research. Companies within this industry/ regime focus on closely related technologies and innovations are homogenous in their direction and rates.

Chemistry based technologies belong to the fundamental-processes regime. They present a medium level of technological opportunities, persistence innovation and high entry barriers. Process innovation is dominant and the source of external knowledge comes from the users. This regime benefits from direct contribution of academic research.

Within the complex (knowledge) system regime electrical, electronic, mechanical and transportation technology built the knowledge base. The regime is to find in the aerospace and motor vehicle sector and characterised by a medium to high technological opportunities. Entry barriers exist based on knowledge and scale and persistence of innovation. The high degree of differentiation is the distinctive feature of this industry. Technological competencies, upstream production technologies and external knowledge sources from research are the base for this high differentiation.

The product-engineering regime is characterised by low entry barriers, mechanical engineering technologies, medium to high levels of technological opportunities and low levels of persistence in innovation. Non-electrical machinery and instruments are essential parts of this regime. The regime differentiate itself from the others by a high diversity off technical trajectories. Innovation can be found in the products and external knowledge comes mainly from the users.

The continuous processes regime represents a variety of production activities e.g chemical process industries as paper and textiles, food and tobacco as well as metallurgical process industries such as metals and building materials. The technological opportunities are rather low as well as the technological barriers and the persistence of innovation. The knowledge base composed out of chemical and metallurgical process and mechanical and electrical technologies. Firms within this regime have a differentiated knowledge base within the technical field but are technological heterogeneous. Innovation comes from upstream processes and capital-embodied knowledge.

Based on the paper of Breschi et. al (2000) the dimension of Marsili and Verspagen (2001) can be backed. Breschi et. al (2000) also propose technological opportunities , cumulativeness of technological innocation and appropriability of innovations as important factors when defining technological regimes.

The last factor we want to discuss in the determining an industry is the velocity of the environment a company is operating in. A high velocity hence meaning that there are large an unpredicted changes in the industry and a moderate velocity when there is little predictable change (Battleson et al. , 2016).

2.6 Industry 4.0 Technologies

Technology plays an important role in Industry 4.0 and researches have emphasised this importance. Also researcher have focused functions resulting from the technology. Here we want to highlight the technology behind the functions.

2.6.1 Technology adoption models

To measure the maturity of a company in the sector of industry 4.0 one first needs to find out how they perceive the technology. This can be done by a technology adoption model.

Venkatesh, Thong and Xu, developed in 2012 the extended unified theory of acceptance and use of technology (UTAUT). In their model they connect moderators as age, gender and experience with expectations, social influence conditions habits and hedonic motivation (Figure 3).

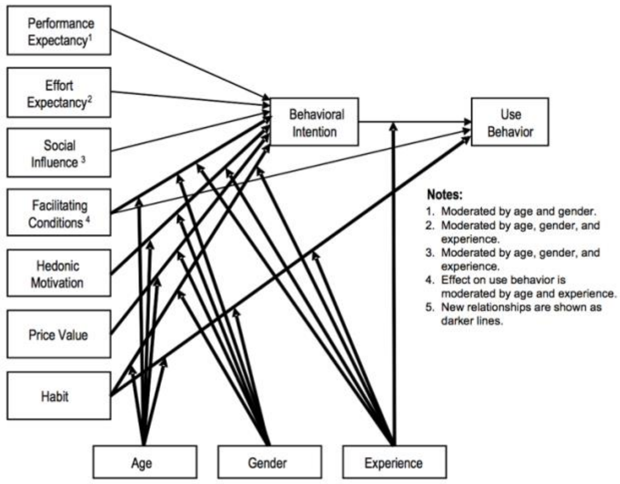


Figure 3: Extended UTAUT according to Venkatesh, Thong and Xu (2012)

2.6.2 Cloud computing

Cloud computing can be seen as one of the most base functionalities of I4.0. This is because it facilitates the connection between different other technologies. For example cloud computing machines can be connected to Big Data systems and hence provide the user insight about the production at any place of the world as long there is an internet connection.

As Baun at al. 2011 elaborate "cloud computing uses virtualization and the modern Web to dynamically provide resources of various kinds as services which are provisioned electronically. These services should be available in a reliable and scalable way so that multiple consumers can use them either explicitly upon request or simply as and when required"

To aid the functionality different types of cloud computing systems have been evolved. These types are Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS) (Srinivasan, 2014) (U.S. Department of Commerce, 2011).

Further clouds can be classified as private cloud, community cloud, public cloud and hybrid cloud. The private cloud is a cloud that is designed to be for a single user only. Meaning that one cloud is exactly for one company and it can be assessed by different employees via different logins. Further this cloud can be owned and managed internally by the company or external by a third party or a connection of both. It can be situated on and off the company's premises. The community cloud is to some extent similar. The only difference is that instead of one single company or person the cloud is owned by a community or organisation that share the same business concerns. The public cloud is owned by an academic, business, non-profit or governmental organisation or combination of it. It is situated on the premises of the cloud owner and can be accessed by the general public. The last form is the hybrid cloud which is a combination of the features of two or all three different clouds (Srinivasan, 2014) (U.S. Department of Commerce, 2011).

Also there is no difference whether the servers for a cloud are on the premises or not according to the U.S. Department of Commerce (2011), the IT consultant Visconti (2018) suggest that there is a difference. He draws a clear cut, calling off premises the cloud and on premises server data centres.

This functionality leads to many challenges for the technology and for the user. These are lack of control, security, privacy, proper service management, cloud outages, service availability, hanging cloud provider, shut down of cloud provider (Srinivasan, 2014). Depending on the extent and the gravity of the challenges a company needs to decide whether they should pay for a cloud service or if they need to install their own data centre.

Next to the challenges there are certain advantages for companies using cloud computing (Srinivasan, 2014). See Appendix 8.

Next to the interfaces of the clouds, virtualisation plays an important role in cloud development. This is essentially important for those companies that are providing cloud services to other companies. Based on the type of virtualisation different advantages occur.

Once a system is installed, whether cloud or data centre, metrics need to be used to measure the performance of the cloud. For example response times, business logic calculation times, transaction processing times (Babcock, 2016). Also the time the virtual servers are available is an important measure according to industry specialists and one should aim for the highest possible value meaning it is 100% available.

2.6.3 Big Data

Big Data evolved out of common databases. The amount of data generated was exceeding the capability of common databases. Therefore conventional search engines and relational database management systems (RDBMS) are complemented with newly designed DBMS such as NoSQL, NewSQL and Search-based systems (Moniruzzaman & Hossain, 2013).

Van Rijmenam (2018) suggest in his article that a company goes through 5 development stages when it comes to the usage of big data. These are infancy, technical adoption, business adoption, enterprise adoption and data & analytics as a service. See Appendix 9. Also this model has no scientific proof, it was written by an industry expert and comparing it with technology adoption models and the model from Chen, Chi and Stor (2012) makes it valid enough.

Chen et al. (2012) claim that in the field of big data, business intelligence and analytics (BI&A) has become more important over the last 2 decades. There are 3 development stages of BI&A. These stages are BI&A 1.0, BI&A 2.0 and BI&A 3.0. BI&A 1.0 is based on Data management and warehousing. The 8 following capabilities are considered to be BI&A 1.0: reporting, dashboards, ad hoc query, search-based BI, OLAP, interactive visualization, scorecards, predictive modelling, and data mining" (Chen et al., 2012). The rise of the internet and the web in the early 2000s offered new opportunities on data collection, analytical research and development. Therefore the BI&A 2.0 can also be seen as the first online stage of Big Data. This stage adds to the traditional internal company data also the data gained from the web. The Web detailed and IP-specific user search and interaction logs are continuously collected by cookies and server logs. Further nowadays with web 2.0 the amount of company, industry, product and customer information data increase. There is not just a one way communication but customer can actively state their opinion on social media. Customer transaction analysis, web design, market structure analysis, product recommendation, product placement optimization can be achieved by using web analytic tools like Google analytics. The latest step of the development is the BI&A 3.0. The major player is the Internet of things. As the function and data gathering of the other chapter we will not further go in depth here.

Based on the amount of different industries and the different types of sensors Chen et al. (2012) also proposes what kind of application are useful for what kind of industry. See Appendix 10.

2.6.4 Internet of Things

The internet of things (IOT) is the connection of basically any device on or off to the internet. This includes everything from coffee maker to cell phone. This also includes single components of more complex machines like airplane turbines (Morgan, 2014). The number of sensors is going to grow according to I-scoop(n.d.) with an annual compound growth rate of 11.3% until 2022. This proves the importance on IOT for I4.0.

Lee and Lee (2015) list 5 crucial technologies in their paper. These are radio frequency identification (RFID), wireless sensor networks (WSN), middleware, cloud computing, IoT application software. The RFID allows for automatic identification and to capture data by using tags, a reader and radio waves. There are three types of RFID tags passive, active and semi active ones. Wireless sensor networks (WSN) are composed of a set of spatial dispersed autonomous sensors to monitor physical and environmental conditions. Middleware is a software layer that is used in order to simplify the communication hence input and output between different software applications. Cloud computing is another component. Due to its ability to store and access to resources as long there is internet available it is used to store and distribute data. The last part of IOT are IOT applications. They enable a reliable and robust communication between devices and other devices as well as humans. Also IOT applications should provide an easy to understand interface for the end user. These technologies enable the end user to track behaviour, enhanced situational awareness and sensor driven decision analytics. Furthermore the IOT facilitates process optimization, optimized resource consumption and complex autonomous systems (Chui, Löffler & Roberts, 2010).

Gubbi et al. (2013) group the usage of the IOT according to their study in Melbourne. Therefore the urban application of IOT can be found in healthcare, emergency services, defence, crowd monitoring, traffic management, infrastructure monitoring, water, building management and environment control. See Appendix 11.

Ismail (2017) classifies 3 stages of maturity when it comes to the IOT. The first stage is when a company is just using the IOT to spot arising issues. The second stage is when a company uses the IOT in order to create new revenue streams based on the data gained from the IOT. The last stage is when a company uses this technology to change their business model.

Bsquare Corp. (2015) explains the maturity model in 5 stages. The first stage of IOT maturity is hence simple device connectivity and data forwarding. The second stage is then the possibility of real time monitoring. Within this stage a company is enabled to condition based maintenance. This improves in the long run operational efficiency, reduces service costs and provide information to guide future product design. Regulatory compliance is improved as well as IOT enhanced by the integrity of devices. Also data can be monitored in time human interaction is still necessary. The third stage is data analytics. This stage allows for data discovery, machine learning, cluster analysis and the digital model. Automation

As the definition of IOT and CPS is not clear in the literature we define the CPS as a sub stage of the IOT, hence when virtual and physical systems are connected but are not yet connected to the internet. Therefore a CPS could also be seen as an inner firm IOT.

2.6.5 Virtual Reality

Virtual reality(VR) and augmented reality(AR) will play another key role in I4.0 as mediating between CPS/ IOT and the user. Virtual reality hence can be used to simulate and interactively explore the behaviour of a production system (Gorecky et al, 2014) but also can help in the product development process, skills training and in the customer product communication (Ottosson, 2002). The application field of the VR and AR is quite similar. Therefore we shall assume that hardware and software component criteria are similar as well. Hence the evaluation can be done as in AR.

2.6.6 Augmented Reality

The augmented reality (AR) has in contrast to the virtual reality a stronger connection to the reality. While in the virtual reality everything can be modelled completely the AR is the connection between virtual and reality. This means AR is the computer-aided enhancement, with virtual object, of the human perception (Gorecky et al, 2014).

Devices that can be used to aces the AR range from smart glasses over tablets, smartphones and stationary computers. The application that can be run be any of these devices can be web based, native or hybrid applications.

Data to empower AR system should come from "product creation process (e.g. CAD-models of products and production facilities, process descriptions), the technical documentation (e.g. data sheets, handbooks), or the operative production process itself (i.e. operation status, process parameters)" (Gorecky et al, 2014).

The information coming from these should then be integrated in a context-sensitive system which allows the application to use context oriented information as well as fitting this information to the specific situation. Also context-broker systems should be embedded to aggregate raw sensor data from different sources for higher -value context information. This can also be seen as the connection to the IOT/CPS.

The interfaces of the devices should withstand the rough manufacturing environment and should work without control problems. Further AR should provide the use of touchscreens, voice and gesture recognition to access the technology in all given environments. This means that usability has to be achieved effectively, efficiently, and satisfactorily in order to call the AR system mature.

2.6.7 Cyber Security

Cyber security is one of the main pillars when it comes to I4.0. The importance becomes clear considering a the fact that Windows alone possess alone about 40-60 million lines of codes. Each line written by and software developers. This amount of lines of codes present the big threat for I4.0. The more lines of code the more possibilities for attacker to find a loophole in it: Same counts for the amount of sensors connected in a system as every sensor can be seen as another entrance point to the system.

The International Telecommunications Union (ITU) (International Telecommunications Union, n.d.) defines cyber security as :

"The collection of tools, policies, security concepts, security safeguards, guidelines, risk management approaches, actions, training, best practices, assurance and technologies that can be used to protect the cyber environment and organization and user's assets. Organization and user's assets include connected computing devices, personnel, infrastructure, applications, services, telecommunications systems, and the totality of transmitted and/or stored information in the cyber environment. Cybersecurity strives to ensure the attainment and maintenance of the security properties of the organization and user's assets against relevant security risks in the cyber environment. The general security objectives comprise the following:

- Availability
- Integrity, which may include authenticity and non-repudiation
- Confidentiality"

Von Solms & van Niekerk (2013) claim that cyber security is built op out of information security, information and communication security plus new threats as cyber bullying, home automation, digital media. Information security is concerned about the protection of Data while information and communication technology is concerned with the systems it is stored on and the way of transmitting data. Von Solms (1998) further defines information security as the mean to business continuity and limitation of business damage through the impact of security incidents.

Especially when it comes to security one should not only consider the scientific world but also standard developing organisations (SDO). The most important SDOs are the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), and the International Telecommunication Union (ITU).

2.6.8 3D Printing

3D printing has gained in popularity in recent years and the capabilities are increasing. There are different types of 3D printers depending on the good to print. According to The 3DInsider (n.d.) there are 9 types of printers. This amount of printers allows for production in many different sectors ranging from consumer products, weapons, drugs to organ transplants.

Yeheskel (2018) accesses the maturity of 3D printing via the manufacturing readiness level (MRL)(OSD Manufacturing Technology Program, 2012). The levels are: basic manufacturing implications identified, manufacturing concepts identified, manufacturing proof of concepts developed, capability to produce the technology in a laboratory environment, capability to produce prototype components in a production relevant environment (PRE), capability to produce a prototype system or subsystem in a PRE, pilot line capability demonstration: ready to begin low rate initial production(LRIP), low rare production demonstration: capability in place to begin full rate production, full rate production demonstrated and lean production takes place.

2.6.9 Drones

Drones gain increasing popularity in today's society. They are used for photography, war and the first companies are developing on drone delivery e.g. amazon, dominos wants to deliver with drones in the future. The variety for the usage is also increasing. On the website Futurism (n.d.) they already propose today 12 potential applications for drones. The MRL model used for accessing the maturity of 3D printing is based on the current research level of drones also applicable.

3. METHOD

3.1 Research Design

A conceptual framework (CF) that determines the Industry 4.0 maturity level of any company is the outcome of this study. This frame shall be called maturity model of Industry 4.0. To achieve this goal the components and the scale of the conceptual framework will be based on existing scientific literature. Hence this part of the study is a deductive one. Further a workshop with several professionals of the industry will be made in order to gain even more validity for this study.

3.2 Conceptualisation of literature review

In order to create a sound and solid CF about Industry 4.0, the procedure proposed by Jabareen (2009) in his paper “Building a Conceptual Framework: Philosophy, Definitions, and Procedure” will be used. He proposes that in order to create a CF existent multidisciplinary literature that uses grounded theory methodology should be used.

Step one therefore is to map out required data sources. Initially we gather general literature about maturity models, conceptual frameworks, Industry 4.0 and Maturity models Industry 4.0. Other keywords for the research were smart Industry, China 2025, Japan 4.1J, AMP 2.0. Next to general literature, literature about technologies of Industry 4.0 were gathered.

In accordance with that, there was extensive reading and categorizing of the selected data.

Papers that provide already a good way on how to access Industry 4.0 are for example “IMPULS - Industrie 4.0-Readiness” by Lichtblau et al. (2015) and “Development of an Assessment Model for Industry 4.0: Industry 4.0-MM” by Gökalp, Sener, Eren (2017). Further MM can be found in section 2.3 or in Appendix 6.

In order to evaluate and analyse the gathered MM of Industry 4.0 we are using the criteria proposed by Gökalp, Şener & Eren (2017) and a criteria for the quality of the literature as well as one for the general structure of the MM. These are; fitness for purpose, completeness of aspects, granularity of dimensions, definition of measurement attributes, description of assessment method, objectivity of the assessment method, ISI journal, completeness of conceptual framework components.

After the comparison of the different MM the best components of each MM will be combined in order to create a new conceptual framework. From the paper “Sustainable Industrial Value Creation: Benefits and challenges of Industry 4.0” (Kiel et al, 2017) the challenges public context and customer orientation were taken and combined with categories of firms as propose by Pavitt (1984). These together built the industry identifier in our model which determines in the end which of the dimensions and sub dimension are necessary to look at when accessing the I4.0 MM.

The general component should be combined from theory about employee skills, company financials, company strategy, investments, how to innovate, leadership and company culture. Hence the dimension for the general component are the same.

The technical component should consist out of the proposed I4.0 technologies by Gökalp et al (2017).

The dimensions proposed in this framework will then be given a measurement scale based on further literature review on the new dimensions. The scales for the maturity will be based on a questionnaire. To appropriately create new measurement scales the survey question will be based on Fanning (2005) as she provides a good overview on what is important when creating a survey.

One way on how to access the technological components is by looking at the horizontal and vertical integration as introduced by Leyh et al. (2016). To access other criteria of maturity, existing maturity model scales are used. Next to the MM proposed above also an article from the UK National Audit office (n.d.) as well as the master thesis of ZHU (2017) have been used.

In order to provide a valid result it has been tried to use as much relevant scientific literature as possible combined with the latest industry trends. One way of our validation is to trying to use mainly SIS journals as these are from higher value than other. Another one the latest research papers from other journals to keep up.

3.3 Professionals workshop conceptualisation

In cooperation with our company contact Paul Hoppener we organised a workshop with 2 industry professionals acting in the Dutch Industry 4.0 sector.

The approach at the company workshop was to start with open questions and narrow these down over the duration of the workshop.

At the start of the workshop we wanted to find out as much as possible general information about Industry 4.0. The reason for using open questions is to have a more exploratory research design. Using this design will help to provide a sufficient content validity as no more new attributes should appear, which means that we have included all necessary components for measuring industry 4.0 maturity.

Later on in the workshop we went through the proposed dimensions. This was done to prove the measurement attributes.

4. RESULTS

4.1 Maturity Model

As the current literature does not provide sufficient input about what components need to be present in a maturity model we defined our own. See Chapter 2.1.

4.2 I4.0 Maturity Model

Based on our findings we created a new maturity model for Industry 4.0 (Figure 4). Compared to currently existing models we added an industry modifier dimension. As suggested by the name modifier this dimension modifies the weight given to a certain dimension in the model based on the industry a company is operating in.

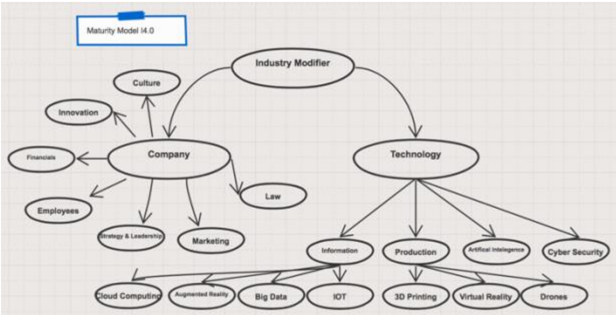


Figure 4: Industry 4.0 Maturity Model

Next to this modifier dimension there are 10 other dimension on which a company is evaluated. These are grouped into 2 domains. One is the traditional company domain and the other is the technology domain. In the frame of this research, we concentrated on creating scales and measure for the technology domain as well as the technology acceptance within the employee dimension.

4.3 Industry Modifier

The industry modifier is used to determine which technologies and business practices are essential for a company. To decide to what kind of industry a company belongs we created a two by two matrix with the aspects Schumpeter industry and the technological opportunities.

	Schumpeter Industry

Technological Opportunities		Mark I	Mark II
	High	Frontier Industries	High-Tech Industries
	Low	Supplier Industries	Traditional Industries

Figure 5: Industry Modifier Matrix (IMM)

The traditional industries hence would consist out of companies that cannot operate with the use of high tech or have a differentiation strategy based on hand-crafting e.g. construction companies, knife manufacturers. The external knowledge comes from users and customers. The entry barrier is high for this industry as established companies have made themselves a good reputation.

Supplier industries are industries where the production rate is high and the main part of production can be done by a few different machines while labour is decreased. The possibility that the production technology changes completely or gets a high amount of new technologies is low.

High tech industries are well established companies that base their innovation on accumulation of knowledge. Due to the size and the amount of internal research these companies have established a fairly high entry barrier.

The frontier industry is an industry that is not completely explored yet. Companies are new and operate in a new field. The opportunities for creating and using new top of the edge technology is high and can change the future regimes.

4.4 Company Domain

The dimensions within the company domain concentrates on the non-technical factors of a company that determine if the same is mature in I4.0 and how strongly they are mature. Dimensions included are culture, innovation, financial, employees, strategy & leadership, and law. Within the frame of the study we have chosen to elaborate in more detail the one dimension which has the biggest impact on I4.0 maturity This is the employees dimension. Regardless that we still want to give a short description what every dimension should be about.

Culture: The culture in a company plays an important role. For example a company that completely identifies itself with old-school crafting technologies e.g. knife manufacturing would most likely not attempt to incorporate I4.0 technologies. Therefore it is important to check for the culture within a company, depending on their chosen industry when accessing I4.0 maturity.

Innovation: The innovation dimension checks for how organised a company organises their innovating operations. In general there are two types of innovation product and process innovation. For both types the appropriate checks in balances should be in place. The balance of these is critical as too many checks can hinder the innovativeness of the company and too few could mean serious reputation damage for example. One way of dealing with the appropriate balance between those is with a stage gate progress to organise innovations. In context of I4.0 this could mean that companies might get to slow because they have not been innovative enough in changing their production processes.

Financial: Without finances no company is able to run. Therefore it is important to know how good a company is doing in their financing activities. The maturity levels within this dimension are: The company has some inadequate financial planning activities in place that affect the day-to-day business. The company has financial management practices (FMP) activities that only provide support for day-to-day activities The firm has FMP that provide so company support in development and day to day business in a stable environment. The company has professional FMP in place to operate in challenging times. The fifth and highest level is when the company has an professional FMP in place that are leading edge and can predict key opportunities and challenges, in order to improve performance.

Strategy and Leadership: In this dimension is built upon the strategy and the leadership of a company. When it comes to strategy there are three levels to consider. The corporate, the business unit and the market strategy. Also strategy should be taken as a base on what a company should be doing we have set is as an extra dimension to check whether the company is aligned with their surrounding environment. When I comes to strategy it is also important that the leaders are mature in the acting in order to persuade day to day business and the overall business strategy.

Law: The law dimension checks how proactive a company is working regarding the laws and social pressures. This means a company needs to recognise social demands before the legislation does and should rearrange their production accordingly before it becomes law. This helps the company ultimately to stay out of law courts and might even grant them governmental funds due to their innovative and caring behaviour.

Marketing: Marketing is art of communication with the customer, finding out what he desires and providing the equivalent product or service. In marketing there are different ways how a company can communicate to their customers. This could be via fliers, posters, internet/radio/television advertisement as well as personal acquisition. Here the industry modifier plays again an important role as there is big difference in approaching business and consumer customers.

Employees: The employee is the person who is ultimately in charge in the production. This may happen by adding value by hand or via using a machine. Therefore it is important to look at the employees skills, their skills development/acquisition. Within the factor of skills development/acquisition the technology acceptance model plays a huge role when it comes to I4.0. The TAM hence suggests that there are moderators that influence the different factors for accepting a new technology.

4.5 Technology Domain

The big advantages in I4.0 are coming from the technological enhancements. Those enhancements are based on information technology and production technology Cyber security comes as a necessity due to the high amount of access points information technology and production technology can be interrupted. A fourth dimension is currently arising, artificial intelligence. Due to its newness and its high impact on the other technologies it is considered as the fourth dimension.

4.5.1 Information Technology

We define information technologies as technologies were data is stored, data is processed(analysed) and where data is available for all users (machine or human. Further information technology connects different machines and technologies together in order to create the fluent production process. One of the key factors for information technology is that is need to be integrated vertically and horizontally.

Big data: Big data is the new trend when I comes to collection data. Big data starts when the information gathered outgrows the traditional RDBMS. Few companies have used RDBMS before and have recognised its importance therefore the he first level is then an infancy level where companies recognise the potential of big data. The second stage is the technical adoption defined by mainly data storing and the usage only by the IT personal. The third level is characterised by structured, unstructured predictive analysis. In the fourth level enterprise adoption metadata, quality and governance is integrated across big data. In the fifth level data is available on self-service. Hence the company is operating as data service provider that shares analytics and across the enterprise.

Cloud computing: Also identified as one of the most essential criteria when it comes to I4.0 the measurement is critical. The cloud computing can be structure in external and internal cloud computing as well as in what type of service is provided by the cloud. These types are Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). Further in it needs to be distinguished between service provider and service consumer. The base measurements of performance are the same. Overall response times, business logic calculation times, transaction processing times and availability of the service. The closer a company reaches 100 availability when using or providing a service the higher their maturity rating.

IOT: When it comes to IOT many different components are to consider. From smart products like cars, phones, over smart sensor, RFID tags to smart machine the range of smart devices is big. The first stage of IOT maturity is hence simple device connectivity and data forwarding. The second stage is then the possibility of real time monitoring. The third stage is data analytics followed by the fourth stage of automation. The fourth stage we consider as the point where the introduction of smart products makes most sense. Especially as all machines are connected and the analytics are already mature. Until this point we considered the process more as a cyber physical system. But after stage 4 one can talk about the IOT. This would also imply that from this stage onwards smart products would not only deliver during the production but also after they have been distributed to the customer. The last stage then is the on board intelligence. Meaning that every machine and every connected device has its own data analysis function.

Augmented reality: Augmented reality is not per definition an information technology as it is not particularly meant to distribute store data and connect machine with each other. Nevertheless we consider it as one. This is due to its actual application for the end User. This means that AR is used as an interface to provide the user with on side, in time, relevant data. To have this functionality it must be interconnected with all the sensors and data storages. Also it should be accessible to all internal user of the company and should provide for customers or suppliers the amount of data that is just necessary to disclose. Here we propose that the lowest maturity level is that the company hasn’t implemented VR and the higher that VR is implemented with all its aspects.

4.5.2 Production

Production technologies use data from the information technology in order to produce products. In terms of I4.0 new production technologies such as 3D printing and drones are important. The general assessment of each of the production technologies is based on the MRL model. The levels of maturity are hence: basic manufacturing implications identified, manufacturing concepts identified, manufacturing proof of concepts developed, capability to produce the technology in a laboratory environment, capability to produce prototype components in a production relevant environment (PRE), capability to produce a prototype system or subsystem in a PRE, pilot line capability demonstration: ready to begin low rate initial production(LRIP), low rare production demonstration: capability in place to begin full rate production, full rate production demonstrated and lean production takes place. For simplification and standardisation of the model, two MRL steps will form one maturity level.

4.5.3 Cyber Security

We define the maturity of cyber security based on the latest and newest ISO standards on the market. Hence the more ISO standards a company satisfies the higher its maturity level.

4.6 Maturity Level

The assessment way of this MM should be visual. Hence there should two separate star models representing each of the domains. Within the star model each dimension of the domain is present. Every domain can score between the maturity levels 1-5 hence presenting a map on where the company is high in maturity and where the company needs develop. An overall maturity score shall not be given as this will minimise the accuracy of the models output.

4.7 Two scans

In the introduction we mentioned that we would like to have a short and a long scans as a result. Therefore we suggest to use the industry modifier and the company domain as a short scan. Also the short part does not give detailed insight about the I4.0 it gives the user of the scan a good impression where one is using technology or not. When going through all three, the industry modifier, the company domain and the technology domain.

5. LIMITATIONS

There are different limitations to this model. The first and foremost limitation is that it is a model and a model just presents a simple picture of the reality. Further the existing research regarding technological regimes hence the base for the industry modifier is rather old and specifically states that the technological regimes can change over time especially when there are big changes in technology. In addition to that the industry modifier is supposed to assign certain values to certain dimensions to rank the importance of the dimension to each other. As this research was conducted as a literature research with the validation of industry professionals, no quantitative data to this topic could be collected.

The model has just been validated within the frame of the workshop with the professionals. Hence another limitation is that the model has not been used to access any company with it.

One of the hardest points to measure is cyber security. This is because security gaps are mostly not known until a breach occurs. Therefore ISO standard are the closest we can get to the maturity of cyber security.

6. FUTURE RESEARCH

The field of Industry 4.0 is still developing therefore there are still many topics to research. Related to this study, the first field of research to mention should be the relation between the types of industries to the identified dimension in Industry 4.0. Another point that could become important in the next years could be the trend of artificial intelligence and how this is impacting Industry 4.0.

7. ACKNOWLEDGMENTS

To all the people who influenced me on my path of life so far, you all have encouraged me to go my way no matter what. A special thanks goes to my first supervisor Dr. R.P.A. Raymond Loohuis and Paul Hoppener who made it possible and helped me with feedback to write my thesis. Also I would like to thank my second supervisor Dr. A.M. Ariane von Raesfeld Meijer who provided extra study material and feedback. To my parents that always stood by my side and helped me to their best knowledge.

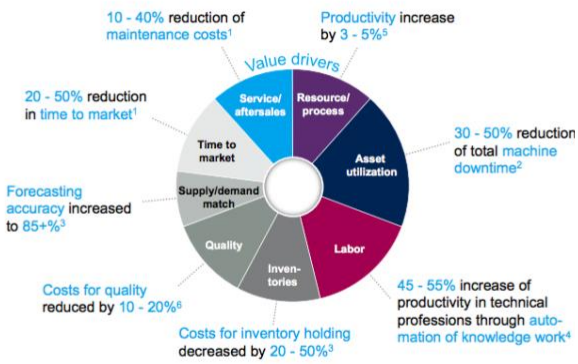
8. APPENDIX

The McKinsey Digital Compass maps Industry 4.0 levers to tl value drivers

1 Maintenance, repair, and operations
SOURCE: McKinsey

Appendix 1: Digital Compass according to McKinsey and Company(2015)

Indicative quantification of value drivers

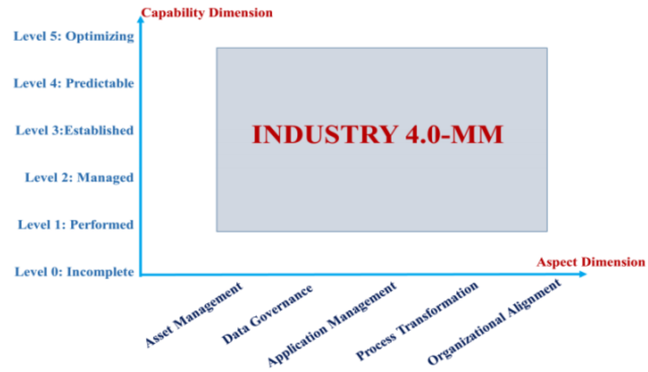


1 Cf. McKinsey Global Institute: Big data: The next frontier for innovation, competition, and productivity 2 McKinsey analysis
3 McKinsey analysis 4 Cf. McKinsey Global Institute: Disruptive Technologies 5 See, for example, ABB case study
6 Cf. T. Bauernhansl, M. ten Hompel, B. Vogel-Heuser (Hrsg.): Industrie 4.0 in Produktion/Automatisierung/Logistik (2014)
SOURCE: McKinsey

Appendix 2: Digital Compass and weights according to McKinsey and Company(2015)

	1 Digital novice	2 Vertical integrator	3 Horizontal collaborator	4 Digital champion
Digital business models and customer access	First digital solutions and isolated applications	Digital product and service portfolio with software, network (M2M) and data as key differentiator	Integrated customer solutions across supply chain boundaries, collaboration with external partners	Development of new disruptive business models with innovative product and service portfolio, lot size 1
Digitisation of product and service offerings	Online presence is separated from offline channels, product focus instead of customer focus	Multi-channel distribution with integrated use of online and offline channels; data analytics deployed, e. g. for personalisation	Individualised customer approach and interaction together with value-chain partners. Shared, integrated interfaces.	Integrated Customer Journey Management across all digital marketing and sales channels with customer empathy and CRM
Digitisation and integration of vertical and horisontal value chains	Digitised and automated sub processes. Partial integration including production or with internal and external partners. Standard processes for collaboration partly in place	Vertical digitisation and standardised and harmonised internal processes and data flows within the company; limited integration with external partners	Horizontal integration of processes and data flows with customers and external partners, intensive data use through full integration across the network.	Fully digitised, integrated partner ecosystem with self-optimised, virtualised processes, focus on core competency; decentralised autonomy. Near real-time access to extended set of operative information
Data & Analytics as core capability	Analytical capabilities mainly based on semi-manual data extracts; Selected monitoring and data processing, no event management	Analytical capabilities supported by central business intelligence (BI) system Isolated, not standardised decision support systems	Central BI system consolidating all relevant internal and external information sources, some predictive analytics Specific decision support and event management systems	Central use of predictive analytics for real-time optimisation and automated event handling with intelligent database and self-learning algorithm enabling impact analysis and decision support
Agile IT architecture	Fragmented IT architecture in-house.	Homogeneous IT architecture in-house. Connection between different data cubes developing.	Common IT architectures in partner network. Interconnected single data lake with high-performance architecture	Single data lake with external data integration functionalities and flexible organisation. Partner service bus, secure data exchange
Compliance, security, legal & tax	Traditional structures, digitisation not in focus	Digital challenges recognised but not comprehensively addressed	Legal risk consistently addressed with collaboration partners,	Optimising the value-chain network for compliance, security, legal and tax
Organisation, employees and digital culture	Functional focus in "silos"	Cross-functional collaboration but not structured and consistently performed	Collaboration across company boundaries, culture and encouragement of sharing	Collaboration as a key value driver

Appendix 3: Maturity Model PWC according to PWC(2016)



Appendix 4:MM according to Gökalp, Sener, Eren (2017)

Aspect Dimensions:
Asset management: IT systems of a company
Data Governance: Capability level of data collection, usage, analytics. Big data tools and data driven services
Application Management: abstract dimension of interaction between applications and manufacturing and automation systems
Process Transformation: transformation of basic processes as planning, acquisition, production, sales and distribution into the digital world
Organisational Alignment: org. structure, strategy, knowledge about smart manufacturing concept, personal

Appendix 5: Elaborated Aspect dimensions according to Gökalp, Sener, Eren (2017)

#	Model/Research Name	Research Context	ISI Journals	Maturity levels	Dimensions
1	Industry 4.0 readiness and maturity of manufacturing enterprises	Manufacturing	0	5; scored individually per sub dimension; overall M. calculate by the weights of the sub-dimension and its score	9; Strategy, Leadership, Customers, Products, Operations, Culture, People, Governance, Technology

2	Impuls - Industrie 4.0 Readiness	Industrie 4.0 Readiness		5-6; individually per sub dimension; overall score determined be the lowest sub score	6 main dimension; Strategy and organization, smart factory, smart operation, smart products, data-driven services, employees, and further 18 sub dimensions
3	Digital Compass	Digitization of the manufacturing sector		NA	8 Main dimensions, Resources/ process, Asset utilization, labor, inventories, quality, supply/demand match, time to market, Service/ Aftersales, 26 sub dimensions
4	Industry 4.0: Building the digital enterprise	Worldwide industrial companies		6	1 dimension
5	SIMMI 4.0 – A Maturity Model for Classifying the Enterprise-wide IT and Software Landscape Focusing on Industry 4.0	Technological MM		5	4; Vertical integration, horizontal integration, Digital product development, cross sectional criteria
6					

Appendix 6: Table of maturity models with a high impact

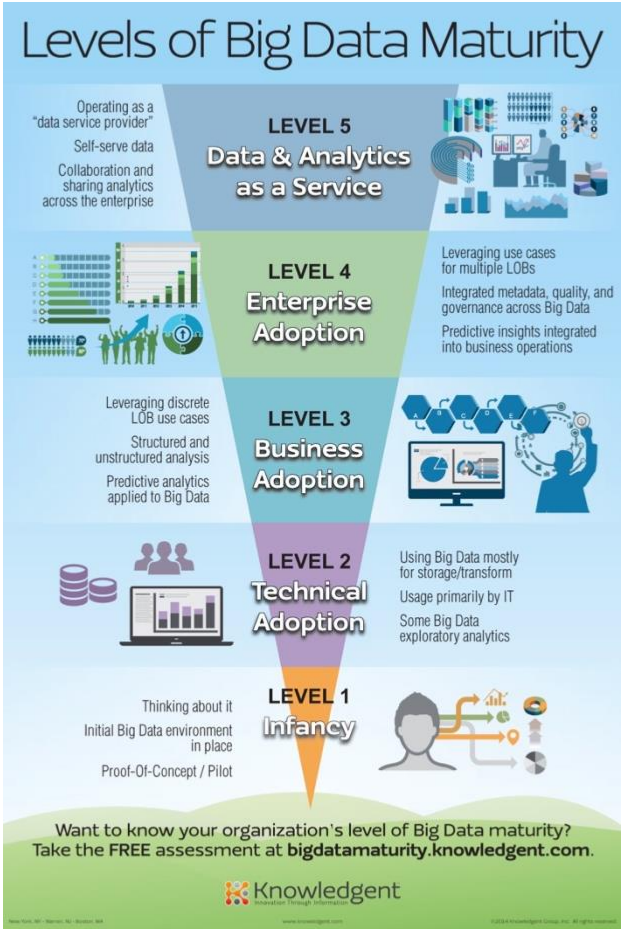
Criteria #	Criteria	Definitions
C1	Fitness for Purpose	The level of fitness of the corresponding MM in terms of measuring maturity level in the context of Industry 4.0.
C2	Completeness of Aspects	The level of completeness of aspects in terms of addressing all or a subset of major aspects in the context of Industry 4.0
C3	Granularity of Dimensions	The level of detail of explanations of the attributes in the corresponding dimensions.
C4	Definition of Measurement Attributes	It questions whether the corresponding MM provides the description of the measurement attributes, or not.
C5	Description of Assessment Method	It questions if the study provides a complete description of the assessment method.
C6	Objectivity of the assessment method	The level of objectivity of maturity assessment method of the study. The definitions of the attributes, practices, and each level of the maturity should be described unambiguously. And the overall maturity level should correctly reflect the number of questions positively answered.

Appendix 7: Criteria for MM assessment according to Gökalp, Sener, Eren (2017)

Business benefit	Small business	Medium sized business	Large business
Service availability	Y	Y	Y
Service reliability	Y	Y	Y
Meeting demand elasticity	Y	Y	Y
Ability to pay-as-you-go	Y	Y	Y
Service automation	–	Y	Y
Email support	Y	Y	–
Database support	Y	Y	–
Customer relations management support	–	Y	Y
Access control support	–	–	Y
Security	–	Y	Y
Business continuity	–	Y	Y
Data storage	–	Y	Y
Data backup and recovery	–	–	Y
Meeting regulatory compliance	–	–	Y
Meeting industry compliance	Y	Y	Y

– denotes that the benefit is not significant

Appendix 8: Summary of Benefits of cloud computing per business size according to Srinivasan (2014)



Appendix 9: Levels of Big Data Maturity according to Van Rijmenam (2018)

Table 2. BI&A Applications: From Big Data to Big Impact					
	E-Commerce and Market Intelligence	E-Government and Politics 2.0	Science & Technology	Smart Health and Wellbeing	Security and Public Safety
Applications	• Recommender systems • Social media monitoring and analysis • Crowd-sourcing systems • Social and virtual games	• Ubiquitous government services • Equal access and public services • Citizen engagement and participation • Political campaign and e-polling	• S&T innovation • Hypothesis testing • Knowledge discovery	• Human and plant genomics • Healthcare decision support • Patient community analysis	• Crime analysis • Computational criminology • Terrorism informatics • Open-source intelligence • Cyber security
Data	• Search and user logs • Customer transaction records • Customer-generated content	• Government information and services • Rules and regulations • Citizen feedback and comments	• S&T instruments and system-generated data • Sensor and network content	• Genomics and sequence data • Electronic health records (EHR) • Health and patient social media	• Criminal records • Crime maps • Criminal networks • News and web contents • Terrorism incident databases • Viruses, cyber attacks, and botnets
	Characteristics: Structured web-based, user-generated content, rich network information, unstructured informal customer opinions	Characteristics: Fragmented information sources and legacy systems, rich textual content, unstructured informal citizen conversations	Characteristics: High-throughput instrument-based data collection, fine-grained multiple-modality and large-scale records, S&T specific data formats	Characteristics: Disparate but highly linked content, person-specific content, HIPAA, IRB and ethics issues	Characteristics: Personal identity information, incomplete and deceptive content, rich group and network information, multilingual content
Analytics	• Association rule mining • Database segmentation and clustering • Anomaly detection • Graph mining • Social network analysis • Text and web analytics • Sentiment and affect analysis	• Information integration • Content and text analytics • Government information semantic services and ontologies • Social media monitoring and analysis • Social network analysis • Sentiment and affect analysis	• S&T based domain-specific mathematical and analytical models	• Genomics and sequence analysis and visualization • EHR association mining and clustering • Health social media monitoring and analysis • Health text analytics • Health ontologies • Patient network analysis • Adverse drug side-effect analysis • Privacy-preserving data mining	• Criminal association rule mining and clustering • Criminal network analysis • Spatial-temporal analysis and visualization • Multilingual text analytics • Sentiment and affect analysis • Cyber attacks analysis and attribution
Impacts	Long-tail marketing, targeted and personalized recommendation, increased sale and customer satisfaction	Transforming governments, empowering citizens, improving transparency, participation, and equality	S&T advances, scientific impact	Improved healthcare quality, improved long-term care, patient empowerment	Improved public safety and security

Appendix 10: Application to be used per Industry according to Chen et al. (2012)

Citizens	
Healthcare	Triage, patient monitoring, personnel monitoring, disease spread modeling and containment—real-time health status and predictive information to assist practitioners in the field, or policy decisions in pandemic scenarios
Emergency services, defense	Remote personnel monitoring (health, location); resource management and distribution, response planning; sensors built into building infrastructure to guide first responders in emergencies or disaster scenarios
Crowd monitoring	Crowd flow monitoring for emergency management; efficient use of public and retail spaces; workflow in commercial environments
Transport	
Traffic management	Intelligent transportation through real-time traffic information and path optimization
Infrastructure monitoring	Sensors built into infrastructure to monitor structural fatigue and other maintenance; accident monitoring for incident management and emergency response coordination
Services	
Water	Water quality, leakage, usage, distribution, waste management
Building management	Temperature, humidity control, activity monitoring for energy usage management, D heating, Ventilation and Air Conditioning (HVAC)
Environment	Air pollution, noise monitoring, waterways, industry monitoring

Appendix 11: Potential IOT application in the urban area according to Gubbi et al. (2013)

Table 5
Sectoral technological trajectories: Determinants, directions and measured characteristics

			Determinants of technological trajectories		
			Sources of technology	Type of user	Means of appropriation
Category of firm		Typical core sectors			
(1)		(2)	(3)	(4)	(5)
Supplier dominated		Agriculture; housing; private services traditional manufacture	Suppliers Research extension services; big users	Price sensitive	Non-technical (e.g. trademarks, marketing, advertising, aesthetic design)
Production intensive	Scale intensive	Bulk materials (steel, glass); assembly (consumer durables & autos)	PE suppliers; R&D	Price sensitive	Process secrecy and know-how; technical lags; patents; dynamic learning economies;
	Specialised suppliers	Machinery; instruments	Design and development users	Performance sensitive	design know-how; knowledge of users; patents
Science based		Electronics/electrical; chemicals	R&D Public science; PE	Mixed	R&D know-how; patents; process secrecy and know-how; dynamic learning economies

ᵃ PE = Production Engineering Department.

Appendix 12: Industry classification (Pavitt, 1984) part1

Technological trajectories	Measured characteristics			
	Source of process technology	Relative balance between product and process innovation	Relative size of innovating firms	Intensity and direction of technological diversification
(6)	(7)	(8)	(9)	(10)
Cost-cutting	Suppliers	Process	Small	Low vertical
Cost-cutting (product design)	In-house; suppliers	Process	Large	High vertical
Product design	In-house; customers	Product	Small	Low concentric
Mixed	In-house; suppliers	Mixed	Large	Low vertical High concentric

Appendix 13: Industry classification (Pavitt, 1984) part2

9. MATURITY MODEL QUESTIONAIR

9.1 Industry Modifier

1.	**How familiar are you with industry 4.0**?
O	Highly familiar
O	
O	
O	Not Information about Industry 4.0
2.	**Which industry sector do you operate in?**
O	Software
O	Manufacturing
O	Chemicals
O	….
3.	**What business strategy do you follow**?
O	Focus cost cutting
O	Cost cutting
O	Differentiation
O	Focus Differentiation
4.	**What is the Size of your company? (In employees)**
O	0-10
O	11-50
O	50-100
O	Over 100
5.	**What is your company's revenue?(In Million €)**
O	Under 1
O	1-5
O	5-10
O	10-25
O	Over 25
6.	**To what extent are you dispersed?**
O	One company facility
O	Two company facilities
O	Plenty company facilities
7.	**Number of suppliers?**
O	One
O	Few
O	many
8.	**Does your company focus lie on B2B or B2C or C2C?**
O	B2B
O	B2C
O	C2C

9.2 Company Domain

9.2.1 Culture

1.	**Do employees identify themselves with the company?**
O	Fully True
O	
O	
O	Not True
2.	**Do Employees from the same hierarchy level get along with each other?**
O	Fully True
O	
O	
O	Not True
3.	Are Employees bond to strict company rules and procedures and tasks when acting in their position?
O	There are strict procedures the employee has to follow
O	There are procedures the employee has to follow
O	There are few procedures the employee has to follow but mainly can decide on his own how tasks are performed
O	The employee decides what task he performs in which order, there are just few procedures he has to follow in order to meet company standards(e.g. reporting)
4.	**The reputation of the company is aligned with the company vision?**
O	Completely aligned
O	´
O	
O	No alignment
5.	**The facility/ facilities design aligns with company vision?**
O	True
O	
O	
O	Not True

9.2.2 Innovation

1.	**What is the driving innovation technology in your company?**
O	Product
O	Process
O	Both
O	None
2.	**Does your company use mechanisms for the selection and exploration of innovations? (e.g stage gate mechanism)**
O	Yes, the company has it fully implemented
O	Yes the company has it implement for either product or process innovation
O	No, the company has no mechanism for the selection of innovations.
3.	**Does your company provide incentives for employees with new innovative ideas out of their normal job description?**
O	Yes
O	No

9.2.3 *Strategy & Leadership*

1.	**How would you describe the implementation status of your Industry 4.0 strategy?**
O	No strategy
O	Strategy in development
O	Strategy formulated
O	Strategy in Implementation
O	Strategy implemented
2.	**Do you use indicators to track the implementation status of your Industry 4.0 strategy?**
O	Focus cost cutting
O	Cost cutting
O	Differentiation
O	Focus Differentiation

3.	**In which parts of your company have you invested in the implementation of Industry 4.0 in the past two years?**

	Large	Medium	Small	None
RND	O	O	O	O
Production/Manufacturing	O	O	O	O
Purchasing	O	O	O	O
Logistics	O	O	O	O
Sales	O	O	O	O
Service	O	O	O	O
IT	O	O	O	O

4.	**In which parts of your company have you planned to invest in the implementation of Industry 4.0 in the next 5 years?**

	Large	Medium	Small	None
RND	O	O	O	O
Production/Manufacturing	O	O	O	O
Purchasing	O	O	O	O
Logistics	O	O	O	O
Sales	O	O	O	O
Service	O	O	O	O
IT	O	O	O	O

4.	**In which areas does your company have systematic technology and innovation management?**
O	IT
O	Production Technology
O	Product development
O	Services
O	Centralised, in integrative Management
O	No systematic technology and innovation management
5.	**Do managers take initiative when opportunities for the company arise?**
O	Yes, always
O	Yes, mostly
O	Yes, but rarely
O	No, never
6.	**Do manager motivate the employees to work at their optimum?**
O	Yes, always
O	Yes, mostly
O	Yes, but rarely
O	No, never
7.	**Does the your company provide team building activities in order to understand the importance of each other jobs?**
O	Yes, once every month
O	Yes, once every year
O	Yes, only with new employees
O	No team building activities are in place

9.2.4 *Employees*

1.	**Do your employees have the awareness of sustainability?**
O	Sustainability is not known by the employees
O	-
O	We are aware of sustainability and half of us can follow this philosophy
O	-
O	Sustainability is not known by the employees
2.	**Can your employees continuously develop themselves in your company in order to meet the future growth from the company? (e.g. IT skills)?**
O	Employees are encouraged to develop themselves, and can receive fully support from the company. We believe that developing employees is a conducive investment for both sides
O	-
O	Employees want to develop themselves. But no support comes from the company.
O	-
O	Employees only need to finish the jobs assigned to them. No further requirement or support from the company
3.	**Are your employees able to work in a multidisciplinary team when the project is complex and needs multidisciplinary knowledge?**
O	They are NOT able to collaborate with staff from the other disciplinary
O	-
O	Employees are willing to collaborate with the others, but there is no mechanism in the company to support them.
O	-

O	They are NOT able to collaborate with staff from the other disciplinary.
4.	**What is the average age of your employees?**
O	18-23
O	24-33
O	34-53
O	54-

9.2.5 Marketing

1.	**What media do you use in order to advertise your company's product/service? (multiple answers possible)**
O	TV
O	Radio
O	Newspaper
O	Magazines
O	Social media
O	Company website
O	Influencer
O	Traditional advertisement (e.g. flyers, banners)
2.	**How can customer contact you?**
O	Call centre
O	Email
O	WhatsApp
O	Automated customer service
O	Drop by at the sore
O	Automated online chats
3.	**How do your customers place an order?**
O	Via an catalog where customers can select among our products.
O	-
O	Via an ordering template where customers can specify its requirements
O	-
O	Via an web application where customers can configure their own products
4.	**How are customers' orders transformed into a scheduled production process?**
O	Orders are manually planned into the production schedule
O	ERP system automatically makes schedules for the machines and human recourses to manufacture the product.
O	Systems (ERP, MES and etc.) collaborate together, and autonomously make optimal decisions for the orders in terms of production process.
5.	**Based on what data are marketing add published?**
O	No data
O	Based on assumptions
O	Companies internal customer segmentation
O	From market research
O	Based on Data retrieved from big data analysis

9.2.6 Financials

1.	**What emphasis do executive team and board place responsibility in company and persona financial matters.**
O	No collective engagement, limited communication of financial information
O	Board and executive team only pay attention to own areas of responsibility
O	Board and executive team act collectively but are slow in decision making
O	Board and executive team act collectively, make strategic and financial decisions as a team, frequent financial information e.g. monthly
O	Board and executive team act collectively; make strategic and financial decisions as a team; frequent financial information e.g. monthly; evaluation between investment, costs, service delivery; They routinely and productively challenge staff to emphasize importance of financial information
2.	**Does the company have the capability to access sufficient funds for process innovation?**
O	Yes the company has easy to access funds to pay for the process innovation
O	Yes, but it takes the company long to convince investors
O	No, the company does not have the capability to access funds
3.	**Are Financial systems integrated into a general system?**
O	Yes financial systems are completely integrated into the companies cloud
O	Yes the financial systems are integrated into and internal system
O	No financials systems are kept separate for each department and unit
O	Financial systems are not consistent and not stored in a central accessible data storage

9.2.7 Law

1.	**How does your company scope with changing law requirements?**
O	The Company follows law requirements for the most time
O	
O	The company follows all the laws and analysis the political environment for potential changes in law.
O	
O	The company is proactive when it comes to new laws. Hence the company does not only look at the political developments but set standards themselves before the even become law.
2	**The company is aware of the different law systems it is operating in.**
	Completely true
	To some extent true
	Not true

3.	**The company is aware of the possibilities they have in protecting their IP.**
O	Completely true
O	To some extent true
O	Not true

9.3 Technology Domain

1.	**Which technologies do you use? (Multiple answers possible)**
O	Sensor technology
O	Mobile devices
O	RFID
O	Real time location systems
O	Big data to store and evaluate real-time data
O	Cloud technologies as scalable IT infrastructure
O	Cyber physical systems
O	IOT
2.	**Machines/systems can be controlled through IT**
O	Fully implemented
O	
O	To some extent implemented
O	
O	Not implemented
3.	**Can data be shared with the suppliers?**
O	No data can be directly observed by the supplier/ or company
O	
O	Some data can
O	
O	Important data that is necessary for the production is shared between company and supplier
4.	**Can customer data directly be accessed from the company?**
O	No data of the customer can be directly observed by the company
O	
O	Some data can
O	
O	Important data that is necessary for the satisfaction of the customer can be shared between company and customer
5	**Data can be access from everywhere in the world in real time by the user of the data**
O	This statement is completely true
O	The data can only be accessed but not in real time
O	The data can be accessed but slowly
O	This statement is not true

9.3.1 Cloud computing

1.	**Are you a cloud service provider?**
O	Yes
O	No
2.	**What online availability can you provide?**
O	
O	Yes, key production and machine data is being collected
O	No, data is being collected.
3.	What type of cloud system do you provide?
O	PaaS
O	SaaS
O	IaaT

9.3.2 Augmented reality

9.3.3 Big Data

1.	**Do you store data from machine and production process?**
O	Yes, all data is being collected
O	Yes, key production and machine data is being collected
O	No, data is being collected.
2.	**Do you analyse the data gathered to improve company processes?**
O	Yes, all data is accessed in order to improve company performance
O	Yes, some data is accessed for company improvements
O	No, the data is just stored
3.	**Do you use Big Data in order to prevent failures to arise?**
O	Yes, all data is accessed in order to prevent failures to occur
O	Yes, some data is accessed in order to prevent the most critical processes
O	No, the data is just stored
.	**Do you collect customer data via the internet?**
O	Yes, all data is being collected
O	Yes, key production and machine data is being collected
O	No, data is being collected.
.	**Do you use this data in order to improve your product/service?**
O	Yes
O	No
	Do you use online data to create customer specific advertisement?
O	Yes
O	No
	Which online platforms do you use to advertise?

	YouTube
	Facebook
	WeChat
	WhatsApp
	Instagram
	Others_____________

9.3.4 IOT

1.	**M2M: Machines communicate data underneath each other, no data needs to be put in manually**
O	Fully implemented
O	To some extent implemented
O	Not implemented
2.	**Interoperability: integration and collaboration with other machines/systems possible**
O	Fully implemented
O	To some extent implemented
O	Not implemented
3.	

9.3.5 3D Printing

1.	**Is there any additive manufacturing method in your company? (e.g. 3D printing)**
O	Conventional manufacturing methods are used in the company.
O	We use additive manufacturing methods in the design and engineering processes (or in the fabrication process).
O	We use additive manufacturing methods in both the design and engineering processes and the fabrication processes
2.	**Do you analyze the data gathered to improve company processes?**
O	Yes, all data is accessed in order to improve company performance
O	Yes, some data is accessed for company improvements
O	No, the data is just stored
3.	**Do you use Big Data in order to prevent failures to arise?**

9.3.6 Virtual Reality

1.	**Which stage describes your virtual capabilities best?**
O	basic manufacturing implications identified
O	manufacturing concepts identified
O	manufacturing proof of concepts developed
O	capability to produce the technology in a laboratory environment
O	capability to produce prototype components in a production relevant environment (PRE)
O	capability to produce a prototype system or subsystem in a PRE
O	pilot line capability demonstration: ready to begin low rate initial production(LRIP)
O	low rare production demonstration: capability in place to begin full rate production
O	full rate production demonstrated and lean production takes place
2	**In which areas do you use VR?**
O	Production
O	Skill
O	Prototyping
O	Customer contact (hence customer can see the product in the VR)

9.3.7 Drones

1.	**Which stage describes your virtual capabilities best?**
O	basic manufacturing implications identified
O	manufacturing concepts identified
O	manufacturing proof of concepts developed
O	capability to produce the technology in a laboratory environment
O	capability to produce prototype components in a production relevant environment (PRE)
O	capability to produce a prototype system or subsystem in a PRE
O	pilot line capability demonstration: ready to begin low rate initial production(LRIP)
O	low rare production demonstration: capability in place to begin full rate production
O	full rate production demonstrated and lean production takes place

9.3.8 Cyber security

Due to the lack of access to the necessary ISO standards this part needs to be postponed for the future

10. LIST OF ACRONYMS

- AR = Augmented reality
- CF = Conceptual framework
- CPS = Cyber physical system
- DBMS = database management systems
- FA = fully achieved
- ETL = extraction, transformation, load
- IaaT = Infrastructure as a Service
- IOT = Internet of Things
- IEC = International Electrotechnical Commission
- ISI = Institute for Scientific Information
- ISO = International Organization for Standardization
- ITU = International Telecommunication Union
- I4.0 = Industry 4.0
- MM = Maturity model
- MMM = Multi-dimension MM
- MRL = manufacturing readiness level

- NA = not achieve/not available
- OLAP = online analytical processing
- PaaS = Platform as a Service
- PA = partially achieved
- RDBMS = relational database management systems
- RFID = radio frequency identification
- SaaS = Software as a Service
- SDO = standard developing organisations
- SMM = Single-dimension MM
- VR = Virtual reality
- WSN = Wireless sensor networks

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